SIG Aviation

Safety impact of wind turbines in the vicinity of aerodromes and air routes

Contract: EASA.2019.CEI.14EC021

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Executive Summary

Task definition

This report is the product of contract EASA.2019.CEI.14.EC021 on the assessment of safety impacts, including appropriate mitigation measures, of wind turbines in the vicinity of aerodromes and air routes and provide regulatory recommendations on the detection, lighting and marking of wind turbines.

Results and Conclusions

The study identified that the main risk related to wind turbines is related to low-level flights of under Visual Flight Rules. The Basic Regulation (EU) 2018/1139 and the Aerodrome Regulation (EU) 139/2014 provide various instruments intended to mitigate the risks from wind turbines from the aerodrome perspective. The study found that some of these regulatory mitigations can be improved, and the number of mitigation options can be increased.

The ADR regulation requires the safeguarding of aerodromes against the effects of wind turbines. Improvements can be made to provide supportive material on what safeguarding entails, how it should function or who is responsible for the safeguarding. The study identified that a wide variety on this process exists between Member States. In addition, in the absence of a clear regulatory framework, the Competent Authority of each Member State have deployed different solutions. This has resulted in a wide variety between Member States on how wind turbines are lighted and marked.

It is recommended that EASA embraces the safeguarding concept but strengthens it by defining in more detail the process, responsibilities and criteria for both the Competent Authority and the Aerodrome Operator. As wind turbines, due to their dynamic properties, cannot be considered as ‘traditional’ obstacles, a further development of the regulatory framework will be required. This would allow the attribution of additional safety margins to cater for densely populated area’s (wind farms) and downwind turbulence caused by wind turbines. A significant risk is formed by the obstacle data management process as it is the basis for a number or mitigations. Improvements, particular on the responsibility of the AO and interaction with other stakeholders in this process can be achieved.

The promotion of one-stop-shop principles for the application process should include an independent, and preferably proactive, assessment similar to how Eurocontrol mitigates the risk for radar interference from wind turbines. This report proposes a workflow for this process.

Embedding a risk-based concept in the regulatory development ensures that the framework better meets the operating environment, as examples suggest that the simple application of size-based criteria for wind turbine lighting and marking might be counterproductive in a complex operating environment. In other words: the cumulative risks from wind turbines are not only related to height. Defining the wind turbines lighting requirements on height criteria only might therefore not sufficiently mitigate the total risk. The existing certification standard however can be easily transformed in risk based criteria that will provide more flexibility for Member States to apply a lighting solution that matches the operational environment of the wind turbine(s).

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1 Introduction

The European Union has set ambitious targets for the transition to renewable energy sources. The Renewable Energy Directive and the Energy Union Strategy have played a crucial role in motivating member states to invest heavily in wind energy projects, with the goal of reaching a 45% renewable energy target by 2030.

As a result of these factors, the growth of wind turbines in Europe has been significant. The capacity of onshore wind installations in Europe surpassed 200 GW in 2020. This growth is projected to continue in the coming years as more countries commit to increasing their share of renewable energy in their energy mix. With continuous technological advancements and a supportive policy environment, onshore wind power is expected to play a crucial role in shaping Europe's sustainable energy future.

Wind turbines can have an impact on aircraft safety, particularly in terms of potential hazards during flight operations.

Traditionally, aviation authorities have managed the obstacle risk for aviation by developing requirements, mostly related to the location, height and marking of obstacles. However wind turbines are not static obstacles. When in operation, the entire turbine acts dynamically, causing different effects compared to traditional obstacles.

This study has been developed on behalf of the European Aviation Safety Agency, EASA and aims to identify the consequence of wind turbines on aviation safety, and how to mitigate these risks in the domain of aerodrome safety.

1.1 How the work was done

The work related to this report was performed by the contracted expert from January to October 2023 in a combination of desktop research, work and meetings with EASA, industry representatives, stakeholders and Aviation Authorities from various Member States. As part of the work, survey methods were used to include airspace users and procedure design experts. The contracted expert experienced an overwhelming interest and open participation from all contacted parties.

The project followed a workflow that is common for safety investigations to ensure that the results of the investigation are as unbiased as possible. Using this protocol led to the following project steps:

1. Definition of problem statements – what are the assumptions about safety and wind turbines?
2. Literature review – what information is contained in published literature about these assumptions?
3. Description of the wind turbine industry and outlook – how does it look, and how will it look in the near future?
4. Regulatory review – what do the current aviation safety related requirements say about wind turbines?
5. Assessment methodology – definition of the method used to assess the current situation.
6. Main conclusions and recommendations – what can be said about all this and what should EASA do?

This report will start with the main conclusions and recommendations. The remainder of the report and its appendices contain information resulting from the above steps that led to these conclusions and recommendations. Where possible, dynamic cross references have been used to point the reader to the supportive material.

1.2 Outlook on future expansion of wind turbines in Europe

This section contains a summary of Appendix A1 – Background information on wind turbines.

At this moment in time, wind energy generated in the European Union is dominated by onshore wind turbines.

Presently constructed onshore wind turbines have a height up to 300 meters (1.000 feet). A higher tower gives the rotor access to stronger and more consistent wind speeds, which results in increased energy generation. A larger rotor allows a larger wind energy potential to be captured. Wind turbines have an operational life time of approximately 20 years. This means that existing wind turbines will soon be replaced with modern higher wind turbines.

Between now and 2027 the required wind energy production will be double in order to meet the European renewable energy target by 2030. The outlook is that wind turbines will further grow in number, size and output.

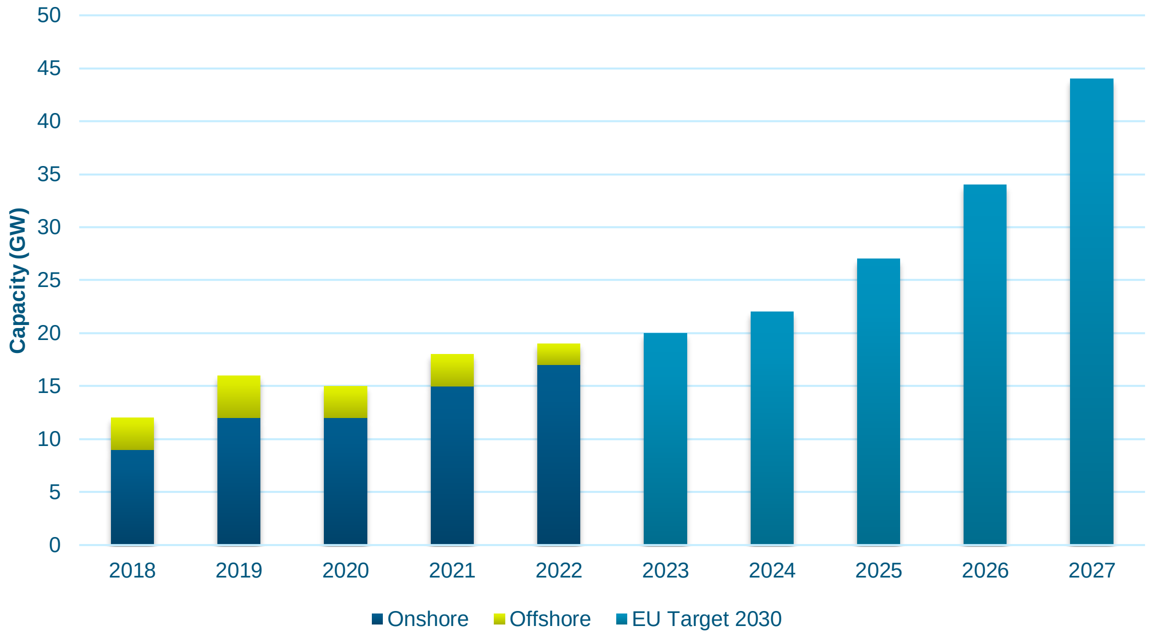

Figure 1.2-1 - Wind energy production to date and future EU targets[1]

[1] *Data from Wind Europe market overview reports*

2 Main conclusions and recommendations

2.1 General

The project specified that the safety assessment should concern the safety impact of wind turbines in the vicinity of aerodromes in the context of the Basic Regulation (EU) 2018/1139 and Commission Regulation (EU) No. 139/2014 for aerodrome safety, the so-called Aerodrome Regulation. In accordance with Article 2 of the Basic Regulation, the European aerodrome safety regulations are applicable to all aerodromes that are open to public use, which serve commercial air transport and have a paved instrument runway of 800 metres or more, or exclusively serve helicopters using instrument approach or departure procedures; unless they have been exempted on the basis of certain conditions, such as a low number of passenger and cargo traffic.

According to EASA's annual safety review of 2022 a total of 542 aerodromes are within the scope of the European aerodrome safety Regulation of which 398 have been certified while 127 aerodromes are granted an exemption. There are approximately 3.200 aerodromes in Europe[2] of which 60% has a paved runway, which means that many aerodromes are outside the scope of the EU regulatory framework.

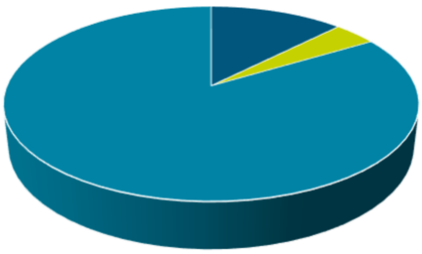

Figure 2.1-1 European aerodromes and ADR Regulation

The ADR Regulation is applicable to approximately 16% or the European aerodromes with a paved runway, and 23% of those have been granted an exemption. The conclusion is that 88% of the European aerodromes are regulated on a national level.

The safety assessment performed as part of this study clearly identifies that the majority of wind turbine related risk, from an aviation perspective, is associated with aircraft flying very low-level in deteriorated meteorological conditions either during day or at night.

This type of aviation activity is mostly conducted from aerodromes that are regulated on a national level outside the scope of ADR Regulation. The location where the risk is manifested, mostly relates to the surroundings of the aerodrome. This means that the recommendations made in this report should not only be reviewed in an EASA ADR context, but also on a national level to ensure that the highest risks identified can be effectively mitigated.

[2] *2023 data from Statista.com*

2.2 Operational and technical procedures for approval of wind turbines

The following essential processes have been identified in the safety assessment to ensure effective safety mitigations for wind turbine safety can be implemented:

1. the aerodrome safeguarding process;
2. the obstacle data management process;
3. the operational environment around the wind turbine(s); and
4. the lighting and marking of wind turbines.

2.2.1 Effective mitigation measures

2.2.1.1 Safeguarding process

Safeguarding is the process by which, in consultation and within the capability of the stakeholders, the environment surrounding an aerodrome is protected from developments and activities that have a negative impact on aviation safety. It is therefore the safeguarding process that should provide with effective mitigation measures when the safeguarding process identifies a deteriorated safety level.

At present, the interpretation of the ADR Regulations determine which stakeholder is attributed with what responsibility regarding this safeguarding process. One point of view is that the Competent Authority of a Member States is solely responsible for the safeguarding process. The other point of view is that Aerodrome Operator also bears responsibilities to safeguard the aerodrome and its surroundings, whilst the Competent Authority is mainly responsible to verify the functioning of this safeguarding process as part of its oversight program. According to the ADR Regulation, the process of safeguarding should be part of the Management System of the AO.

Challenge

The use of the 'Management System' philosophy and the attribution of responsibilities this brings for all stakeholders is still relatively new in the ADR domain. The study identified, through interactions with Member States and EASA that, not all stakeholders have the same understanding on roles and responsibilities, particularly in the safeguarding process and obstacle data management process. As the largest part of protection of aerodrome surroundings is regulated on a national level, this can explain why in some Member States the responsibility of the Aerodrome Operator in the safeguarding process is different.

The ADR Regulation provides limited material on how the AO can fulfil safeguarding requirements in respect to wind turbines. There is no information provided on what should be part of the safeguarding process, which stakeholders should be involved and what could be acceptable mitigation measures. As a result, the process, extend and methodology of consultation varies widely between Member States. Considering the attributed responsibilities in the ADR Regulation towards the AO's Management System and the obstacle management process, it is recommended that future safeguarding criteria in Authority (AR) and Operator Requirements (OR) should cover this.

Recommendation for EASA

1. EASA should provide clear and practical information on the roles and responsibilities of stakeholders in the safeguarding process in respect to wind turbines.
2. Additional AMC and GM is required for an AO to define acceptable safety assessment methods.
3. Define principles of consultation and collaboration in the safety assessment method
4. Use safeguarding criteria that relate to the risk represented by the type of operation conducted at the aerodrome and in the surroundings.

5. The regulatory material for both AR and OR, should be based on generic descriptions that allow the application of the method under varying national existing provisions. The regulatory material should promote a risk-based assessment rather than a criterium based approach. This means for example that the lighting and marking requirements are not only based on height, but also on the risk that the wind turbine poses. It can also mean that if there is a low-risk environment, alleviations would be possible on those requirements.

An effective mitigation measure for aerodrome safeguarding is the collaboration between stakeholders during consultations. Some Member States have implemented a one-stop-shop principle to streamline the applications from wind turbine developers. With respect to the **Error! Reference source not found.** of wind turbines in Europe this method can provide a shorter application phase and can also ensure a better consultation of all affected parties. The safeguarding process of aerodromes and the surroundings could become an integral part of such one-stop-shop process.

Research indicates that an effective method of triggering a safeguarding consultation process is the proactive production of safeguarding maps depicting the areas upon which consultation should take place. The Eurocontrol method for zonal assessments functions in a similar way and is assessed as an example to ensure consultation of all affected parties.

2.2.1.2 Obstacle data management process

Regulation (EU) 2017/373 containing the rules for Air Traffic Management and Air Navigation Services in Annex VI attributes responsibility on obstacle data management to the AIS providers of AIS in a Member State. The Aerodrome Regulation 139/2014 in ADR.OPS.B.075 requires the Aerodrome Operator to include obstacles in its safeguarding process. The project identified the importance of clarity to all the stakeholders involved their respective roles and responsibilities, as well as the necessary actions for implementation and continued maintenance of the obstacle data management process. This is particularly true in this example where multiple regulations address the same topic of obstacle data management.

Challenges

The original intent of ICAO Annex 15 on obstacle data sets being that for all IFR aerodromes in the AIP, Area 2 data would be published. As this was not considered feasible or necessary by some States, the standard for the provision of a full Area 2 data set was revised in ADR Regulation, when the EU transposed the ICAO Annex 15 requirements into the EU regulatory framework for aviation safety. The provision of data for Areas 2b, 2c and 2d for all aerodromes designated as international in the National AIP section AD 1.3 – 'Index to aerodromes and heliports' is now a Guidance Material/Acceptable Means of Compliance and only the part of Area 2 is required in an implementing rule. However not all Member States apply this principle.

Urban air mobility is defined as air operations above urban areas (at least for part of the flight), in "U-space airspace". This Very Low Level (VLL) airspace was limitedly exploited in the past, possibly resulting in a lower regulatory priority. As a consequence, the accuracy and integrity of obstacle data is not very high, particularly in more remote areas. With the interest in UAM, there is an increased demand for obstacle data of higher accuracy, particularly at Very Low Level (VLL) altitude.

EHLE AD 2.10 AERODROME OBSTACLES

Area 2		
OBST ID/ Designation	OBST type	OBST position
1	2	3
-	-	-

Area 3		
OBST ID/ Designation	OBST type	OBST position
1	2	3
EHLE013	Control tower	522720.7N 0053127.4E

Remarks
6
• Obstacles penetrate ICAO Annex 14 Volume I obstacle limitation surfaces. • No obstacle data sets AVBL for area 2 and 3.

Figure 2.2-2 AIP extract regarding obstacle data sets for areas 2 and 3, and an aircraft approaching that aerodrome[3]

The obstacle data management process is fundamental for the correct functioning of a number of existing mitigations:

- obstacle awareness during preparation and flight for aircrew;
- establishment of operational minimum safe altitudes and obstacle clearance altitudes;
- optimum functioning of EGWPS and TAWS onboard of aircraft; and
- functioning of MSAW and APM systems for air traffic controllers.

From the research data it becomes clear that the interpretation on responsibilities regarding obstacle data management differ widely between MS. Some AO are responsible for a visual verification of the visual approach surfaces only, whilst other AO have full responsibility on the entire obstacle data set.

Recommendation for EASA

The ADR Regulation should attribute clear responsibilities between stakeholders with respect to obstacle data management, taking the entire obstacle data process into consideration.

Recommendation for Competent Authority

The national policy for the safeguarding of aerodromes should be assessed to consider its effectiveness, particularly in relation to the presence of wind turbines and the obstacle data management process. The exclusion of specific areas[4] from the obstacle data management process can result in unknown/charted wind turbines. Consideration should also be given if current aerodrome safeguarding policies sufficiently assess the wind turbines in the vicinity of the aerodrome, particularly for aerodromes exempted from the ADR Regulation. If a Member State does not have a national aerodrome safeguarding policy, it is recommended that one be established.

2.2.1.3 Operational environment around the wind turbine

The construction of new wind turbines or repowering of older wind turbine models (with higher models) will have an effect on the minimum safe altitude around the wind turbine. For VFR flights, the pilot would need to apply an obstacle clearance margin in both lateral and vertical sense.

[3] The wind turbines in the background are approximately 530' high and 6.000 meters from the ARP.
[4] Requirements from ICAO Annex 14, included in Basic Regulation 2018/1139

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VFR flights

The standard vertical clearance for VFR flights is 150 meter (500 feet)[5] above the highest obstacle[6] within a radius of 150 m (500 feet) from the aircraft. The minimum aircraft altitude over a modern isolated wind turbine, with a height up to 1.000 feet, should be 1.500 feet.

VFR airspace usually has an upper limit defined by the lowest controlled airspace at that location. The VFR airspace is particularly low in close proximity to aerodromes that are used for both VFR and IFR traffic. When a cloud-base is present, this can further lower the maximum altitude for VFR traffic.

For locations with multiple wind turbines in the surrounding of an aerodrome and/or published VFR routes, the assessment of the minimum required vertical clearance should be based on the higher of:

a) The single wind turbine scenario above (1.500 ft AGL); or
b) The minimum altitude[7] to allow a single engine aircraft to drift down (in case of engine failure) over the wind turbines and maintain the 500 ft clearance over the wind turbines on the outside perimeter.

Without vertical separation, the minimum lateral distance on the upwind side of wind turbines should be 150 meter[4]. However, it is unlikely that VFR pilots would apply practical lateral separation of less than 500 meters, consideration that this is the minimum distance to remain clear of clouds and estimating distances in aircraft is extremely difficult. Without vertical separation, the minimum distance on the downwind side should be 9 x the wind turbine's rotor diameter to ensure that turbulence is dissipated sufficiently. For taller wind turbines this would be approximately 1.000 meter.

The combination of both lateral and vertical separations, can result in the following effects:

1. A reduction in airspace volume available for aircraft, particularly when the area is limited by deteriorated weather; and
2. The formation of (unofficial) flight corridors by aircraft avoiding overflying wind farms.

Both effects increase the aircraft density in the airspace available, resulting in a higher collision risk. This collision risk with other aircraft would exist only for VFR flights and is likely be higher in deteriorated meteorological conditions.

Recommendations

The safety effects of this reduction in airspace volume should be part of the safeguarding process of aerodromes, and the mitigations that this process produces.

IFR flights

The standard vertical clearance for IFR flights is 300 meter (1.000 ft)[4] above the highest obstacle within a radius of 8.000 meter of the estimated position of the aircraft, or the published MSA whichever is higher.

The estimated position of the aircraft can theoretically be influenced by wind turbines in two ways:

1. Onboard of the aircraft for flight crew by multipath propagation of ground-based VHF navigation signals confusing the navigation equipment; and
2. On-ground for air traffic controllers by masking primary or secondary radar returns[8].

[5] *SERA.5015(b)*
[6] *Modern wind turbines constructed today have a height up to 300 meters (1.000 feet), and rotor diameters ranging from 80 to 150 meters or more.*
[7] *A typical glide ratio of 7:1 can be used to determine minimum crossing altitudes for wind farms for single engine aircraft.*
[8] *In theory the SSR position data could also be compromised by a position error in the onboard navigation equipment.*

Considering the first possibility of position uncertainty and the availability of alternative navigational sources not influenced by wind turbines, the likelihood for this scenario is considered remote. The absence of ECCAIRS data related to position errors from multipath propagation supports this assessment. Regarding the second possibility, Eurocontrol developed an assessment method[9] to identify and mitigate the effects of wind turbines on radar installations. Provided this method is followed and the restrictions are implemented, the risk can be sufficiently mitigated from ADR perspective.

Recommendation for Competent Authority

Ensure that the Eurocontrol guidelines for assessing the detrimental impact on Secondary and Primary Surveillance Radars caused by wind turbines are implemented by Member States.

Ensure that the approval planning process includes criteria related to the accessibility of aerodromes and areas serviced by helicopter emergency medical services (HEMS) and State flights.

2.2.1.4 Lighting and marking of wind turbines

From the regulatory assessment, stakeholder interviews and the assessment of existing lighting and marking specifications in various Member States, it is clear that there is a potential for harmonisation with respect to the lighting and marking requirements included in the ADR Regulation. At present, most Member States apply national variants of the ICAO and EASA specification standards.

These national standards mostly use the height of the wind turbine to define the required lighting and marking. However, a wind turbine is not a static object but has dynamic properties that have an effect on safety. Some Member States have partially addressed some of these by marking of wind turbine blade tips. Additionally, the size of wind turbines has increased significant. With a mix of newer (taller) and older (shorter) wind turbines in the same area, turbines next to each other can be completely differently lighted and marked. The existence of national variants resulted in a variety of practices between, and even within individual Member States.

The existence of multiple lighting and marking variants in close proximity does not promote safety. In practice it has the opposite effect, particularly on the visual identification of obstacles in less than optimum visibility or lighting conditions. Due to limitations in human performance, the pilot will avoid the most visible wind turbine, and likely have more difficulty in identifying other (less visible) wind turbines. The risk for this depends highly on the present background lighting, meteorological visibility and environment of the wind turbine.

In lieu of wildlife protection and human welfare, maintaining consistency in the application of the standard has become more challenging for regulators resulting possibly in more deviations from the standards.

[9] *EUROCONTROL-GUID-0130*

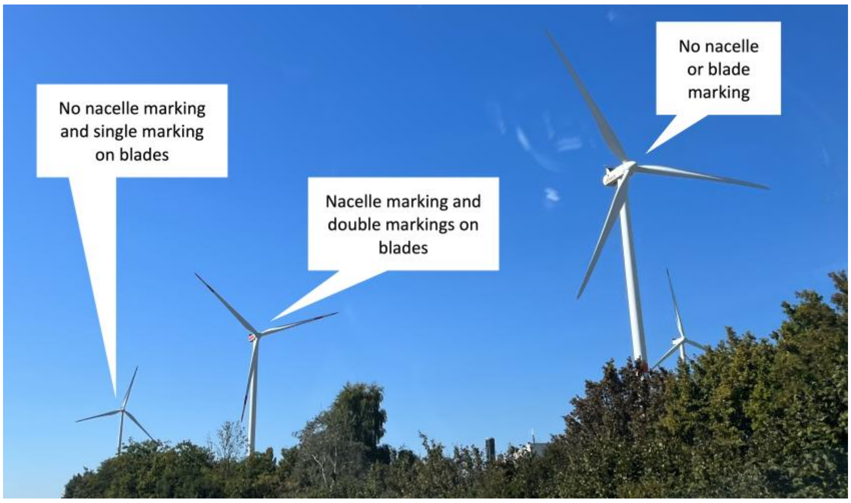


Figure 2.2-3 Observed differences regarding wind turbines in close proximity of each other

Developing marking and lighting requirements based on risk criteria, rather than height criteria, will allow for a simpler and more uniform categorisation of wind turbines and requirements for markings and lights. In addition, risk-based criteria accommodate existing national variants more easily, resulting in harmonization.

Light and intensity control

The assessment and stakeholder review concluded that the intensity of obstacle lights can be reduced without measurable safety effects provided sufficient meteorological visibility exists for the reduction.

Table 2.2-1 – Dimmed light intensity

Background light	Visibility (meter)	Dimmed obstacle light intensity (candela)	Percentage of normal light intensity
Day	> 10.000	> 50	10%
	5.000 – 10.000	> 150	30%
	< 5.000	> 500	100%

Automated obstacle lighting based on aircraft detection will increase safety as it provides instantaneous awareness on the presence and location of wind turbines. Depending on the detection method, additional requirements regarding aircraft equipment might need to be implemented that could conflict with requirements to operate State aircraft without detection to third parties. An alternative solution exists using active radar to detect aircraft. Both methods would need to function on a fail-safe basis, meaning that failure in the detection system results in obstacle light activation.

Pilot controlled lighting would enable the pilot to activate the lights by transmitting on a specific VFH frequency. This method would require knowledge on the existence of wind turbines and is therefore only considered safe in less accessible environments such as offshore windfarms.

NVG

There are different classes of NVG which registers lights within certain wavelengths such as 645 to 900 nanometres. Depending on the night vision goggles used, certain types of NVG could potentially filter out obstacle lights that operate outside the detectible spectrum.

Obstacle recognition is crucial to ensure safe separation, particularly during reduced visibility conditions in close proximity of obstacles. This flight profile is typical for HEMS and State flights.

Recommendation for EASA

Include wavelength specifications in the CS for obstacle lighting to ensure that obstacle lights maintain their risk mitigation functionality while using enhanced vision systems.

2.2.1.5 Table with operational and technical risk mitigation options

Table 2.2-2 – Operational and technical risk mitigation options

Type	Mitigation	Criteria	Purpose	Negative effect
Operational	Increased vertical obstacle clearance height for VFR	Clearance > 1.000 ft	• Safety factor around wind turbines. • Increased safety for forced landing scenario.	• More vertical airspace required • Concentration of traffic • Inadvertent IMC • Larger traffic patters
Operational	Minimum lateral clearance distance for wind turbines	Distance > 9xD	• Prevent aircraft upset.	• Concentration of traffic
Operational	Safety assessment in application phase	Independent criteria required	• Ensure accessibility of aerodrome • Ensure HEMS employability • Identify operational risk mitigations required	• Operational expertise required • Possible bias in assessment
Technical	Identification of wind turbines	Surveying areas 2 and 3	• Obstacle awareness. • Correct MSA and obstacle clearance altitudes. • Optimum functioning of tactical recovery systems.	• NIL
Technical	Wavelength specification for obstacle lights in CS	Depending on EVS specification	• Restore risk mitigation purpose of obstruction lights.	• Replacement costs for non-compliant installations
Technical	Relationship between recommended lighting options and risk profile of wind turbine		• Ensure that lighting and marking of wind turbines is based on height criteria and operational risk.	• More fluid application of requirements can result in objections from wind turbine owners
Technical	Specify maximum inoperability of obstruction lights	To be determined	• Ensure risk mitigation purpose of obstruction lights are functioning.	• Additional work
Technical	Include specifications for remotely or automated control of obstacle lights in standard.	Depending on application type	• Wildlife and public health protection.	Depending on application type: • onboard equipment required • redefinition of airspace requirements • operating costs
Technical	Include areas 2/3 in obstacle monitoring requirements	ICAO Annex 14	• Ensure that obstacle data is complete. • Ensure that obstacle data set is suitable for future air mobility concepts. • Harmonization.	• Costs
Technical	Attribute clear responsibilities for obstacle management process		• Prevent unknown obstacles and ensure integrity on existing data. • Harmonization.	• Need to align national processes for certified aerodromes

2.2.2 Safety Assessment of impact from wind turbines

2.2.2.1 Safeguarding process

The safety assessment of wind turbines contains multiple perspectives from the point of view of Aerodrome Certification, Air Navigation Service Providers, Commercial Air Transport, General Aviation, Procedure designers, Radar specialists, Regulatory Oversight, Wind Turbine subject matter experts. These different disciplines should all be included in the safeguarding process with respect to wind turbine safety.

2.2.2.2 Application process for wind turbines

The following generic obstacle permission process has been developed to help provide a harmonised approach to the process by which obstacles are planned, notified and surveyed. It is difficult, if not impossible, to define a process which can be applied uniformly across different Member States, as its influence extends well beyond the aviation sector and is impacted by national planning regulations and cartographic practices.

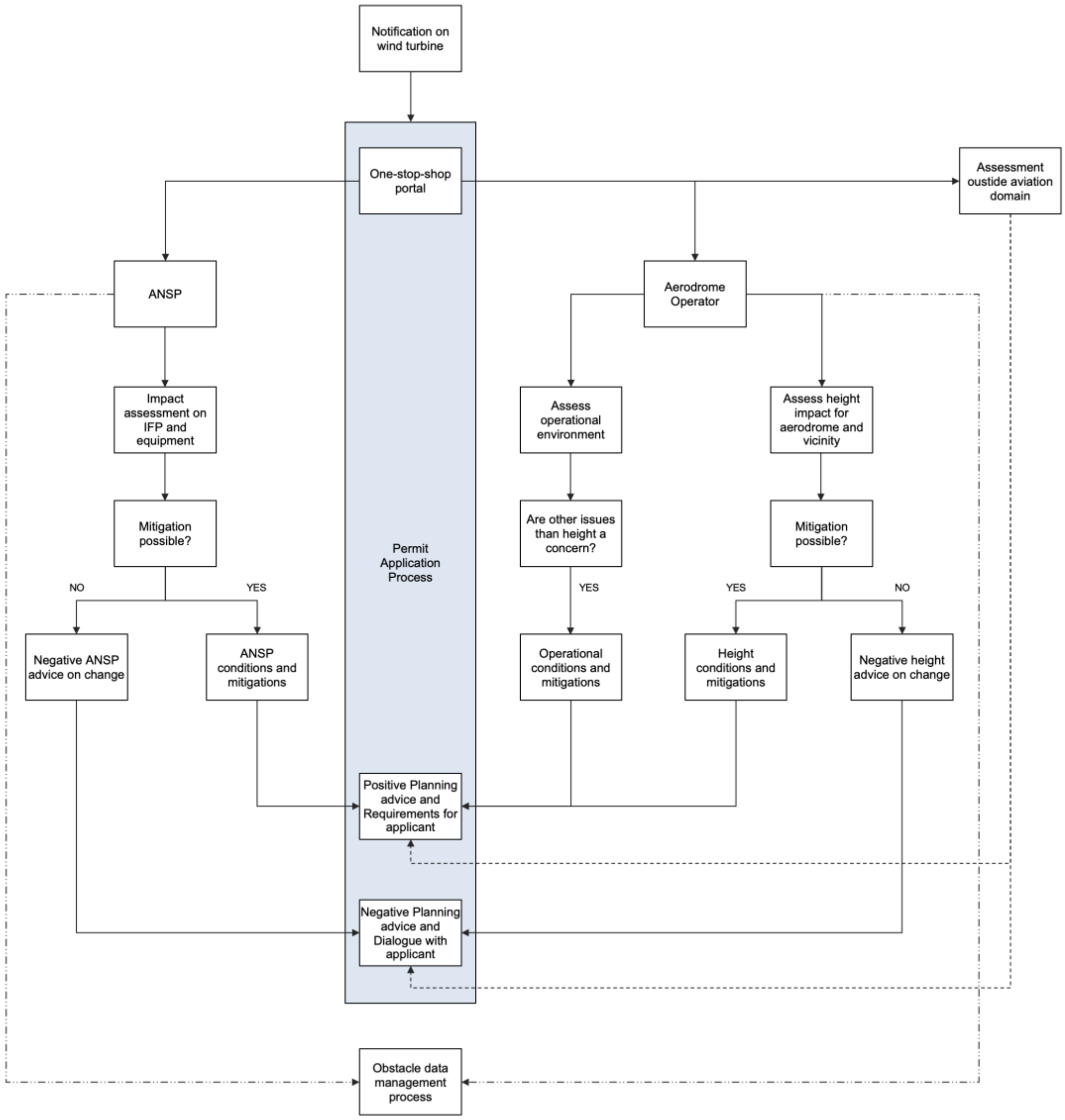


Figure 2.2-1 – Proposed safety assessment process in planning phase

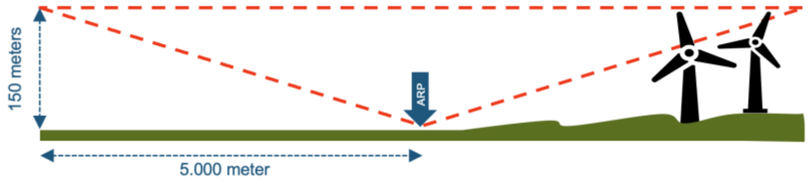
Proposed assessment criteria
The ANSP assessment criteria are left outside the scope of this report. Various documents listed in the literature list cover this process extensively.

Height impact
The height criteria applied for the aerodrome will depend largely on the type of flight procedures established. For aerodromes with IFP, the design organisation will need to be consulted to verify and formulate advice and/or mitigations for wind turbines penetrations in the OLS.

For aerodromes that are not using IFP, an assessment will be required to determine the height impact of the wind turbine on visual approaches.

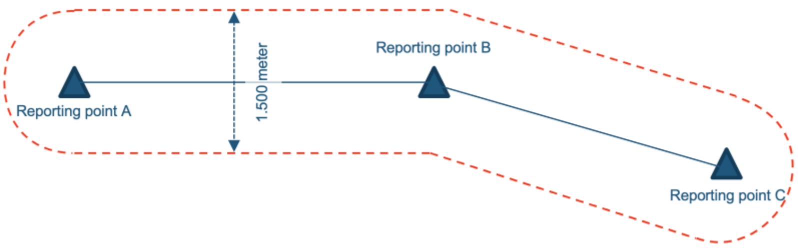
The following assessment steps are recommended for single engine fixed wing aircraft visual approaches:

1. When no obstacle limitation surfaces are determined, use a complementary conical surface centred on the aerodrome reference point with a radius of 5.000 meter and an outer circle of 150 meter above the aerodrome elevation. Wind turbines penetration this conical service can pose a hazard to aircraft using the aerodrome for approach, traffic pattern, take-off and landing. In such case, a study taking the locations, dimensions and altitude of the visual circuit into consideration is required to determine the potential hazard.

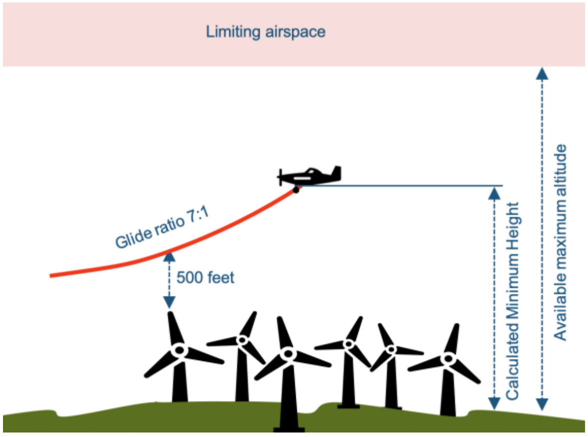


2. Mitigation is required for wind turbines that penetrate this complementary conical surface. These mitigations can be one or more of the following options:
    a. height limitations on the wind turbine;
    b. increased height for the traffic pattern;
    c. isolating the segment of the conical surface that is infringed for air traffic; and/or
    d. ensuring aerodrome publications clearly identify the collision risk for aircraft.

3. For obstacles located outside the lateral dimensions of the complimentary conical surface but within a corridor of 1.500 meter with a published VFR route as its centre: determine the maximum allowable altitude in the airspace immediately above ground level for that VFR route.



4. Calculate the height of the wind turbine + 500 feet (applicable minimum obstacle clearance for VFR). For wind farms, calculate the height required to cross the outer perimeter at a height of not less than the turbine height + 500 feet, assuming a glide ratio of 7:1 for an engine failure above the centre of the wind farm.



5. If the calculated minimum height is more than 2/3 of the available maximum altitude in that airspace class, a detailed assessment is required on the effects of the wind turbine for passing aircraft and determine possible mitigations. These mitigations can be one or more of the following options:
    a. Ensuring acceptance of VFR traffic in the limiting airspace;
    b. Raising the base altitude of the limiting airspace
    c. Relocating the VFR route;
    d. Ensuring publications clearly identify the collision risk for aircraft on that VFR route; and/or
    e. Limiting the height of the wind turbine, when the above mitigations cannot be implemented for that VFR route.

Operational assessment

For other than height issues, an assessment of the operational environment is required. Other than height issues are derived from the safety assessment and concern the following risk factors:

1. The lighting and marking of other wind turbines in the vicinity of the planned wind turbine;
2. The type of air traffic to the aerodrome;
3. The accessibility of the aerodrome;
4. The location and altitude of VFR routes for the area under responsibility of the AO; and
5. The minimum distance of wind turbines to the approach and departure area.

The risk factors are used to determine the most appropriate lighting and marking option for the wind turbine. Refer to Chapter 2.3.1 - Provisions for detection, marking and lighting.

2.2.2.3 Obstacle data management

The safety assessment displays a clear cause-and-effect relationship between the obstacle management process and collision risk with wind turbines. Failures in this process have an effect on mitigation and recovery levels for obstacle avoidance.

For IFR flights, the probability for the publication of incorrect obstacle clearance altitudes is considered lower compared to the probability of incorrect minimum safe altitudes used for VFR flights. Reason for this is that the regulatory compliance level is generally in function with organisational size, meaning that the probability of unknown or uncharted obstacles being erected close to a larger aerodrome is relatively low. This also means that for smaller aerodromes, the mitigations resulting from obstacle data management are weaker.

Challenge

The requirements regarding obstacle data management are traditionally scattered in the various regulations related to the main different domains in aviation. There are no “easy access rules” centrally regulating obstacle data management. The provisions of ICAO annexes 4, 15 and 14 regarding obstacle coverage areas, limitation surfaces and take-off flight paths have a close relationship with the Aerodrome Operator, but this is clearly not the only stakeholder that exist. The relationship explains why obstacle management has become part of ADR Regulation to some extent, but also explains the possible different interpretations that exits as to whom exactly is responsible for what geographical area.

Obstacle awareness is an important element to enable risk mitigation. Inadequate obstacle data management will result in fewer obstacles being identified and published on charts and moving maps. The VFR safety survey conducted as part of this project identified that the majority of VFR pilots use electronic data derived from obstacle data sets to identify collision risks before and during flight. The stakeholder interviews conducted identified that, for low-level HEMS operations, the current AIP data[10] alone is insufficient to mitigate the collision risk.

Operational minimum safe altitudes and obstacle clearance altitudes are established using obstacle data sets. Failures in the obstacle data management process can result in errors with respect to minimum altitudes and climb requirements increasing the collision risk for IFR flights.

To ensure IFR flights do not collide with ground and obstacles, onboard alerting systems[11] and on-ground MSAW and/or APM systems are used. These systems are mostly described as independent safety nets. However, they their functioning depends on the basis of an accurate terrain and obstacle data set and valid accurate position (3D) information on the aircraft. All of these elements have a relationship with wind turbines, either through interference of radio signals or the obstacle data management process.

2.3 Regulatory proposals

2.3.1 Provisions for detection, marking and lighting

It is proposed to include a cross reference between the risk factors identified in this study and the recommended marking and lighting options for wind turbines included in the ADR Regulation. An example of such cross reference from the risk factors identified in Chapter 2.2.2.2 and the existing lighting recommendation is provided below.

Lighting and marking of other wind turbines

New wind turbines should be lighted and marked identical to other wind turbines present within a radius of 1.500 meter from the location of the new wind turbine to ensure a common standard is maintained for that area that promotes visual detection. If marking and lighting is required due to the new wind turbines dimensions[12], the applied standard should also apply in retrospect to any existing wind turbine within a radius of 1.500 meter.

[10] Of at least one Member State
[11] EGWPS and TAWS
[12] Refer to Appendix A1 for information on re-powering of wind turbines

Type of air traffic to the aerodrome/VFR route

The type of VFR air traffic and operations to the aerodrome should be used to determine a risk factor. The purpose of the risk factor is to ensure that lighting and marking of wind turbines in the vicinity is adapted for the risk they pose to air traffic.

Table 2.2-1 Risk factor for type of VFR operation

Type of VFR operation	VFR Day	VFR Night	Special VFR[13]
Leisure flights	Low	Medium	High
Training flights	Low	Medium	High
HEMS flights	Low	High	High
State flights	Low	High	High

Density of wind turbines

The density of wind turbines around the aerodrome and VFR routes should be used to determine a risk factor. For this purpose all wind turbines within a radius of 45 km from the Aerodrome Reference Point should be used to determine the wind turbine density around the aerodrome.

Table 2.2-2 Risk factor for wind turbine density

Number of turbines per km²	Risk factor
< 0,25	Low
0,25 – 0,5	Medium
> 0,5	High

Table 2.3 – 1 Recommended (existing) EASA lighting based on risk factor (instead of height)

Wind turbine RISK	Location of light	Obstacle light	ICAO type	Criterium
LOW	Nacelle	1x LIM FLG R	Type B	Unobstructed view on light
MEDIUM	Nacelle	2x LIM FLG R[14,15]	Type B	Second light serves as alternate Unobstructed view on lights
	Tower (1/2 tower height)	3x LIL FLG R[14]	Type E	Unobstructed view on light from every angle Flash same rate as nacelle
	Tower (1/2 tower height)	3x LIL F R[14]	Type A or B	When type E not suitable Unobstructed view on light from every angle Flash same rate as nacelle
HIGH	Nacelle	2x LIM FLG R[14,16]	Type B	Second light serves as alternate Unobstructed view on lights Provided additional lights not required
	Tower (1/2 tower height)	3x LIL FLG R[14]	Type E	Unobstructed view on light from every angle Provided additional lights not required Flash same rate as nacelle
	Tower (1/2 tower height)	3x LIL F R[14]	Type A or B	When type E not suitable

[13] Special VFR is a sub-category of VFR allowing operation in meteorological conditions not meeting Visual Meteorological Conditions (VMC) minima.

[14] Light compatible with EVS wavelength spectrum

[15] Maximum inoperability AA days

[16] Maximum inoperability BB days

				Unobstructed view on light from every angle Flash same rate as nacelle Provided additional lights not required

It is recommended to include the safety assessment criteria related to lighting and marking of wind turbines, included in Chapter 2.2.2 - Safety Assessment of impact from wind turbines, in the regulatory framework.

It is recommended to include criteria on the maximum inoperability duration of obstruction lights to ensure risk mitigation purposes of obstruction lights are functioning.

It is recommended to include wavelength specifications for obstacle lights in the EASA CS to restore the risk mitigation properties for obstruction lights when using Enhanced Vision Systems.

It is recommended to include criteria and specifications for remotely or automated control of obstacle lights in the EASA standard to promote wildlife and public health protection.

2.3.2 Charting of wind turbines

It is recommended to re-evaluate the existing exemption allowing exclusion of the ICAO areas 2 and 3 from the obstacle monitoring requirements to ensure that the obstacle data set for certified aerodromes is complete and accurate. This is of particular importance for the accurate electronic charting of wind turbines on avionics and handheld devices.

It is recommended to include requirements for Member States to clearly identify and attribute responsibilities for the specified areas for obstacle surveying and obstacle data management related to EASA certified aerodromes under their control to ensure no gaps exist.

2.3.3 Safety Assessment Criteria

It is recommended to include the safety assessment method and criteria developed in this project, and covered in Chapter 0 -

Operational and technical procedures for approval of wind turbines, in the regulatory framework to create a legal basis allowing Member Status to ensure compliance.

2.4 Safety Promotions

2.4.1 General Aviation community

With respect to the safety of wind turbines this report identifies risk exposure to be largest for the GA community. The study also identified that:

1. The data available in ECCAIRS regarding interactions between wind turbines and GA aircraft is lacking in comparison with the input from commercial aviation transport organizations; and
2. Maintaining an increased lateral and vertical separation distance between GA aircraft and wind turbines lowers the wind turbine collision risk, but can also introduce other risks.

It is recommended to develop a safety campaign for the GA community to promote reporting on wind turbine related events and increase awareness on the safety risks.

2.4.2 Member States

This report identified that the risk related to wind turbines is largest for aerodromes that are exempted from the Basic Regulation and certified in accordance with national requirements.

For this purpose, it is recommended that EASA ensures that the information from this report and the developed regulatory framework is promoted for national adaptation by Member States to increase safety at smaller aerodromes.

3 Regulatory assessment

3.1 Introduction

An assessment of Commission Regulation (EU) No 139/2014 of 12 February 2014 laying down requirements and administrative procedures related to aerodromes pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council was made at the start of the project.

The goal of this assessment was to identify the existing regulatory elements related to the safeguarding of aerodromes in respect to wind turbines and to insert those elements in the causal map identifying possible gaps.

The assessment was performed by two external experts and the results were discussed with EASA staff members. The external experts were asked to perform the assessment in an unbiased manner and identify where the ADR requirements relate to wind turbines.

The sections below summarize the results of the assessment in three subsections related to generic requirements, and requirements specific for Member States and Aerodrome Operators. In Appendix – Regulatory Assessment, a cross reference between the summary and regulation on article level is present.

It is important to emphasize that this assessment only concerns the requirements related to aerodromes (ADR), and only reflects the interpretation of requirements by the experts working on this project.

3.2 Summary of regulatory assessment

3.2.1 General principles

1. All aerodromes with a paved instrument runway open to public commercial air transport (either scheduled or unscheduled) should follow the provisions of the Basic Regulation 2018/1139, or have been exempted to do so.

   Basic Regulation 2018/1139, article 2
2. The routes and areas to arrive and depart from an aerodrome shall provide protection from wind turbines as obstacles, and the effects from those wind turbines.

   Basic Regulation 2018/1139, Annex VII paragraph 1.2
3. For the purpose of safeguarding the airspace, obstacle monitoring surfaces shall be defined, implemented and monitored.

   Basic Regulation 2018/1139, Annex VII paragraph 3.1.1
4. A “consultations” process is required with regards to the safety impacts of wind turbines within certain lateral limits from an aerodrome or those above a certain height, or irrespective of the wind turbine height when its position can cause hazardous obstacle-induced turbulence for aircraft or interference with communication and/or navigation equipment.

   The Aerodrome Regulation 139/2014, cover regulation article 10
5. Depending on the type of runway at an aerodrome, different height criteria exist aimed to prevent penetration of a protection or limitation surface for arriving or departing aircraft. For departing aircraft, a safety assessment is required for wind turbines penetrating the take-off climb surface.

   Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.J.470, 475, 480, 485
6. Only wind turbines meeting the definition of an obstacle should be marked and/or lighted. The suggested colour for painting wind turbines is given as ‘white’ without further specification. This wording allows application of a different colour as ‘white’ to functions as a colour for marking. Lighting requirements for wind turbines are, in

essence, not existing due to the chosen wording "where deemed necessary" in combination with an option to differentiate from the CS based on a safety assessment.

Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.851

3.2.2 Member State/Competent Authority requirements

7. Member States bear the overall responsibility to safeguard aerodromes against activities and development causing unacceptable risks to aircraft.

Basic Regulation 2018/1139, Chapter III, Section IV article 38

8. In fulfilling its responsibility of safeguarding aerodromes, the MS may allocate the different tasks associated with this process to different entities and organizations provided a seamless organization is ensured.

The Aerodrome Regulation 139/2014, cover regulation (7)

9. The Competent Authority is responsible to verify how the Aerodrome Operator safeguards the aerodrome against adverse effects of wind turbines as part of its oversight program.

The Aerodrome Regulation 139/2014, ADR.AR.C.005

3.2.3 Aerodrome Operator requirements

10. To provide protection from wind turbines and as part of its management system, the Aerodrome Operator is responsible to make arrangements with third parties that are essential to manage the safety risk of wind turbines.

Basic Regulation 2018/1139, Annex VII paragraph 2.2

11. As part of the initial and continued certification process, the Aerodrome Operator is responsible to define and maintain the obstacle monitoring surfaces as part of its Management System to ensure safe operation of aircraft, and accessibility of the aerodrome.

The Aerodrome Regulation 139/2014, ADR.OR.B.025
The Aerodrome Regulation 139/2014, ADR.OPS.B.075
Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.H.405

12. The surveying for aeronautical data of the obstacle monitoring surfaces can be subcontracted to a third party, but remains the responsibility of the AO.

The Aerodrome Regulation 139/2014, ADR.OR.D.010

13. The AO should provide data to users, ANSP and AIS providers on hazardous obstacles inside the aerodrome boundary or those obstacles that penetrate any of the obstacle monitoring surfaces.

The Aerodrome Regulation 139/2014, ADR.OR.D.007

14. The AO should have formal arrangements with ANSP, AIS providers and the Competent Authority to provide obstacle data outside the aerodrome boundary.

The Aerodrome Regulation 139/2014, AMC 1 ADR.OPS.A.005

15. The AO shall define in the Aerodrome Manual the obstacle monitoring surfaces, obstacle control procedures and procedures related to the mitigation of hazards from wind turbines.

The Aerodrome Regulation 139/2014, ADR.OR.E.005
The Aerodrome Regulation 139/2014, ADR.OPS.B.075

16. The hazard identification and risk mitigation process for wind turbines falls under the responsibility of the AO and is controlled under a quality management process as part of the Aerodrome Operators Management System.

The Aerodrome Regulation 139/2014, ADR.OR.C.005
The Aerodrome Regulation 139/2014, ADR.OR.D.007

17. The Aerodrome Operator shall monitor activities and developments related to wind turbines and take measures to mitigate risks.

Basic Regulation 2018/1139, Chapter III, Section IV article 38

18. Safety measures taken by the AO could include imposing limitations of the aerodrome usability in terms of traffic types and meteorological conditions.

Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.840, 841

19. The requirement to conduct a safety assessment for obstacles with a height above 150 meters AGL located outside the OLS lateral boundaries only applies to areas under control of the aerodrome operator.

Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.847, 848, 849

20. The specifications on how to mark and/or light objects, depending on their height, only apply to areas under control of the aerodrome operator.

Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.851

3.2.4 Specific requirements related to marking and lighting

ICAO[17] refers to several different standard obstacle light types and attributes. EASA refers to the ICAO definition of lighting types, and has specified requirements for wind turbines in CS ADR-DSN.Q.851. The EASA requirements included in CS ADR-DSN.Q.851 apply to wind turbines that are considered to be an obstacle. With this applicability, wind turbines below or outside the defined OLS would not need to be lighted provided they are assessed as not being a hazard to air navigation. The GM1 on CS ADR-DSN.Q.851 define that the requirements should be interpreted as a minimum standard.

ICAO recommendations and EASA regulations on marking of wind turbines are very similar.

Marking

The rotor blades, nacelle and upper 2/3 of the supporting tower of wind turbines should be painted white, or if after a safety assessment, it is determined that other colour will improve safety.

The EASA regulations on marking of wind turbines are very similar to the ICAO recommendations.

Lighting

ICAO and EASA both use the height categories of 45-150 meters and 150 meters and higher, above ground level (AGL). The solutions suggested for both categories are the same.

The recommended solutions scale with height in regard to the number and positioning of tower lights. ICAO and EASA do not differentiate their recommendations according to whether a wind turbine is on- or offshore.

[17] *ICAO SARPs Annex 14, chapter 6, table 6-1*

Table 3.2-1 Present date EASA options for wind turbine lighting[18]

Wind turbine height (meters AGL)	Location of light	Obstacle light	ICAO type	Criterium
45 - 150	Nacelle	1x LIM FLG R	Type B	Unobstructed view on light
150 – 315	Nacelle	2x LIM FLG R	Type B	Second light serves as alternate Unobstructed view on lights
	Tower (1/2 tower height)	3x LIL FLG R	Type E	Unobstructed view on light from every angle Flash same rate as nacelle
	Tower (1/2 tower height)	3x LIL F R	Type A or B	When type E not suitable Unobstructed view on light from every angle Flash same rate as nacelle
> 315	Nacelle	2x LIM FLG R	Type B	Second light serves as alternate Unobstructed view on lights Provided additional lights not required
	Tower (1/2 tower height)	3x LIL FLG R	Type E	Unobstructed view on light from every angle Provided additional lights not required Flash same rate as nacelle
	Tower (1/2 tower height)	3x LIL F R	Type A or B	When type E not suitable Unobstructed view on light from every angle Flash same rate as nacelle Provided additional lights not required

[18] *This table has been constructed from CS ADR-DSN.851, tables Q-1, 2 and 3*

4 Safety assessment

For the purpose of this study, a decision was made to use a causal mapping method to correlate the regulatory framework with the specific safety concerns related to wind turbines. A causal map is the visual representation of the causal relationships between various variables or factors in a system.

Aviation requirements are specific criteria, conditions, or standards to ensure the safe and effective operation of aircraft. The common objective of requirements for wind turbines is this safety goal. The causal map is intended to provide insight to how efficient existing regulatory mitigations are in achieving this goal.

4.1 General problem statements

In an early moment of the study, through various discussions with EASA staff, an overview of existing assumptions describing the perceived safety impact of wind turbines on aviation safety was made.

The following 4 assumptions were defined to create logic in the safety assessment and provide guidance for this report. It is important to emphasize that these assumptions should not be interpreted as conclusions of the safety assessment, but merely represent a starting point in the assessment process.

Assumption 1 – Obstacle properties

Wind turbines, especially the larger ones found in modern wind farms, can represent significant obstacles to air navigation. They may obstruct the flight path of low-flying aircraft, including helicopters and small planes, which are commonly used for emergency medical services, aerial surveying, and other tasks that require low-altitude flight.

Assumption 2 – Interference on essential equipment

Wind turbines can cause reflections and attenuations in electromagnetic signals, leading to potential radar and communication interference. This interference can affect air traffic control systems and weather radar, reducing their effectiveness in detecting aircraft and weather patterns.

Assumption 3 – Turbulence

Wind turbines create wake turbulence, which can pose a risk to aircraft, particularly during flight at lower altitude and speed such as during takeoff and landing. The turbulence generated by the rotating blades may affect the stability of smaller aircraft flying in close proximity to the wind turbines.

Assumption 4 – Identification

Wind turbines taller than a certain height are required to have aviation obstruction lighting and markings to enhance visibility to aircraft, especially during night-time and low-visibility conditions. When not properly lighted or marked, the wind turbine might not be observed sufficiently in time to ensure separation can be maintained.

4.2 Methodology

4.2.1 Cause and effect relationship

In general, a cause-and-effect relationship refers to a connection between two or more events or variables, where one event (the cause) leads to or influences another event (the effect). In other words, there is a cause-and-effect link that explains why a particular outcome occurs.

Cause and effect relationships are not always simple and direct. Sometimes, multiple factors contribute to an effect, making it challenging to establish a straightforward cause-and-effect connection. Additionally, correlation (a statistical relationship between variables) does not always imply causation. When identifying cause and effect relationships, it is essential to establish a valid and reliable connection between the cause and its effect.

Recognizing cause and effect relationships allows an accurate assessment of potential risks. By understanding how certain actions or conditions lead to negative outcomes, proactive measures can be taken to mitigate risks and improve overall safety.

4.2.2 Map description

For the development of the causal map, this study identified three main events that can have a negative impact on the regulatory safety goal:

1) Collision of an aircraft with a wind turbine;
2) Collision between aircraft due to the presence of a wind turbine; and
3) Collision of an aircraft with terrain due to the presence of a wind turbine.

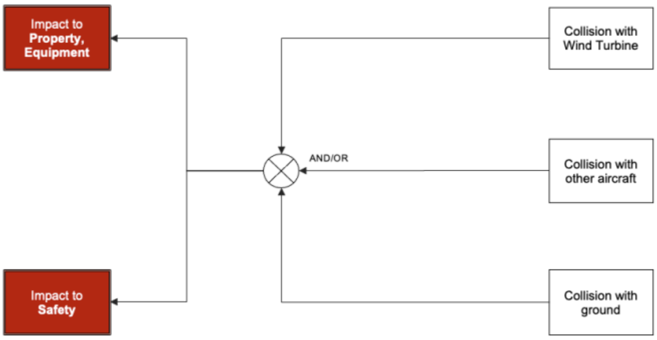


Figure 4.2-1 Main risk descriptors

For each of these main events, requirements should exist to prevent unsafe situations. By defining the cause-and-effect relationships, it is possible to visualize the existing regulatory mitigations. In the context of this study, these downstream cause-and-effect relationships are referred to as causal branches.

4.2.3 Causal branch – Collision with a wind turbine

Controlled Flight into Terrain (CFIT) occurs when an aircraft inadvertently flies into terrain, water, or an obstacle. Most CFIT accidents occur in the approach and landing phase of flight and are often associated with approaches flown visually or using non-precision navigation procedures.

The causal branch for a collision between an aircraft and wind turbine is defined as a CFIT incident and can be formed by five main events:

1) Wind turbine not visually identified.
2) Insufficient vertical obstacle clearance.
3) Incorrect separation margin between aircraft and wind turbine.
4) Unnoticed lateral position error of the aircraft.
5) Absence of independent collision warning.

The above events are characterized by an AND/OR relationship. This means that either a combination of these events, or the existence of a single event could result in a collision.

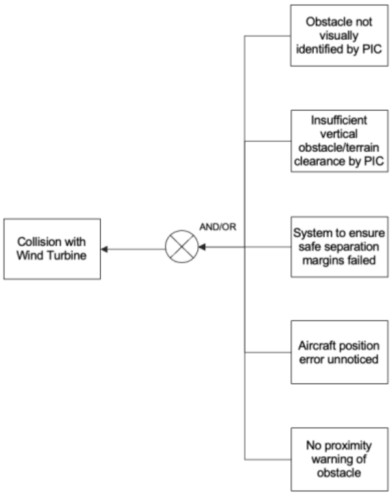


Figure 4.2-2 Collision risk with wind turbine

Each of these five events can be further expanded to further describe their cause-effect relationships. To improve the readability of this report, this expansion is included in [Appendix A7 - Appendix – Expanded causal map with deeper relationships]

4.2.4 Causal branch – Collision with other aircraft

The construction of new wind turbines, or repowering older models with taller turbines will have an effect on the minimum safe altitude in that area and possibly the airspace available for certain types of traffic. In combination with other altitude limiting factors (cloudbase, geographical limits, horizontal airspace limits) this can result in the unintentional development of corridors used by VFR traffic. The concentration of traffic in a smaller volume of airspace increases the aircraft density in these corridors, resulting in a higher collision risk.

This collision risk with other aircraft would exist only for VFR flights, as traffic separation for IFR flights is an ATC responsibility.

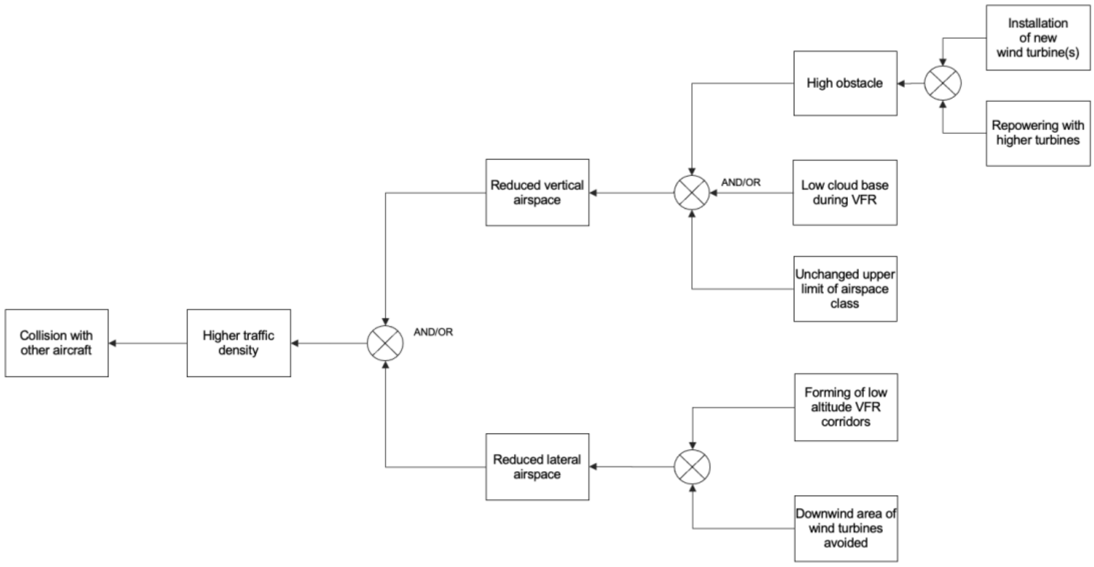


Figure 4.2-3 Collision with other aircraft

4.2.5 Causal branch – Collision with ground

The terrain collision risk resulting from wind turbines is an effect of an aircraft upset or loss of control scenario.

Aircraft upset is a condition in which the attitude or airspeed of an aircraft is outside the normal design limits. This situation can result in the loss of control of the aircraft during flight. These accidents often result from poor energy and attitude management or degradations of aerodynamic performance for due to turbulence, windshear or disturbance of the airflow over an aircraft control surface.

Wind turbines can generate turbulence in the downwind area of the rotor. This turbulence could result in an aircraft upset, with an aircraft in close proximity to the ground during take-off or landing.

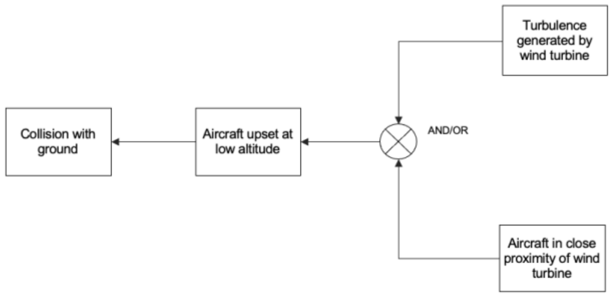


Figure 4.2-4 Collision with ground

4.3 Results

4.3.1 Causal map versus regulatory coverage

When comparing the causal map in relation to the regulatory assessment performed, this relationship can be visualized using a simple colour scheme.

The colour scheme below uses:

- WHITE when the relationship is not regulated through the ADR Regulation;
- GREEN when based on research information the consequence is considered to have an insignificant effect;
- YELLOW when that relationship is covered by ADR Regulation;
- BLUE when that relationship is not covered by ADR Regulation and a negative safety potential exists; or
- ORANGE when that relationship is covered by ADR Regulation and negative safety potential exists.

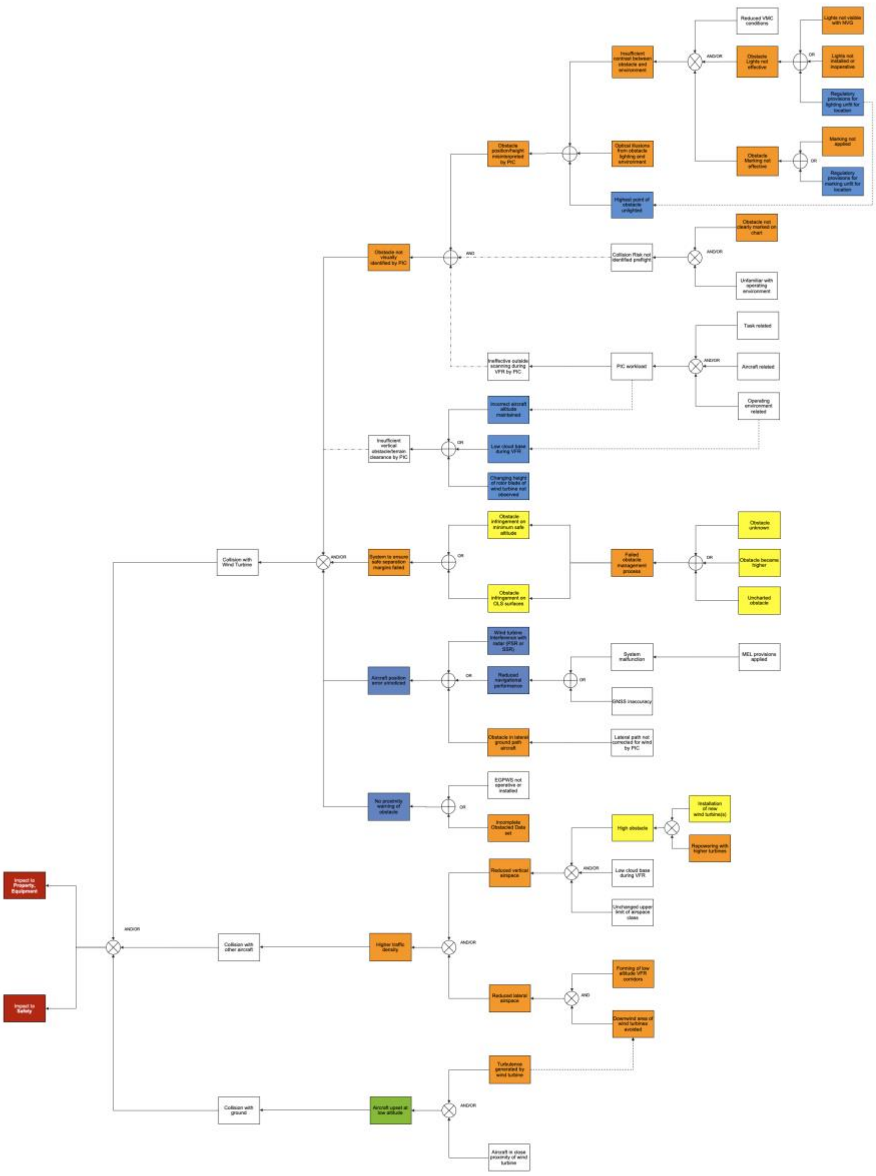


Figure 4.3-1 Visualisation of regulatory relationship on safety effects related to wind turbine

From the above figure it becomes clear that areas of interest exist where concentrated effects are manifesting or risk mitigations would be most effective.

4.3.2 Turbulence

In respect to the assumption that wind turbine turbulence can cause a collision with the ground due to aircraft upsets, the research information indicates that possible effects can be mitigated by defining a minimum downwind distance from the wind turbine.

The remaining relationship of wind turbine turbulence in the causal map, is that a secondary effect remains to be valid: the avoidance of certain areas where wind farms are located from risk avoidance strategies resulting in a reduced airspace volume and possibly a higher air traffic density.

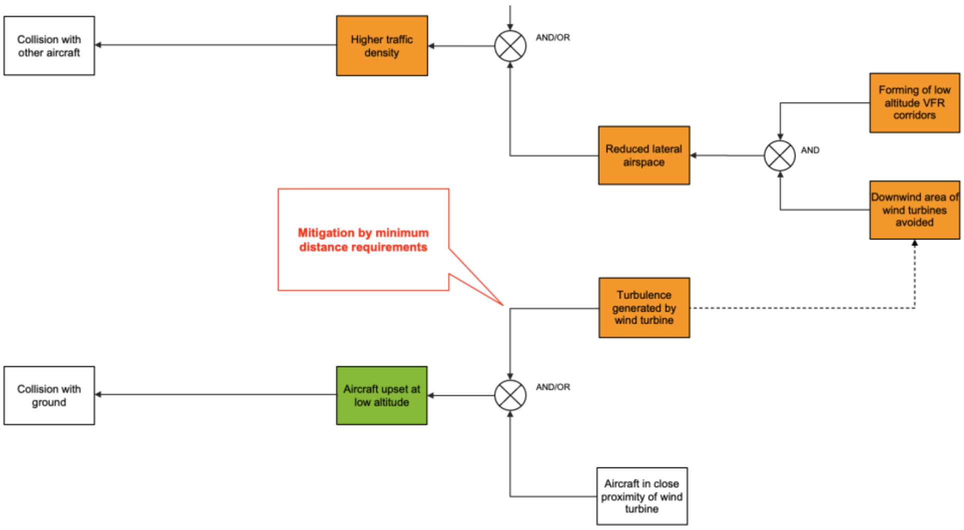


Figure 4.3-2 Ground collision due turbulence mitigated by minimum distance requirements

4.4 Hotspot 1 – (visual) Identification of wind turbine

The following elements within this focal area were identified as to where the existing requirements could be strengthened or included in order to further reduce the risk of obstacles (height and position) being misinterpreted by pilots.

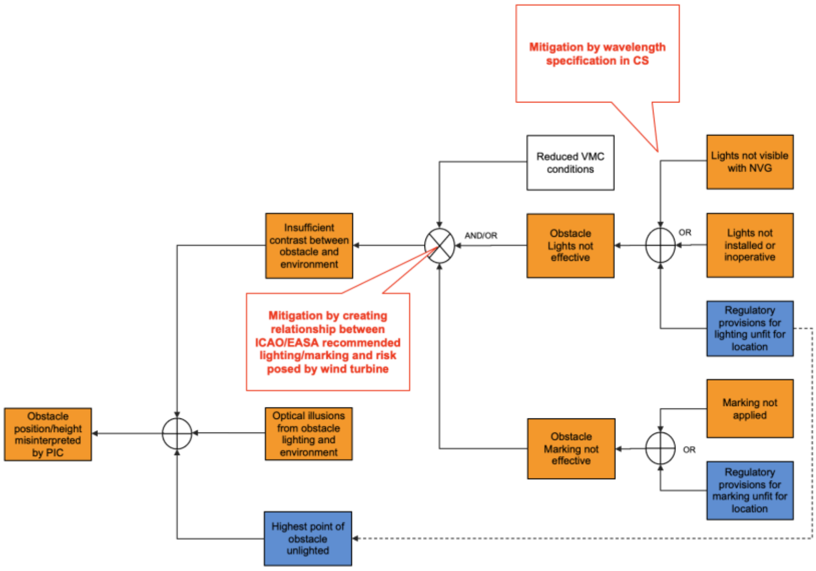


Figure 4.4-1 Wind turbine identification

4.4.1 Effectiveness of existing lighting and marking provisions

The existing EASA lighting and marking requirements are based on wind turbine height. Using hard criteria can result in a binary approach with respect to the question if a wind turbine should be marked or lighted. The operational environment in which the object is located is an important factor in the risk the wind turbine poses and should be considered.

On a national level, significant differences in these criteria between Member States are applied and observed. This results in wind turbines that are lighted and marked distinctively different across borders. Within Member States the application of national requirements is not always consistently followed either. For example, two parallel lines of wind turbines, each on one side of a river where one side is being lighted, and the other is not. In another example the requirement is to apply blade markings from a certain blade length, resulting in two adjacent wind turbines where one has red markings on the blade tips, and the other has not. With a different year of construction or slightly different height, wind turbines can be lighted and marked distinctively different, even when they are in close proximity of each other.

The observed differences applied between Member States underline the necessity of having flexibility on lighting and marking options, based on the particular environment in which the wind turbine operates. In that sense the existing lighting and marking provisions can be considered not suitable enough to cover a variety of (risk based) scenarios.

Conclusion 1

Differences applied in marking and lighting can result in a misinterpretation of the obstacle (location and height) by the pilot, particularly in combination with the deteriorated meteorological visibility, ambient light and differences in lighting/marking of other turbines in close proximity. The result is a higher probability of a collision between aircraft and wind turbine. These differences exist both between Member States, and within individual Member States.

4.4.2 Inclusion of additional regulatory lighting and marking provisions

The safety assessment identified various elements regarding the lighting and marking provisions that are currently not covered by the ADR Regulation:

1. The ICAO requirements and Certification Specifications cover both colour and luminance of obstacle lights, but do not include specifications for the wavelength of obstacle lights. The absence of these wavelength specification allows for the installation of lights that are not visible when using enhanced vision methods, such as night vision goggles. Including this specification in the CS is required to ensure mitigation exists.

2. The requirements for obstacle lighting typically simply specify if an obstacle light is required, but do not consider the continued uninterrupted functioning of required lights during their lifespan. There are no requirements[19] for the continued operability of obstacle lights. This can result in obstacle lights being unknowingly inoperative for longer periods rendering mitigations provided by the requirement ineffective.

3. Wind turbines are designed as visually unobtrusive as possible to increase public acceptance. The effects of this are particularly visible in the variants that exists on a national level with respect to lighting and marking. Although not directly covered by the causal map, the use of more recently developed Automated Dependent Lighting Systems is considered beneficial, particularly for pilots to receive a visual trigger on nearby obstacles, and for purposes of ensuring public and wildlife health in the surroundings of wind farms. At present, the use of such systems is not covered by requirements or guidance material.

4. The requirements should provide decision makers with detailed information on what lighting solution is recommended based on the risk environment of the wind turbine. In low-risk environments the need for lighting and marking may differ compared to high-risk environments, even for similar sized wind turbines.

Conclusion 2

The existing requirements in ADR Regulation regarding marking and lighting of wind turbines can be improved, particularly in areas where technological advances have been made and by redrafting requirements to take the risk environment into consideration when choosing a lighting option. Providing guidance material or certification standards for national authorities will enable and further drive the implementation of systems and equipment with a safety benefit.

[19] *Installation of multiple lights on one wind turbine are usually intended to counteract the coverage of one obstacle light by a turning blade, and do not necessarily intent to cover failure of individual lights or the failure of the lighting control system installed.*

SIG Aviation

4.5 Hotspot 2 – Obstacle Data Management

The assessment displays a clear cause-and-effect relationship between the obstacle data management process and collision risk with wind turbines. Failures in this process have a bifold effect related to the mitigation and recovery sides of obstacle avoidance.

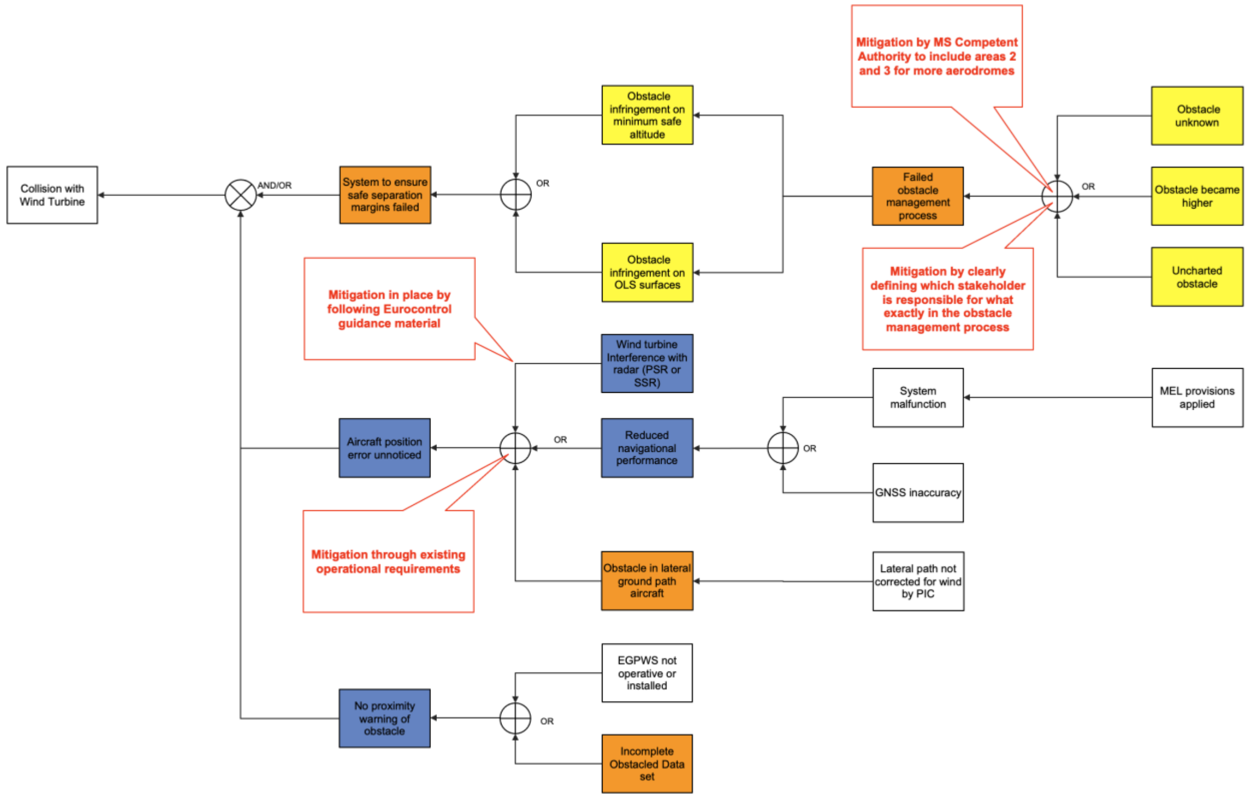


Figure 4.5-1 Hotspot on obstacle data management

For IFR flights, the probability for the publication of incorrect obstacle clearance altitudes is considered lower compared to the probability of incorrect minimum safe altitudes used for VFR flights. Reason for this assessed lower probability is that the regulatory awareness is generally in function with aerodrome size, meaning that the probability of unknown obstacles being erected close to a large aerodrome is relatively low.

As clear from the regulatory assessment, the ADR Regulation has a strong relationship with the obstacle data management process. There are various components regarding obstacle data management that need to be considered in this context. Obstacle data management is a complex interdisciplinary process involving multiple stakeholders, each with their own capabilities and understanding of the process and their responsibilities.

Figure 4.5-2 Stakeholders in obstacle data management

The data collection process involves the definition of various complex surfaces, paths and areas, each with their own purpose. Important in the context of this study is that each of these can be managed by different stakeholders involved in the process:

- Area 3 most closely resembles the geographical area within the aerodrome perimeter;
- Areas 2a, b and c basically cover the area in the surrounding of the aerodrome up to a distance of 10 kilometers;
- Area 2d covers an area up to 45 kilometers from the aerodrome or up to the TMA boundary; and
- Area 1 to cover the entire territory of a Member State.

Traditionally, the area of responsibility of the Aerodrome Operator was limited to the aerodrome perimeter. Today however, the ADR requirements with respect to safeguard the aerodrome dictate a broader approach, and wider area of responsibility – also geographically. As part of the initial aerodrome certification process and during operation of the aerodrome, the ADR Regulation in point ADR.OPS.B.075 on safeguarding of aerodromes attributes some responsibility to the AO on monitoring the aerodrome and its surroundings and to have procedures in place to mitigate the risks associated with obstacles.

The different interpretations on responsibilities regarding obstacle data management have, the following effects:

1. Some defined areas are not surveyed;
2. Unclarities between stakeholders exist on responsibilities;
3. The associated costs with obstacle data management can unwillingly influence the quality of the obstacle data set when levied to smaller AO[20]; and
4. Obstacle data are not maintained and continuously updated to reflect new or updated obstacles.

The above in combination with the knowledge that the majority of the risks related to wind turbines are related to Very Low-Level VFR flights, validates the hotspot in relation with obstacle data management.

[20] *The costs related to obstacle data management, including surveying and acquiring the required knowledge can be relatively high, particularly for smaller aerodromes.*

When the usage of the obstacle data is further explored, the following additional elements should be considered:

1. The development of new transport applications, such as the future air mobility concept, in Very Low-Level (VLL) airspace will increasingly require more accurate obstacle data management processes. In addition, the typical HEMS and rotor wing state flight require accurate data on all obstacles.
2. In relation to collision avoidance, the need for accurate obstacle data is not limited to a small subset of the obstacles existing in an area (ICAO refers to the dominant obstacles), but rather to the entire set.

Conclusion 3

The effectiveness of ADR Regulation in attributing responsibility to the AO on aerodrome safeguarding, including the various obstacle monitoring surfaces, is co-dependent on the existing responsibility of the Member States in accordance with the Basic Regulation and Article 8 of the Aerodrome Regulation in safeguarding the aerodrome surrounding and to ensure obstacle data management.

Conclusion 4

For EASA certified aerodromes, the ADR Regulation should attribute clear responsibilities between stakeholders with respect to obstacle data management, taking the entire obstacle data process and lifecycle of obstacles into consideration to ensure safety mitigations function. For national aerodromes, the ADR Regulation framework on obstacle data management should provide guidance for MS competent authorities on obstacle data management, particularly as these national aerodromes carry the majority of wind turbine related risks.

Conclusion 5

In order to be “future proof” and promote a level playing field between certified aerodromes, the ADR Regulation can be improved by defining qualitative requirements in terms of reliability, accuracy and integrity for the obstacle data management process.

4.6 Hotspot 3 – Higher traffic density

The third hotspot that indicates a relationship between ADR Regulation and wind turbines is manifested in terms of an increasing traffic density.

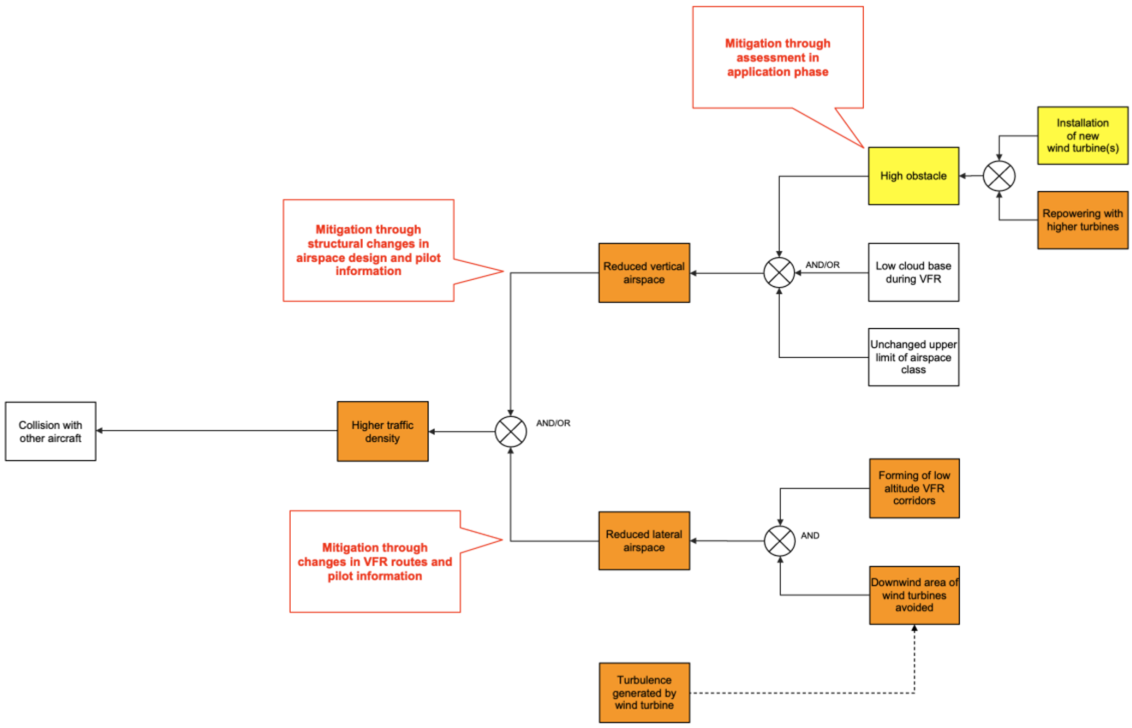


Figure 4.6-1 Traffic density increase

The argument that the vertical airspace is reduced, is valid if there is an upper airspace limit defined and the minimum flight altitude is raised due to an obstacle. The upper limit can either be a restriction resulting from airspace design or usage, and a limit resulting in meteorological conditions.

4.6.1 Why does the vertical airspace reduce?

As a practical example, the figure below illustrates the effect. The airspace above the aerodrome consists of a typical Control Zone (CTR) and Terminal Manoeuvring Area (TMA), both with lower and upper limits. In addition, a Transponder Mandatory Zone (TMZ) is implemented.

The CTR is from ground level to 2.500 feet AMSL, whilst the TMA is from 1.500 feet AMSL to flight level 065. The TMZ is from 1.200 feet AMSL to flight level 065. Various wind turbines are located in this area, on the boundary of the TMA wind turbine of 790 feet AMSL is visible. Considering a minimum obstacle clearance altitude of 500 feet, the minimum aircraft altitude for that point would be 1.200 feet AMSL. This leaves only 300 feet vertical airspace remaining which would be insufficient for VFR aircraft crossing safely. For VFR aircraft without a transponder, this route is not available.

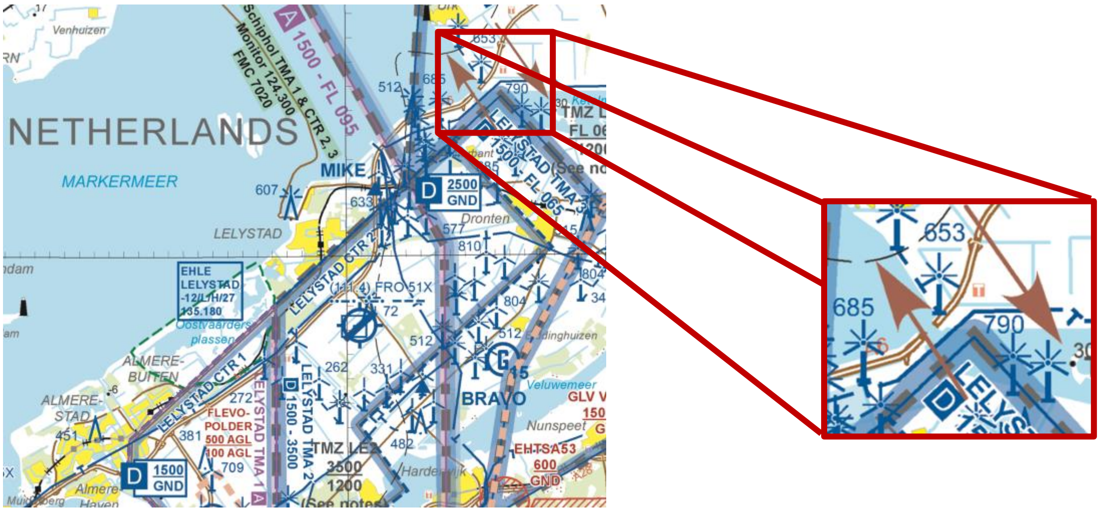


Figure 3.6-2 Reduced vertical airspace example (chart)

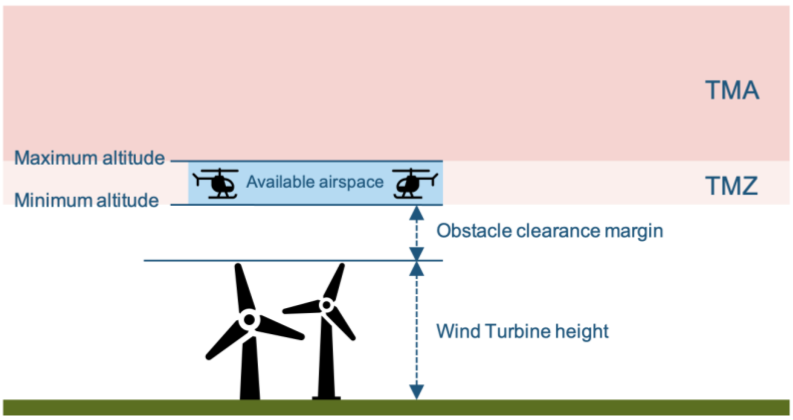


Figure 3.6-3 Reduced vertical airspace example (side view)

The lateral separation distance practically applied varies widely between VFR pilots. SERA.5005(f) requires a minimum of 150 meter. However, it is unlikely that the lateral separation would be less than 500 meters consideration that this is the typical minimum distance applied by for VFR flights.

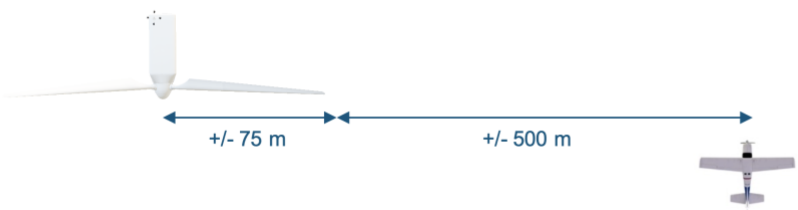


Figure 4.6-4 Lateral separation (top view)

The combination of both lateral and vertical effects, can result in the following effects:

1. A reduction in airspace volume available for aircraft, particularly when the area is limited by additional constraints.
2. The formation of (unofficial) flight corridors for aircraft

Both effects will result in an increase in traffic density, resulting in a higher aircraft collision risk.

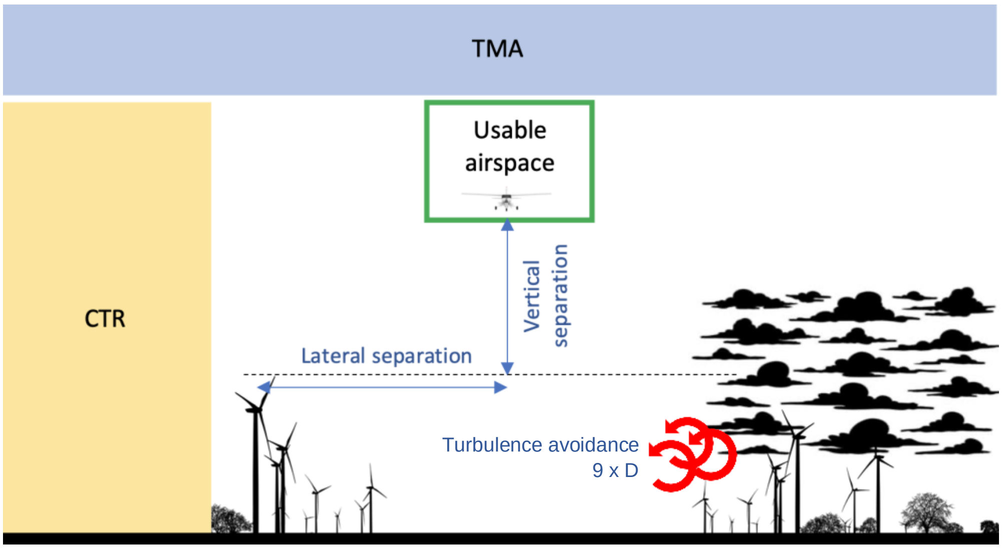


Figure 4.6-5 – Usable airspace reductions

Conclusion 6

The construction of wind turbines in proximity of an aerodrome will have an effect on the collision risk for VFR traffic. The magnitude of the effect varies depending on the particulars of the aerodrome surroundings and should be part of the safeguarding assessment in the application phase of the wind turbine.

SIG Aviation

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A1 Appendix – Background information

A1.1 General

A wind turbine is a device that converts kinetic energy from the wind into electricity.
These turbines can be located on land (onshore) or at sea (offshore). A group of wind turbines is called a wind farm.

There are three main variables that determine how much electricity a turbine can produce:

1. Wind speed – Stronger winds allow to produce more electricity. Wind turbines generate electricity at wind speeds of 15 – 90 kilometre per hour.
2. Rotor radius – The larger the radius or "swept area" of the blades, the more electricity can be produced. Doubling the blade radius can result in four times more power.
3. Air density – "Heavier" air exerts more lift on a rotor. Air density is a function of altitude, temperature and air pressure. High altitude locations have lower air pressure and "lighter" air so they are less productive turbine locations. The dense "heavy" air near sea level drives rotors more effectively.

Wind turbines are manufactured in a wide range of shapes and sizes, but the most common design is the one with 3-blades mounted on a horizontal axis. Their output ranges from 100 kilowatts to 15 megawatts.

The design of a modern wind turbine is optimized for aerodynamic performance and efficiency. The rotor blades are usually made of lightweight composite materials, such as fiberglass or carbon fibre, which are both strong and flexible. The blade design is carefully engineered to minimize aerodynamic drag and maximize lift, allowing the turbine to efficiently extract energy from the passing wind.

Onshore wind farms used to be more prevalent due to their lower installation costs and the availability of suitable land areas for wind turbine deployment. Offshore wind energy is expected to experience a more substantial growth due to its vast resource potential and reduced impact for citizens in terms of land usage, noise generation and vision pollution, compared to onshore wind farms.

A1.2 In numbers

In 2022, new wind installations in Europe totalled 19.1 GW in 2022, with 16.7 GW of wind capacity installed onshore and 2.5 GW offshore. During 2022, 87% of wind installations in was constructed onshore. For the EU to reach a 45% renewable energy target by 2030, wind energy installations need to average 31 GW per year between 2023 and 2030.

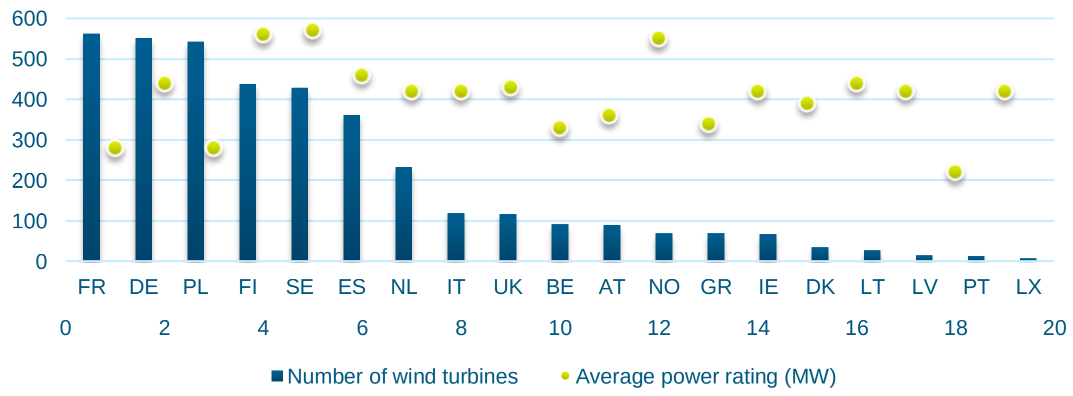


Figure A1.2-1 - Number of wind turbines in Europe in 2022 and their average power rating

A1.3 In operational lifetime

Wind turbines have a finite operational lifetime. For the older turbines this is typically in the region of 15 – 25 years. More modern turbines will likely have longer lifetimes.

When the wind farm reaches the end of its operational lifetime, assuming its lifetime is not extended by replacing components or blades, the turbines will be shut off, taken down and removed. This is known as decommissioning.

As an alternative to decommissioning, replacing all the hardware with modern turbines and accessories is defined as repowering. Repowered wind farms often have and increased capacity due to the technological advances since the early original turbines were installed.

Many of Europe's onshore wind farms are approaching the end of their planned operational lifetime. Currently, 6% of Europe's total wind energy is generated by turbines that have been running for more than 20 years. By 2030, 30% of today's installed wind capacity will be more than 20 years old. On average, Denmark, Spain and Portugal have the oldest wind turbines. Germany has the largest installed capacity which could potentially be repowered with 17 GW older than 15 years.

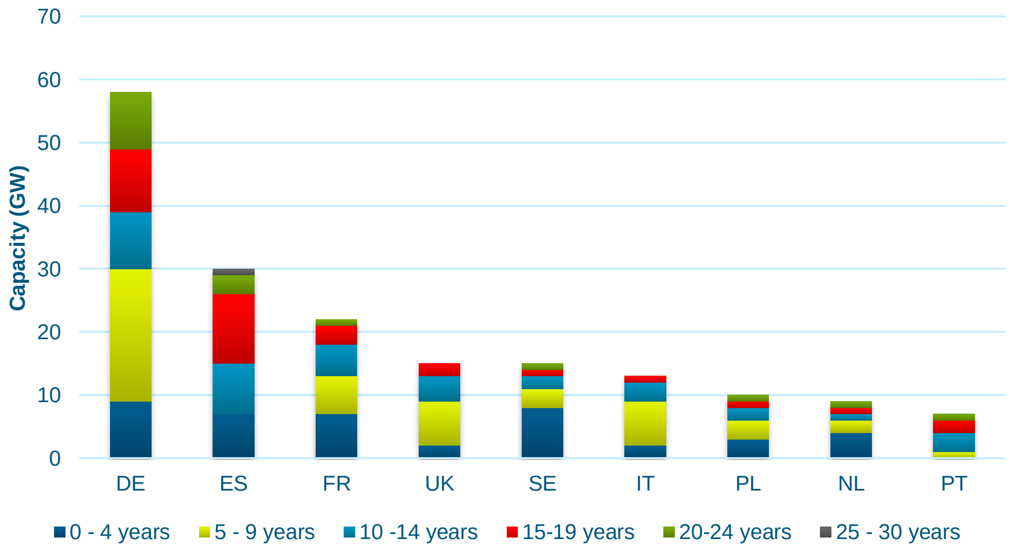


Figure A1.3-1 - Operational age of wind turbines in Europe

Repowering will have an effect on the height of the wind turbines at that specific location, as the capacity of a wind turbine is directly proportional to the size of the installation.

A1.4 In size

Wind turbines have evolved significantly in terms of height and size, becoming larger and more efficient.

In terms of height, modern onshore wind turbines have a height up to 300 meters (1.000 feet), with a higher potential. The height of a wind turbine is measured from the ground to the tip of the blade in its highest position. The tower is a crucial aspect for the height of modern wind turbines. A higher tower gives the rotor access to stronger and more consistent wind speeds, which results in increased energy generation.

The size of a wind turbine is determined by the diameter of the rotor or the length of the blades. The rotor diameter is the circle swept by the rotating blades, and it plays a vital role in determining the turbine's capacity. Modern wind turbines have rotor diameters ranging from 80 to 150 meters or more.

The size and type of wind turbines installed in Europe varies between countries. The average power rating of turbines installed onshore in 2022 was 4.1 MW, equal to the figure for 2021. Before this, the average power rating grew from a value of 2.4 GW in 2013, an increase of more than 70% over the last decade. The average power rating of onshore turbines ordered over the year 2022 was 5.1 MW.

In order to make increase the economic viability of wind turbines in areas characterised by lower wind speeds, turbines with relatively larger rotor diameters and lower power ratings are being developed. Their deployment in the near future will further increase the height, and diameter, of wind turbines.

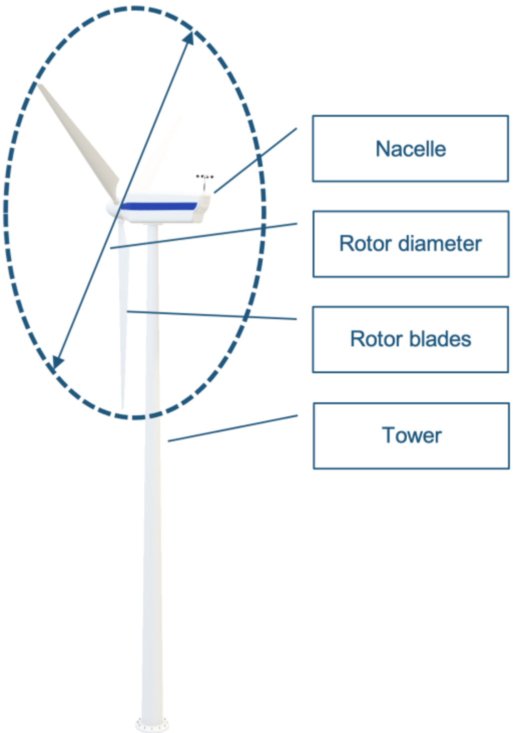


Figure A1.4-1 Wind turbine terminology

A1.5 Outlook on future expansion

The outlook is that wind turbines will further grow in size and output. This is driven by recognition of wind energy as a key component of the transition towards green energy.

For the scope of this report, a distinction between energy generated on land and offshore is made. The ratio between wind energy generated onshore and offshore in the European Union (EU) varies but is generally dominated by onshore wind energy.

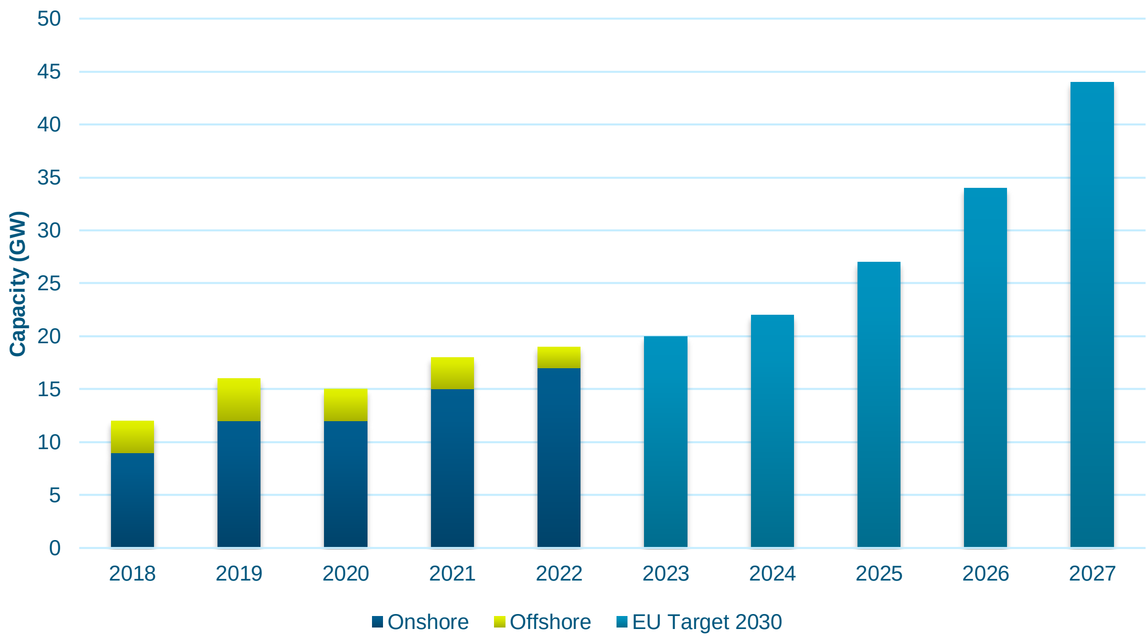


Figure A1.5-1 - Wind energy production to date and future EU targets

A2 Appendix – Regulatory Assessment

A2.1 Introduction

An assessment of Commission Regulation (EU) No 139/2014 of 12 February 2014 laying down requirements and administrative procedures related to aerodromes pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council was made at the start of the project

The goal of this assessment was to identify the existing regulatory elements related to the safeguarding of aerodromes in respect to wind turbines and to insert those elements in the causal map identifying possible gaps.

The assessment was performed by two external experts and the results were discussed with EASA staff members. The external experts were asked to perform the assessment in an unbiased manner and identify where the ADR requirements relate to wind turbines.

The sections below summarize the results of the assessment in three subsections related to generic requirements, and requirements specific for Member States and Aerodrome Operators.

It is important to emphasize that this assessment only concerns the requirements related to aerodromes (ADR), and only reflects the interpretation of requirements by the experts working on this project.

A2.2 Summary of assessment

A2.2.1 General principles

1. All aerodromes with a paved instrument runway open to public commercial air transport (either scheduled or unscheduled) should follow the provisions of the Basic Regulation 2018/1139, or have been exempted to do so.

2. The routes and areas to arrive and depart from an aerodrome shall provide protection from wind turbines as obstacles, and the effects from those wind turbines.

3. For the purpose of safeguarding the airspace, obstacle monitoring surfaces, that meet the requirements of ICAO Annex 14 for the type of runway at the aerodrome, shall be defined, implemented and monitored.

4. A “consultations” process is required with regards to the safety impacts of wind turbines within certain lateral limits from an aerodrome or those above a certain height, or irrespective of the wind turbine height when its position can cause hazardous obstacle-induced turbulence for aircraft or interference with communication and/or navigation equipment.

5. Depending on the type of runway at an aerodrome, different height criteria exist aimed to prevent penetration of a protection or limitation surface for arriving or departing aircraft. For departing aircraft, a safety assessment is required for wind turbines penetrating the take-off climb surface.

6. Only wind turbines meeting the definition of an obstacle should be marked and/or lighted. The suggested colour for painting wind turbines is given as ‘white’ without further specification. This wording allows application of a different colour as ‘white’ to functions as a colour for marking. Lighting requirements for wind turbines are, in essence, not existing due to the chosen wording “where deemed necessary” in combination with an option to differentiate from the CS based on a safety assessment.

A2.2.2 Member State/Competent Authority requirements

7. Member States bear the overall responsibility to safeguard aerodromes against activities and development causing unacceptable risks to aircraft.

8. In fulfilling its responsibility of safeguarding aerodromes, the MS may allocate the different tasks associated with this process to different entities and organizations provided a seamless organization is ensured.

9. The competent authority can perform safety assessments as be part of the safeguarding process of an aerodrome, provided a functional separation exists with the oversight on that aerodrome.

10. The Competent Authority is responsible to verify how the Aerodrome Operator safeguards the aerodrome against adverse effects of wind turbines as part of its oversight program.

A2.2.3 Aerodrome Operator requirements

11. To provide protection from wind turbines and as part of its management system, the Aerodrome Operator is responsible to make arrangements with third parties that are essential to manage the safety risk of wind turbines.

12. As part of the initial and continued certification process, the Aerodrome Operator is responsible to define and maintain the obstacle monitoring surfaces as part of its Management System to ensure safe operation of aircraft, and accessibility of the aerodrome.

13. The surveying for aeronautical data of the obstacle monitoring surfaces can be subcontracted to a third party, but remains the responsibility of the AO.

14. The AO should provide data to users, ANSP and AIS providers on hazardous obstacles inside the aerodrome boundary or those obstacles that penetrate any of the obstacle monitoring surfaces.

15. The AO should have formal arrangements with ANSP, AIS providers and the Competent Authority to provide obstacle data outside the aerodrome boundary.

16. The AO shall define in the Aerodrome Manual the obstacle monitoring surfaces, obstacle control procedures and procedures related to the mitigation of hazards from wind turbines.

17. The hazard identification and risk mitigation process for wind turbines falls under the responsibility of the AO and is controlled under a quality management process as part of the Aerodrome Operators Management System.

18. The Aerodrome Operator shall monitor activities and developments related to wind turbines and take measures to mitigate risks.

19. Safety measures taken by the AO could include imposing limitations of the aerodrome usability in terms of traffic types and meteorological conditions.

20. The requirement to conduct a safety assessment for obstacles with a height above 150 meters AGL located outside the OLS lateral boundaries only applies to areas under control of the aerodrome operator.

21. The specifications on how to mark and/or light objects, depending on their height, only apply to areas under control of the aerodrome operator.

A2.2.4 Cross reference between summary and requirement

The summary number in table below, refers to the numbers used in the paragraphs above.

Table 2.2-1 – Summary and requirement cross reference

Summary number	Related Requirement
1	Basic Regulation 2018/1139, article 2
2	Basic Regulation 2018/1139, Annex VII paragraph 1.2
3	Basic Regulation 2018/1139, Annex VII paragraph 3.1.1
4	The Aerodrome Regulation 139/2014, cover regulation article 10
5	Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.J.470, 475, 480, 485
6	Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.851
7	Basic Regulation 2018/1139, Chapter III, Section IV article 38
8	The Aerodrome Regulation 139/2014, cover regulation (7)
9	The Aerodrome Regulation 139/2014, cover regulation, GM1 to article 3.2
10	The Aerodrome Regulation 139/2014, ADR.AR.C.005
11	Basic Regulation 2018/1139, Annex VII paragraph 2.2
12	The Aerodrome Regulation 139/2014, ADR.OR.B.015 The Aerodrome Regulation 139/2014, ADR.OPS.B.075 Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.H.405
13	The Aerodrome Regulation 139/2014, ADR.OR.D.010
14	The Aerodrome Regulation 139/2014, ADR.OR.D.007
15	The Aerodrome Regulation 139/2014, AMC 1 ADR.OPS.A.005
16	The Aerodrome Regulation 139/2014, ADR.OR.E.005 The Aerodrome Regulation 139/2014, ADR.OPS.B.075
17	The Aerodrome Regulation 139/2014, ADR.OR.C.005 The Aerodrome Regulation 139/2014, ADR.OR.D.007
18	Basic Regulation 2018/1139, Chapter III, Section IV article 38
19	Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.840, 841
20	Certification Specifications and Guidance Material for Aerodrome Design, CS ADR-DSN.Q.847, 848, 849

A2.2.5 Specific requirements related to marking and lighting

ICAO[21] refers to several different standard obstacle light types and attributes. EASA basically refers to the ICAO definition of lighting types, and has specified requirements for wind turbines in CS ADR-DSN.Q.851.

Light Type	Colour	Signal type/ (flash rate)	Peak intensity (cd) at given Background Luminance (b)		
			Day (Above 500cd/m2)	Twilight (50-500 cd/m2)	Night (Below 50 cd/m2)
Low-intensity, Type A (fixed obstacle)	Red	Fixed	N/A	N/A	10
Low-intensity, Type B (fixed obstacle)	Red	Fixed	N/A	N/A	32
Low-intensity, Type C (mobile obstacle)	Yellow/Blue (a)	Flashing (60-90 fpm)	N/A	40	40
Low-intensity, Type D (follow-me vehicle)	Yellow	Flashing (60–90 fpm)	N/A	200	200
Medium-intensity, Type A	White	Flashing (20–60 fpm)	20.000	20.000	2.000
Medium-intensity, Type B	Red	Flashing (20–60 fpm)	N/A	N/A	2.000
Medium-intensity, Type C	Red	Fixed	N/A	N/A	2.000
High-intensity, Type A	White	Flashing (40–60 fpm)	200.000	20.000	2.000
High-intensity, Type B	White	Flashing (40–60 fpm)	100.000	20.000	2.000

Figure A2.2-1 ICAO Obstacle light types and attributes

The table shows the peak light intensity in candela of each light type, during various times of day, described by the amount of background luminance. The types A, B and C occur multiple times in the table as each letter is used to describe the type in relation to whether it is a low, medium or high-intensity light. In addition, the table also describes whether the light is white or red and whether the light is flashing or fixed.

For more detailed information see ICAO Annex 14, chapter 6.

[21] *ICAO SARPs Annex 14, chapter 6, table 6-1*

ICAO recommendations and EASA regulations on lighting and marking of wind turbines are very similar. They both recommend a number of different applicable obstacle lighting solutions that are open to variation.

The EASA requirements included in CS ADR-DSN.Q.851 only apply to wind turbines that are considered to be an obstacle. With this applicability, wind turbines below defined surfaces intended to protect aircraft in flight or outside those defined surfaces and assessed as not being a hazard to air navigation would not need to be lighted.

The GM1 on CS ADR-DSN.Q.851 define that the requirements should be interpreted as a minimum standard.

Marking

The rotor blades, nacelle and upper 2/3 of the tower of wind turbines should be painted white, or if after a safety assessment, it is determined that other colour will improve safety.

The ICAO requirements are identical.

Lighting

Table A2.2-2 Present date EASA options for wind turbine lighting[22]

Wind turbine height (meters AGL)	Location of light	Obstacle light	ICAO type	Criterium
45 - 150	Nacelle	1x LIM FLG R	Type B	Unobstructed view on light
150 – 315	Nacelle	2x LIM FLG R	Type B	Second light serves as alternate Unobstructed view on lights
	Tower (1/2 tower height)	3x LIL FLG R	Type E	Unobstructed view on light from every angle Flash same rate as nacelle
	Tower (1/2 tower height)	3x LIL F R	Type A or B	When type E not suitable Unobstructed view on light from every angle Flash same rate as nacelle
> 315	Nacelle	2x LIM FLG R	Type B	Second light serves as alternate Unobstructed view on lights Provided additional lights not required
	Tower (1/2 tower height)	3x LIL FLG R	Type E	Unobstructed view on light from every angle Provided additional lights not required Flash same rate as nacelle
	Tower (1/2 tower height)	3x LIL F R	Type A or B	When type E not suitable Unobstructed view on light from every angle Flash same rate as nacelle Provided additional lights not required

Table A2.2-3 ICAO options for wind turbine lighting

Wind turbine height AGL (m)	Solution	Location of light	Obstacle light	ICAO Type	Candela output	Spacing between light
45-150	1	Nacelle	LIM FLG W	A	20.000	
		Tower	Multiple options	Multiple options	-	Max 105 m

[22] *This table has been constructed from CS ADR-DSN.851, tables Q-1, 2 and 3*

> 150		Nacelle	LIM FLG R	B	2.000	-
	2	Tower	LIL F R	B	32	Max 52 m (alternating types)
		Tower	LIM FLG R	B	2.000	Max 52 m (alternating types)
	3	Nacelle	LIM F R	C	2.000	
		Tower	Multiple options	Multiple options	-	Max 52 m
	4	Nacelle	LIH FLG W	A	200.000	
		Tower	LIH FLG W	A	200.000	Max 105 m

The table contains the three main recommended obstacle lighting solutions, here referred to as solutions 1-3, which all use medium intensity lights (LIM) that ICAO recommends as nacelle lighting for wind turbines. The recommended ICAO type of medium lighting varies, and each solution suggests a different one, Type A, B and C respectively.

As can be seen from the table, all three recommended solutions suggest the use of tower obstacle lighting with different vertical spacing depending on the height.

ICAO and EASA both use the height categories of 45-150 meters and 150 meters and higher, above ground level (AGL). The solutions suggested for both categories are the same.

The recommended solutions scale with height in regard to the number and positioning of tower lights. ICAO and EASA do not differentiate their recommendations according to whether a wind turbine is on- or offshore.

The table includes a 4th solution, shaded as green. This solution is at present not included in the EASA requirements but finds its origin from ICAO as a general obstacle lighting solution. This 4th solution is included as it could give some context as to why some national regulations require the use of high intensity obstacle lights, although ICAO specifically recommend the use of medium intensity lights for obstacle lighting on wind turbines.

A2.3 Basic Regulation 2018/1139

CHAPTER I TEXT ARTICLE 2 (EXTRACT) – SCOPE OF REGULATION

This Regulation shall apply to

…

without prejudice to Union and national law on environment and land-use planning, the safeguarding of surroundings of the aerodromes which:

(i) are open to public use;

(ii) serve commercial air transport; and

(iii) have a paved instrument runway of 800 metres or more, or exclusively serve helicopters using instrument approach or departure procedures;

…

Member States may decide to exempt from this Regulation the … operation of an aerodrome, …, where that aerodrome handles no more than 10 000 commercial air transport passengers per year and no more than 850 movements related to cargo operations per year, and provided that Member States concerned ensure that such exemption does not endanger compliance with the essential requirements for aerodromes (Annex VII).

…

Understanding of requirement

Basic Regulation 2018/1139 is applicable for the majority of aerodromes in the Union that serve commercial air transport, either scheduled or unscheduled and use a paved instrument runway or – in case of rotor wing aircraft *have instrument or departure procedures. Exemptions are possible for low traffic volume aerodromes provided that such exemption has no negative impact on the compliance with the essential requirements stipulated in Annex VII (for aerodromes).*

BASIC REGULATION ANNEX VII ESSENTIAL REQUIREMENTS FOR AERODROMES, POINT 1.2 OBSTACLE CLEARANCE ON AIRCRAFT PROTECTION AGAINST OBSTACLES

…

To protect aircraft proceeding to an aerodrome for landing or for their departure from an aerodrome, arrival and departure routes or areas shall be established. Such routes or areas shall provide aircraft with the required clearance from obstacles located in the area surrounding the aerodrome taking due account of the local physical characteristics.

…

Obstacle clearance shall be appropriate to the phase of flight and type of operation being conducted. It shall also take into account the equipment being used for determining the position of the aircraft.

…

Understanding of requirement

The Basic Regulation attributes responsibility to the aerodrome operator (AO) in establishing arrangements with organisations such as ANSP, procedure designers, AIP providers, obstacle surveyors, etc. to ensure their 'products' or 'activities' are in compliance with the regulations.

BASIC REGULATION ANNEX VII ESSENTIAL REQUIREMENTS FOR AERODROMES POINT PARA 2.1 ON RESPONSIBILITIES OF THE AERODROME OPERATOR

…

The responsibilities of the aerodrome operator are as follows

…

Shall establish arrangements with other relevant organisations to ensure continuing compliance with the essential requirements for aerodromes set out in this Annex. Those organisations include, but are not limited to, aircraft operators, ANS providers, and other organisations whose activities or products may have an effect on aircraft safety

…

Understanding of requirement

The Basic Regulation attributes responsibility to the aerodrome operator (AO) in establishing arrangements with organisations such as ANSP, procedure designers, AIP providers, obstacle surveyors, etc. to ensure their 'products' or 'activities' are in compliance with the regulations.

BASIC REGULATION ANNEX VII ESSENTIAL REQUIREMENTS FOR AERODROMES POINT 2.2 ON MANAGEMENT SYSTEM

…

As appropriate for the type of activity undertaken and the size of the organisation, the aerodrome operator shall implement and maintain a management system to ensure compliance with the essential requirements set out in this Annex, manage safety risks, and aim for continuous improvement of this system.

…

Understanding of requirement]

Safety risks from wind turbines should be managed under the management system of the AO. The term continuous improvement can be seen as an incentive to expand the management system to a wider context.

BASIC REGULATION ANNEX VII ESSENTIAL REQUIREMENTS FOR AERODROMES POINT 3.2 ON SAFEGUARDING FROM OBSTACLES

…

The airspace around aerodrome movement areas shall be safeguarded from obstacles so as to permit the intended aircraft operations at the aerodromes without creating an unacceptable risk caused by the development of obstacles *around the aerodrome. Obstacle monitoring surfaces shall therefore be developed, implemented and continuously monitored to identify any infringing penetration.*

…

obstacles shall be published and, depending on the need, shall be marked and, where necessary, made visible by means of lights.

…

Hazards related to human activities and land use, such as, but not limited to, items on the following list, shall be monitored. The risk caused by them shall be assessed and mitigated as appropriate:

(a) any development or change in land use in the aerodrome area;

(b) the possibility of obstacle-induced turbulence;

(c) the use of hazardous, confusing and misleading lights;

(f) sources of non-visible radiation or the presence of moving or fixed objects which may interfere with, or adversely affect, the performance of aeronautical communications, navigation and surveillance systems.

Understanding of requirement

Obstacle monitoring surfaces are required to be developed, implemented and monitored with the specific purpose to identify and publish obstacles, and safeguard against hazards from wind turbines. Various hazards are listed with a specific relationship with wind turbines (obstacle-induced turbulence, lights, interference with communication and navigation equipment). The responsibility for this requirement is not attributed to any particular organisation or entity

BASIC REGULATION, ARTILCE ARTICLE 38 (EXTRACT) – PROTECTION OF AERODROME SURROUNDINGS

…

Member States shall take the necessary measures to ensure that aerodromes located in their territory are safeguarded against activities and developments in their surroundings which may cause unacceptable risks to aircraft using the aerodrome.

…

The organisations responsible for the operation of aerodromes shall monitor activities and developments which may cause unacceptable safety risks to aviation in the surroundings of the aerodrome for the operation of which they are responsible. They shall take the necessary measures to mitigate those risks in as far as this lies within their control and, where that is not the case, bring those risks to the attention of the competent authorities of the Member State where the aerodrome is located.

…

Understanding of requirement

The aviation authority of the Member State is required to take measures of safeguarding aerodromes, but the AO is responsible for monitoring activities and developments in the surroundings and take measures to mitigate those risks.

The use of "surroundings of the aerodrome" does not clearly define the geographical limits to responsibility of the AO. The term "within control" allows interpretation by the various parties involved on what in reality is under control, or what in theory is considered to be the control of the AO.

A2.4 The Aerodrome Regulation (Commission Regulation (EU) 139/2014)

COVER REGULATION

…

(7) With regard to obstacle management in the aerodrome surroundings as well as to other activities taking place outside the aerodrome's boundary each Member State may designate different authorities and other entities in

charge of monitoring, assessment and mitigation risks. The aim of this Regulation is not to change current allocation of tasks within the Member State. However a seamless organisation of the competences regarding the safeguarding of aerodrome surroundings and the monitoring and mitigating of risk caused by human activities should be ensured in each Member State. It should therefore be ensured that authorities which are entrusted with responsibilities of safeguarding the surrounding of aerodromes have the adequate competencies to fulfil their obligations.

…

Understanding of requirement

The MS has the responsibility to determine which organisation is used with respect to monitoring, assessing and mitigating risks arising from wind turbines in the aerodrome surroundings. For this purpose the MS is required to ensure it has an adequate competency to fulfil this obligation.

This requirement places the MS aviation authority in control to direct the high-level process to determine and assign which organizations in the aviation domain are responsible for the safeguarding process of aerodromes in respect to obstacles and wind turbine specific risks.

INTERACTION BETWEEN VARIOUS ACTORS BECOMES OF SIGNIFICANT IMPORTANCE.

COVER REGULATION ARTICLE 8 (EXTRACT) – SAFEGUARDING OF AERODROME SURROUNDINGS

…

Member States shall ensure that consultations are conducted with regard to safety impacts of constructions:

built within the limits of the obstacle limitation and protection surfaces as well as other surfaces associated with the aerodrome.

proposed to be built beyond the limits of the obstacle limitation and protection surfaces as well as other surfaces associated with the aerodrome and which exceed the height established by Member States.

Member States shall ensure coordination of the safeguarding of aerodromes located near national borders with other Member States.

…

Understanding of requirement

"Consultations" are required for wind turbines that are not vertically penetrating OLS, obstacle protection surfaces (e.g. PAPI) or other surfaces when build within the lateral limits of those surfaces. Beyond the lateral limits of these surfaces, a consultation is required for obstacles exceeding a specific height established by Member States.

It is not clearly defined what amounts to such consultations, or which parties are involved in this process.

COVER REGULATION ARTICLE 9 (EXTRACT) – MONITORING OF AERODROME SURROUNDINGS

…

Member States shall ensure that consultations are conducted with regard to human activities and land use such as:

(b) any development which may create obstacle-induced turbulence that could be hazardous to aircraft operations;

(c) the use of hazardous, confusing and misleading lights;

(f) sources of non-visible radiation or the presence of moving or fixed objects which may interfere with, or adversely affect, the performance of aeronautical communications, navigation and surveillance systems.

…

Understanding of requirement

Irrespective of the location of a wind turbine (refer to article 8 above), that protection surfaces are not penetrated or it the turbine is below a specific height established by a MS consultations are still required for wind turbines if they are known to cause hazardous turbulence, have installed misleading lights or interfere with communication or navigation equipment.

AUTHORITY REQUIREMENTS (ANNEX II) TEXT ADR.AR.C.005 (EXTRACT) – OVERSIGHT

…

The Competent Authority shall verify continued compliance with the certification basis and applicable requirements of aerodromes.

…

The scope of oversight shall take into account … the safety priorities identified.

…

Within its oversight powers, the Competent Authority may decide to require prior approval for any obstacles, developments and other activities within the areas monitored by the aerodrome operator in accordance with ADR.OPS.B.075, which may endanger safety and adversely affect the operation of an aerodrome.

…

Understanding of requirement

The CA is responsible to assess if it needs to require a prior approval for construction of any obstacles, developments and other activities that may endanger safety. The AMC1 requires the CA to have the capability to assess this process.

ORGANISATION REQUIREMENTS (ANNEX III) TEXT ADR.OR.B.015 (EXTRACT) – APPLICATION FOR A CERTIFICATE

…

The applicant should provide the Competent Authority with a description, height, and location of obstacles, in accordance with the applicable aeronautical data requirements (see ADR.OPS.A.005 and AMC1 ADR.OPS.A.005).

…

Understanding of acceptable means of compliance

The AO is responsible for supplying the initial obstacle survey for the areas defined in AMC1 ADR.OPS.A.005 as part of the initial aerodrome certification process.

ORGANISATION REQUIREMENTS (ANNEX III) TEXT ADR.OR.C.005 (EXTRACT) – AO RESPONSIBILITIES

…

The management system shall include a formal process that ensures that hazards in operations are identified and a formal process that ensures analysis, assessment and mitigation of the safety risks in aerodrome operations.

…

Understanding of requirement

The hazard identification and risk mitigation process for wind turbines is part of the aerodromes management system, and falls under the responsibility of the AO.

ORGANISATION REQUIREMENTS (ANNEX III TEXT ADR.OR.D.007 (EXTRACT) – MANAGEMENT OF AERONAUTICAL DATA AND INFORMATION

…

As part of its management system, the aerodrome operator shall implement and maintain a quality management system covering its aeronautical data activities and its aeronautical information provision activities.

…

Understanding of requirement

The information provided as part of the aerodrome certification process regarding obstacle surveyance, is intended to be maintained and controlled by the AO under a quality management process. This includes earlier identified hazard identification and risk mitigation process.

ORGANISATION REQUIREMENTS ANNEX III TEXT ADR.OR.D.010 (EXTRACT) – CONTRACTED ACTIVITIES

…

Contracted activities include all activities within the aerodrome operator's scope in accordance with the terms of the certificate that are performed by other organisations either itself certified to carry out such activity or if not certified, working under the aerodrome operator's approval. The aerodrome operator shall ensure that when contracting or purchasing any part of its activity, the contracted or purchased service or equipment or system conforms to the applicable requirements.

…

Understanding of requirement

According the GM1 for this requirement, the surveying for aeronautical data can be a contracted activity, but the ultimate responsibility remains with the AO.

ORGANISATION REQUIREMENTS (ANNEX III) TEXT ADR.OR.E.005 (EXTRACT) – AERODROME MANUAL

…

The aerodrome manual shall contain

…

its obstacle limitation and protection surfaces and other areas associated with the aerodrome.

…

Procedures for:

18.1 obstacle control and monitoring within and outside of the aerodrome boundaries, and notification to the Competent Authority, of the nature and location of obstacles, and any subsequent addition, or removal of obstacles for action as necessary, including amendment of the AIS publications; and

18.2 monitoring and mitigating hazards related to human activities and land use, on the aerodrome and its surroundings.

…

Understanding of requirement

The aerodrome manual contains the OLS, protection surfaces and other areas, as well as the procedures to control and monitor those both inside and outside aerodrome boundaries.

ORGANISATION REQUIREMENTS (ANNEX IV) TEXT ADR.OPS.A.005 (EXTRACT) – AERODROME DATA

…

The aerodrome operator shall provide data relevant to the aerodrome and available services to the users and the relevant air traffic services and aeronautical information services providers.

…

Electronic obstacle data for all obstacles in Area 2 (the part within the aerodrome boundary) that are assessed as being a hazard to air navigation should be provided.

…

Electronic terrain and obstacle data should be provided for:

(1) Area 2a, for those that penetrate the relevant obstacle data collection surface;

(2) penetrations of the take-off flight path area obstacle identification surfaces; and

(3) penetrations of the aerodrome obstacle limitation surfaces.

…

Electronic terrain and obstacle data should be provided for Area 4 for terrain and obstacles that penetrate the relevant obstacle data collection surface, for all runways where precision approach Category II or III operations have been established and where detailed terrain information is required by operators to enable them to assess the effect of terrain on decision height determination by use of radio altimeters

…

Understanding of requirement

The AO is required to provide obstacle data to users, ANSP and AIS providers, but only for hazardous obstacles inside the aerodrome boundary or those obstacles that penetrate any of the obstacle collection/identification/limitation surfaces.

That means that those obstacles that could be (or have already been) identified as hazardous but are outside the aerodrome boundary or do not penetrate any of the identified surfaces need not to be provided to aerodrome users, ANSP or AIS providers.

OPERATIONS REQUIREMENTS (ANNEX IV) TEXT AMC1 ADR.OPS.A.005 (EXTRACT) – AERODROME DATA

…

The aerodrome operator should establish arrangements with the Air Traffic Services providers and the Competent Authority for the provision of obstacles and terrain data outside of the aerodrome boundary.

…

Understanding of acceptable means of compliance

Formal arrangements between the AO, CA and ANSP are required for the exchange of obstacle data outside the aerodrome boundary.

OPERATIONS REQUIREMENTS (ANNEX IV) TEXT ADR.OPS.B.075 (EXTRACT) – SAFEGUARDING OF AERODROMES

…

The aerodrome operator shall monitor on the aerodrome and its surroundings obstacle limitation and protection surfaces as established in accordance with the certification basis, and other surfaces and areas associated with the aerodrome, in order to take, within its competence, appropriate action to mitigate the risks associated with the penetration of those surfaces and areas; marking and lighting of obstacles in order to be able to take action within its competence, as appropriate; and hazards related to human activities and land use in order to take action within its competence, as appropriate.

…

The aerodrome operator shall have procedures in place for mitigating the risks associated with obstacles, developments and other activities within the monitored areas that could impact safe operations of aircraft operating at, to or from the aerodrome.

…

The risks caused by human activities and land use which should be assessed and mitigated should include:

(1) obstacles and the possibility of induced turbulence;

(2) the use of hazardous, confusing, and misleading lights;

(4) sources of non-visible radiation, or the presence of moving, or fixed objects which may interfere with, or adversely affect, the performance of aeronautical communications, navigation and surveillance systems

…

Understanding of requirement

The AO must monitor the ADR OLS and also a wider area of the ADR to take within its competence action to mitigate the risks of those obstacles, including wind turbines. Risks associated with wind turbines (induced turbulence, misleading lights, interference with equipment) should be mitigated using established procedures.

A2.5 Certification Specifications and Guidance Material for Aerodrome Design (CS.ADR.DSN) Chapter H – Obstacle Limitation Surfaces

TEXT CS ADR-DSN.H.405 (EXTRACT) – APPLICABILITY

…

The purpose of the obstacle limitation surfaces is to … permit the intended aeroplane operations at the aerodromes to be conducted safely.

…

The OLS also help to prevent the aerodromes from becoming unusable by the growth of obstacles around the aerodromes.

…

The effective utilisation of an aerodrome may be considerably influenced by natural features and man-made constructions outside its boundary. These may result in limitations on the range of meteorological conditions in which take-off and landing can be undertaken. For these reasons, certain areas of the local airspace should be regarded as integral parts of the aerodrome environment.

…

Safety measures could be as follows:

(1) promulgation in the AIP of appropriate information;

(2) marking and/or lighting of the obstacle;

(3) variation of the runway distances declared as available;

(4) limitation of the use of the runway to visual approaches only;

(5) restrictions on the type of traffic.

…

In addition to the requirements described in the certification specifications of Chapter H, it may be necessary to call for other restrictions to development and construction on and in the vicinity of the aerodrome in order to protect the performance of visual and electronic aids to navigation and to ensure that such development does not adversely affect instrument approach procedures and the associated obstacle clearance limits.

…

Understanding of requirement

The purpose of establishing OLS is to ensure safe operation of aircraft, and accessibility of the aerodrome. The effectiveness of the aerodrome operations is related to the wind turbines in the local airspace of the aerodrome.

At present, safety measures propose include imposing limitations of the aerodrome usability in terms of traffic types and meteorological conditions.

CS ADR-DSN.J.470 (EXTRACT) – NON-INSTRUMENT RUNWAYS

…

New objects or extensions of existing objects should not be permitted above the conical surface or inner horizontal surface except when the object would be shielded by an existing immovable object, or if after a safety assessment, it is determined that the object would not adversely affect the safety or significantly affect the regularity of operations of aeroplanes.

…

In considering proposed construction, account should be taken of the possible future development of an instrument runway and consequent requirement for more stringent obstacle limitation surfaces.

…

Understanding of acceptable means of compliance

For non-instrument runways, the current criterium for construction or repowering of wind turbines is related to penetration of the conical or inner horizontal surfaces. However, when the possible future development of the runway into an instrument runway is taken into consideration, then more stringent OLS intended for instrument runways can be used in the consultation phase.

CS ADR-DSN.J.475 (EXTRACT) – NON-PRECISION APPROACH RUNWAYS

…

New objects or extensions of existing objects should not be permitted above the approach surface beyond 3 000 m from the inner edge, the conical surface or inner horizontal surface except when the object would be shielded by an existing immovable object, or after a safety assessment, it is determined that the object would not adversely affect the safety or significantly affect the regularity of operations of aeroplanes.

…

Understanding of requirement

For non-precision runways, the current criterium to allow construction or repowering of wind turbines that penetrate the approach, conical or inner horizontal surfaces is a safety assessment.

The requirement does not specify the possibility to apply more stringent criteria to allow future development of the runway into a precision runway, similar to a non-instrument runway.

CS ADR-DSN.J.480 (EXTRACT) – PRECISION APPROACH RUNWAYS

…

New objects or extensions of existing objects should not be permitted above an approach surface or a transitional surface except when the new object or extension would be shielded by an existing immovable object.

…

New objects or extensions of existing objects should not be permitted above the conical surface and the inner horizontal surface except when an object would be shielded by an existing immovable object, or if after a safety assessment, it is determined that the object would not adversely affect the safety or significantly affect the regularity of operations of aeroplanes.

…

Understanding of requirement

For precision runways, the current criterium to allow construction or repowering of wind turbines that penetrate the approach, conical or inner horizontal surfaces is a safety assessment.

CS ADR-DSN.J.485 (EXTRACT) – RUNWAYS MEANT FOR TAKE-OFF

…

Existing objects that extend above a take-off climb surface should as far as practicable be removed except when an object is shielded by an existing immovable object, or if after a safety assessment, it is determined that the object would not adversely affect the safety or significantly affect the regularity of operations of aeroplanes.

…

Understanding of requirement

For departure runways, the current criterium to allow construction or repowering of wind turbines that penetrate the take-off climb surface is a safety assessment.

CS ADR-DSN.J.487 (EXTRACT) – OBJECTS OUTSIDE THE OBSTACLE LIMITATION SURFACES

…

The specifications below apply only to the area under control of the aerodrome operator.

…

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

…

The safety assessment should be conducted for the proposed constructions that extend above the established limits in order to protect safe operation of aircraft. The safety assessment may have regard to the nature of operations concerned and may distinguish between day and night operations.

Understanding of requirement

The requirement to conduct a safety assessment for obstacles with a height above 150 meters AGL located outside the OLS lateral boundaries only applies to areas under control of the aerodrome operator.

CS ADR-DSN.Q.840 (EXTRACT) – OBJECTS TO BE MARKED AND/OR LIGHTED WITHIN THE LATERAL BOUNDARIES OF THE OBSTACLE LIMITATION SURFACES
CS ADR-DSN.Q.841 (EXTRACT) – OBJECTS TO BE MARKED AND/OR LIGHTED OUTSIDE THE LATERAL BOUNDARIES OF THE OBSTACLE LIMITATION SURFACES

…

The specifications for objects to be marked and/or lighted … only to the area under control of the aerodrome operator.

…

A fixed obstacle that extends above a take-off climb, approach or transitional surface within 3 000 m of the inner edge of the take-off climb or approach surface should be marked and if the runway is used at night, lighted.

…

A fixed object that extends above an obstacle protection surface should be marked and, if the runway is used at night, lighted

…

Understanding of requirement

The specifications on how to mark and/or light objects, depending on their height, only apply to areas under control of the aerodrome operator.

CS ADR-DSN.Q.847 (EXTRACT) – LIGHTING OF FIXED OBJECTS WITH A HEIGHT LESS THAN 45 M ABOVE GROUND LEVEL
CS ADR-DSN.Q.848 (EXTRACT) – LIGHTING OF FIXED OBJECTS WITH A HEIGHT 45 M TO A HEIGHT LESS THAN 150 M ABOVE GROUND LEVEL
CS ADR-DSN.Q.849 (EXTRACT) – LIGHTING OF FIXED OBJECTS WITH A HEIGHT 150 M OR MORE ABOVE GROUND LEVEL

…

Understanding of requirement

The CS above start with the condition "the presence of objects which should be lighted" but the lighting requirements for these objects do not contain the same pre-condition. This can be interpreted that lighting is always required.

CS ADR-DSN.Q.851 (EXTRACT) – MARKING AND LIGHTING OF WIND TURBINES

…

When considered as an obstacle a wind turbine should be marked and/or lighted.

…

The rotor blades, nacelle and upper 2/3 of the supporting mast of wind turbines should be painted white, or if after a safety assessment, it is determined that other colour will improve safety.

…

Where lighting is deemed necessary for a single wind turbine or short line of wind turbines, the installation should be in accordance with paragraph (c)(2)(v) below, or as determined by a safety assessment.

…

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 lights should be installed.

…

Understanding of requirement

Only wind turbines meeting the definition of an obstacle should be marked and/or lighted. The suggested colour for painting wind turbines is given as 'white' without further specification. This wording allows a different colour application as 'white' to function as a colour for marking.

Lighting requirements are, in essence, not existing due to the chosen wording "where deemed necessary" in combination with an option to differentiate from the CS based on a safety assessment.

GM1 ADR-DSN.Q.851 – MARKING AND LIGHTING OF WIND TURBINES

…

Additional markings and lighting may be provided to the wind turbines if indicated by a safety assessment.

…

Case by case studies for wind turbines of more than 315 m of overall height may conclude that additional markings and lighting are required.

Understanding of guidance material
The result of a safety assessment can be used to require additional markings and lights.
For wind turbines higher than 315, the provisions for wind turbines below 315 meter must be used, unless an assessment determines other markings.

A3 Appendix – Lighting and marking of wind turbines

A3.1 Height of wind turbines – standard categories

The requirements for wind turbines' obstacle lighting and marking depend on the height of the wind turbine. The used height categories however are not identical and vary between Member States.

Table A3.3-1 Height categories between Member States

Member State	Regulatory height categories (AGL)		
BE	< 100 meters	100 – 150 meters	> 150 meters
NL	< 100 meters	100 – 210 meters	> 210 meters
SE	45 – 150 meters	110 – 150 meters	> 150 meters
NO DE DK	No requirements	100 – 150 meters	> 150 meters
IE	No requirements	> 90 meters	

A3.2 Lighting solutions

The ICAO recommendations and the EASA regulation on obstacle lighting and marking of wind turbines are very similar. They both recommend a number of different applicable obstacle lighting solutions that are open to variation.

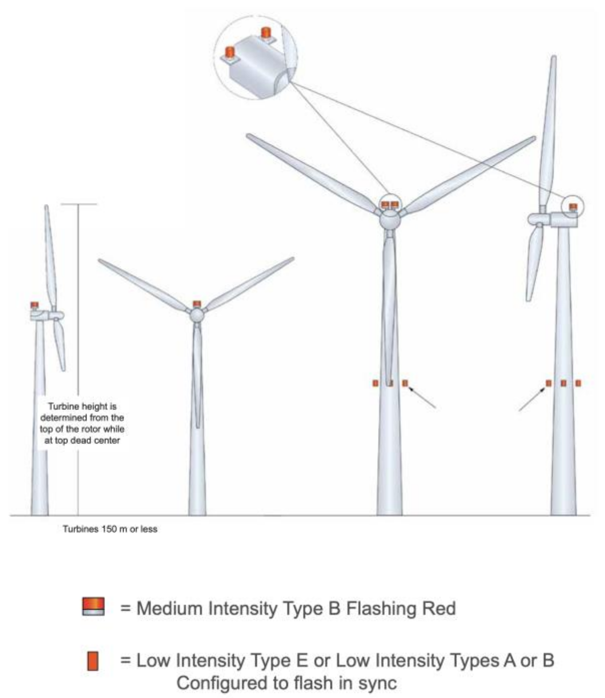


Figure A3.3-1 ICAO/EASA lighting solutions

ICAO and EASA both use the height categories of 45-150 meters and 150 meters and higher. However, the solutions provided for both categories are the same. The recommended solutions scale with height with regard to the number and positioning of tower lights. ICAO and EASA do not differentiate between on- or offshore wind turbines.

Table A3.3-1 EASA/ICAO recommendations on wind turbine obstacle lighting

Wind turbine height AGL (m)	ICAO Type	Location of lights	Obstacle light type	Light output (candela)	Maximum spacing between lights (m)
45-150 meters	A	Nacelle	LIM FLG W	20.000	105
		Tower	Multiple options	-	
	B	Nacelle	LIM FLG R	2.000	52 (alternating spaces)
		Tower	LIL FLR R LIM F R	2.000 32	
	C	Nacelle	LIM F R	2.000	52
		Tower	Multiple options	-	
> 150 meters	A	Nacelle	LIM FLG W	20.000	105
		Tower	Multiple options	-	
	B	Nacelle	LIM FLG R	2.000	52 (alternating spaces)
		Tower	LIL FLR R LIM F R	2.000 32	
	C	Nacelle	LIM F R	2.000	52
		Tower	Multiple options	-	

As part of the work in the North Seas Energy Cooperation, the Danish Transport, Construction and Housing Authority and the Danish Ministry of Energy, Utilities and Climate commissioned the mapping of regulations for lights and markings on wind turbines[23] within the individual North Sea countries (Belgium, the Netherlands, Ireland, the United Kingdom, France, Norway, Sweden, Germany and Denmark).

Where the existing national requirements for wind turbine obstacle lighting and marking are concerned, this report will focus on the onshore wind turbines only. After analysing the mapping, five possible areas of harmonisation of the national regulations are identified.

A3.3 Positioning, number and types of lights

National requirements of the positioning, number and type of lights vary depending on whether the wind turbine is onshore or offshore and whether the turbine is part of a wind farm or not. The differences between national regulations concern both the types of lights required and thereby the brightness, frequency as well as the number-, and position of obstacle lights.

The regulations regarding obstacle lighting on individual onshore wind turbines that are taller than 150 meters require mainly the use of LIM type A and/or LIM type B or C. Norway and Sweden require the use of LIH obstacle lights.

[23] *ATKINS SNC-Lavalin, Mapping of National regulations for lights and markings on wind turbines, July 2019*

Figure A3.3-2 Red obstruction lights in the "Odervorland" wind farm in Germany

Interpretation of the obstacle position and height

Obstacle lights and markings are primarily used to provide a reference point for pilots. A lighted obstacle can become effectively invisible due to background lights when the contrast between the obstacle's lights and the surrounding background lights is insufficient to make the obstacle stand out.

Usually, obstacle lights on wind-turbines are placed on top of the nacelle. The engine nacelle does not correlate with the highest point of the wind-turbine. The highest point of the wind turbine might not be distinguishable from the obstacle lights installed.

Causes for misinterpretation based on obstacle lighting

Competing Light Sources

In environments with numerous light sources, such as a densely lit urban area, an obstacle's lights may be overwhelmed by the brightness of the background lights. For instance, if a tall building has lights on its structure but is surrounded by a cityscape with many other bright lights, those lights may not be distinguishable against the overall brightness of the surroundings.

Insufficient Contrast

To be visible, an obstacle's lights need to create a significant contrast with the background. If the obstacle's lights are relatively dim, small, or not properly configured to stand out against the background lights, they may blend in or go unnoticed.

Glare and Halo Effects

Bright background lights can produce glare or halo effects around the edges of objects, including obstacles. This can make it difficult for observers, such as pilots or mariners, to discern the actual shape and position of the obstacle's lights.

Light Pollution

In areas with high levels of light pollution, caused by excessive or misdirected artificial lighting, the night sky can be brightened to the extent that it becomes challenging to see objects, including lit obstacles, in the distance.

Adaptation to Background Brightness

Human vision can adapt to different levels of brightness, a process known as visual adaptation. When exposed to a bright background for an extended period, our eyes may become less sensitive to differences in light levels, making it harder to notice dimmer lights, even if they are meant to indicate an obstacle.

Inoperative lights

Obstacle lights have an operational lifetime. Without back-up or frequent verification of the correct functioning, the obstacle light may be inoperative rendering the mitigation method useless.

Individual onshore wind turbines lower than 150 meters

In some countries[24], individual wind turbines lower than 150 meters require either light types with a lower light intensity or no obstacle lighting at all. This difference in requirements can be seen both compared to the requirements for individual onshore and offshore wind turbines below 150 meters.

In the case of for example the Netherlands, obstacle lighting is generally not required on wind turbines below 150 meters AGL. There are however exceptions under certain geographical circumstances in which case obstacle lighting of LIM Type A and LIM type C are required. This means that there are situations where the Netherlands could arguably be categorized differently than ‘None’ in the table below.

Table A3.3-2 Individual wind turbine lighting requirements for nacelles

Location	Wind turbine height AGL (m)	Obstacle light type					
		LIL Type A	LIM Type A	LIM Type B or C	LIH Type A or B	Custom	None
Onshore	< 150 meters	DK	BE DE FR	BE DE FR IE NO	SE (type B)	SE	NL UK
	> 150 meters		BE DE DK FR NL	BE DE DK FR IE NL UK	NO (type B) SE (type B)		

Wind farms

Requirements for wind turbine lighting on wind farms can be different from the requirements for individual turbines. Some wind turbines either on or within the perimeter can have less, or no obstacle lighting at all.

The Netherlands, Ireland and the United Kingdom do not require obstacle lighting within the perimeter in some cases. The United Kingdom requires all offshore wind turbines within the perimeter to have a 200 Candela fixed red light on the nacelle, which can be turned on if requested by search and rescue (SAR). In the case of Norway, the necessity for obstacle lighting within the perimeter is decided on a case-by-case basis.

[24] *Denmark, United Kingdom and the Netherlands*

Table A3.3-3 Onshore windfarm lighting requirements for nacelles

Position in windfarm	Wind turbine height AGL (m)	Obstacle light type					
		LIL Type A or B	LIM Type A	LIM Type B or C	LIH Type A or B	Custom	None
Perimeter, corner or bends	< 150 meters		BE DE FR	BE DE FR IE NO	SE (type B)	SE	NL UK
	> 150 meters		BE DE DK FR	BE DE DK FR IE NL UK	NO (type B) SE (type B)		
Within perimeter	< 150 meters	DE (type A) SE (type B)	BE	BE FR IE NO			DE NL UK
	> 150 meters	DK (type A) SE (type B)	BE	BE FR IE NL NO		UK	DE

Table A3.3-4 Onshore windfarm lighting requirements for towers

Location	Wind turbine height AGL (m)	Obstacle light type					
		LIL Type A	LIL Type B	LIL Type E	LIM Type C	Custom	None
Onshore	< 150 meters	BE					
	> 150 meters	BE DE	DE FR	IE	UK	NL	NO SE
Offshore	< 150 meters	BE					
	> 150 meters	BE DE	DE NL				FR IE NO SE UK

Light Intensity and Control

National requirements on the control and intensity of the required lights varies. Most national requirements specify that certain lights are used depending on the background lighting and time of day. Additional requirements exist to control and adjust lights under different circumstances.

Generally, countries use the same light intensity descriptions as ICAO/EASA which change depending on the background light intensity.

Table A3.3-5 Light intensity

Background light	Obstacle light intensity (candela)
Day	> 500
Twilight	50 – 500
Night	< 50

In the UK, Denmark and The Netherlands lights should be dimmed to 30% or 10% of normal light intensity if visibility is 5 kilometres. The light should be further reduced to 10% of the described intensity if the visibility is above 10 kilometres.

Requirements for wind farms differ slightly. Danish requirements state that the lowest measured visibility at any given sensor in the wind farm determines lighting intensity for the whole wind farm. The amount of visibility sensors is assessed on a case-by-case basis. In The Netherlands, a maximum distance of 1500 meters applies between wind turbines equipped with a visibility sensor, and those without one.

In other regulations, additional requirements for control of lights are included. For example, the UK requires that lights can be switched on and off or dimmed on request from the Search and Rescue (SAR) coordination authority or the HEMS/SAR helicopter pilot. The UK regulation requires single 200 candela lights on all wind turbines within the perimeter of a wind farm. However, these lights are only turned on when HEMS or SAR operations are being conducted.

Some regulations allow lights to be turned off and rely on the use of detection technologies for aircrafts nearby. The Norwegian regulation allows lights to be turned off until an object comes within 1.500 meters of the turbines.

A3.4 Marking solutions

Most MS utilize a grey/white colour scheme to mark wind turbines. Few countries have additional requirements for red/orange paint-based markings on the rotor, tower and/or nacelle under certain conditions.

Tower

Some countries[25] require the use of paint-based markings on the wind turbine tower. However, the circumstances for when these are applied differ.

Both France and Belgium, for example, utilise red paint-based marking on the tower of offshore wind turbines that are taller than 150 and 100 meters respectively. The German regulation on paint-based markings on the tower apply to onshore wind turbines taller than 150 meters.

[25] *Belgium, Germany and France*

Nacelle

Paint-based markings on the nacelle are rarely required. Germany and Belgium are the only countries that have regulation which require the use of paint-based markings on the nacelle. This only applies to optional variants, that require no other obstacle lighting.

Blades

Belgium, Germany, France and the United Kingdom all have regulation supporting the use of paint-based markings on the wind turbine blades. However, the application of paint-based markings differs between the countries, and the application even differs within one country.

Both France and Belgium have articles in their regulations requiring the utilization of paint-based markings on the blades of offshore wind turbines taller than 150 and 100 meters respectively.

The specific layout of the required markings differs. For comparison, the German regulation stipulates that for onshore wind turbines with a distance between blade tip and light at more than 50-60 meters, depending on turbine height, require the utilisation of coloured markings on the blade.

The United Kingdom require the use of painted markings solely on the blades of offshore wind turbines. This requirement is referred to as hover-reference markings for HEMS pilots. The placement and shape of the required hover-reference markings are slightly different from marking required by other countries, as they are mainly used as reference points for helicopters hovering over a wind turbine nacelle during rescue operations.

Table A3.3-6 Overview National paint-based marking requirements for wind turbines

	Red/Orange marking	No additional marking
Tower	Belgium (offshore > 100 m) France (offshore > 150 m) Germany (> 150 m) United Kingdom	Denmark Ireland Norway Sweden The Netherlands
Nacelle	Belgium (no obstacle lights) Germany (no obstacle lights)	Denmark France Ireland Norway Sweden The Netherlands United Kingdom
Blades	Belgium (offshore > 100 m) France (offshore > 150 m) Germany (blade tip > 50 m from light) United Kingdom (offshore)	Denmark Ireland Norway Sweden The Netherlands

A4 Appendix – Research information

A4.1 General

The main causes of aviation accidents are related to aircraft being upset in flight (47%), terrain conflict (23%) or obstacle interference (9%)[26]. Over the last 10 years, there have been several reported incidents of aircraft colliding with wind turbines or experiencing close calls with turbines.

- In 2015, a helicopter collided with a wind turbine in Scotland, causing the helicopter to crash and vital injuries to all three occupants.
- In 2017, a small plane collided with a wind turbine in Germany, causing the plane to crash and the death of both occupants.
- In 2018, a small plane made an emergency landing in a field near a wind farm in California after the pilot reported that he had come within 50 feet of colliding with a wind turbine.
- In 2019, a small plane collided with a wind turbine in Norway, causing the plane to crash and the pilot to sustain vital injuries.

Although these incidents underscore the importance of proper safety measures, they also demonstrate that the particular risk of wind turbines is most likely associated with low-flying aircraft such as helicopters and small planes. In addition they underline a shared interest for the wind turbine and aviation industry in protecting financial investments and public perception.

A4.2 Turbulence from wind turbines

The literature review revealed that limited research has been conducted on turbulence from wind turbines, particularly to the dissipation of vortices created by wind turbines. A study from the Kansas Department of Transportation (KDOT) found in 2013 that the spinning blades from wind turbines can create turbulence, in the form of rotational vortices.
Rotational vortices can sustain strength and distance for several miles before fully dissipating. A follow-up study[27] was conducted aimed to classify turbulence from wind turbines and its effects on aircraft and aerodromes. The purpose was to determine the velocity profile, turbulence intensity, variation of velocity deficit, and evolution of vortical structures downstream from a turbine model in controlled aerodynamical conditions.

This second study[1] demonstrated that the wake turbulence caused by the wind turbine normally develops into a helical shape and is strongest at the tip of the turbines blade. When expressed in rotor diameter (D), the turbulence energy from the wind turbine disappears completely from a distance of more than 9 x D downwind from the turbine nacelle. A study[28] conducted by Wind Energy Science, concluded that the highest hazard for (light) aircraft upset exists between 4 x D to 6 x D downwind. This hazard region was confirmed by a German assessment on aircraft loading near wind farms[29], demonstrating that the greatest load factors exist between 3 x D to 7 x D, depending on the wind speed. The turbine wake can be considered stable from a distance starting at 3 x D for low wind speed, and 7 x D for high wind speed.

[26] *European Aviation Safety Agency (EASA). Annual Aviation Safety Review; EASA: Cologne, Germany, 2017*
[27] *Report No. K-TRAN: KU-16-3, January 2018*
[28] *https://doi.org/10.5194/wes-3-833-2018*
[29] *Flight Load Assessment for Light Aircraft Landing Trajectories in Windy Atmosphere and Near Wind Farms, April 2018*

Taking the most conversative study, this would mean that from a distance of 9 x D, for the aircraft class used in the study (light SEP fixed wing):

1) The experienced turbulence is unlikely to exceed the controllability of the aircraft;
2) The aircraft structural limits are not threatened; and
3) Aircraft stall is unlikely for aircraft maintaining their normal speeds.

With a wind turbine rotor diameter of 300 meters, this would equate to a distance of 4.000 meters.

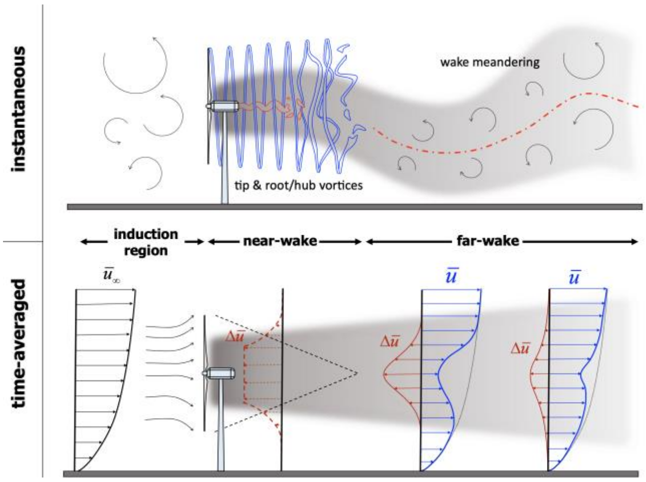


Figure 4.2-1 flow regions in wind turbine turbulence

A4.3 Radar interference by wind turbines

In most cases, the radar sensor outputs will not be provided directly to the ATCO, but will go through Surveillance Data Processing systems. These data processing systems are usually able to digitally remove the effects caused by wind turbines. However, there are still some cases where the sensor output is used directly.

Secondary Surveillance Radar (SSR) is a co-operative surveillance technique. This makes it possible to predict the theoretical range beyond which wind turbines have a manageable impact on the SSR system. Eurocontrol developed guidance material with technical studies for wind turbine constructions in closer proximity to the radar.

Primary Surveillance Radar differ in that the aircraft is non-cooperative and the only 'interface' is the electro-magnetic energy reflected from the body of the aircraft. This requires a more complex assessment based on the specific radar technology and the environment in which it is operated.

A4.3.1 Eurocontrol zonal assessment method

Eurocontrol developed guidelines[30] for assessing the detrimental impact on Secondary and Primary Surveillance Radars caused by wind turbines. In general, this impact depends on the number of wind turbines located in the radar line of sight. The Eurocontrol method aims to target the effort to minimise the impact of wind turbines at the earliest stages of the surveillance chain i.e. at the surveillance sensor level.

The Eurocontrol methodology is based upon the following zone arrangements:

[30] *EUROCONTROL-GUID-0130*

Zone 1: Safeguarding Zone (PSR and SSR):
An initial restrictive or safeguarding region that surrounds the surveillance sensor. Construction of wind turbines is not allowed within this area.
Zone 2: Detailed Assessment Zone (PSR and SSR):
Construction of wind turbines should be opposed unless supported by a detailed technical and operational assessment provided by the applicant and the results of which are found to be acceptable to the surveillance provider.
Zone 3: Simple Assessment Zone (PSR only):
Beyond the detailed assessment zone is a region within which a simple assessment of PSR performance should be sufficient to enable the surveillance data provider to assess the application.
Zone 4: Accepted Zone (PSR and SSR):
Beyond the simple assessment zone are areas within which no assessments are required and within which Surveillance Service providers would not raise objections to wind farms on the basis of an impact to surveillance services.

The PSR safeguarding range where no wind turbine shall be built (zone 1) is derived from the recommendations provided in the ICAO EUR 015 document which is applicable for any obstacle. The term 'safeguarding' within this document is intended to prohibit the construction of a wind turbine.

Table A4.3-1 Eurocontrol recommended ranges for PSR assessment

	Zone 1	Zone 2	Zone 3	Zone 4
Description	0 – 500 m	500 m – 15 km and in radar line of sight (LoS)	> 15 km but within maximum instrumented range AND in radar LoS	Anywhere within maximum instrumented range but not in radar line of sight or outside the maximum instrumented range.
Assessment requirements	Safeguarding	Detailed assessment	Simple assessment	No assessment

Table A4.3-2 Eurocontrol recommended ranges for SSR assessment

Description	0 – 500 m	500 m - 16 km but within maximum instrumented range and in radar Line of Sight (LoS)		> 16 km or not in radar LoS
Assessment requirements	Safeguarding	Detailed assessment		No assessment

These tables are applicable to current wind turbine design, e.g. 3-blades, 30-200 m height, horizontal rotation axis. For other types of turbines, it is recommended to undertake the detailed assessment as long as the wind turbine is in radar line of sight. When outside the radar line of sight of a PSR or SSR, the impact of the wind turbine is considered to be tolerable.

A4.3.2 Eurocontrol mitigations

A certain amount of reduced radar performance is tolerable, either because it is in an area of minimal concern to the ANSP or sufficient operational procedures are in place to address any surveillance short fall.

Otherwise, to accommodate the wind turbine application, three types of mitigation options are proposed by Eurocontrol, either considered individually and/or in combination:

1) Wind turbine design mitigations: Can the wind turbine proposal be modified to eradicate or minimise the effects on systems and operations?
2) Radar Technical mitigations: Can the sensor and/or surveillance system architecture be modified or configured (in terms of location/orientation) to accommodate the wind energy project to within a level of tolerable degradation of an ANSP service?
3) ANSP Operational mitigations: Can operational procedures be modified to accommodate the expected reduction in surveillance quality?

A UK study[31] led to the development of a predictive computer model that was validated against a single wind turbine. The model has shown an accurate prediction capability and helped to identify a list of the key factors influencing the radar signature of wind turbines. The study provided more details in mitigation options, particularly for those mitigations at the wind turbine design and radar technical levels.

The study resulted in the development of an interactive tool where the impact of a single wind turbine on PSR can be simulated on a map view. The existence of such pro-active tools is highly valued by all stakeholders.

A4.4 Rotor wing aircraft

Due to the nature of their typical operational profile, helicopters normally fly at low altitude, often in uncontrolled airspace and mostly during VFR conditions.

Environmental factors such as weather, terrain, obstacles as well as surrounding air traffic have an impact on the conduct of missions and consequently on flight safety. According to various studies, most incidents and accidents with helicopters are related to obstacle or terrain contacts, mostly in aggravating conditions where obstacles are unknown, insufficient ground visibility, difficult terrain, or hoist/sling relation to ground obstacles.

Helicopter operations differ from the typical fixed wing VFR profile in the sense that helicopter operations usually fall under the requirements for commercial air operations or state aircraft. From this perspective, both the organisational requirements and higher pilot qualification levels for commercial operations will result in a more robust safety net.

In normal weather and visibility conditions, a light and medium-sized helicopter operates for transit over land or sea between 1.000 and 5.000 ft AGL, and at 120-150 kts. For surveillance, HEMS or SAR activities, helicopters operate between 30 and 2.000 ft AGL and at speeds less than 80 kts. The HEMS and SAR often operate in more challenging environments such as degraded weather conditions or mountainous areas.

As part of this study, meetings with industry stakeholders were organised. One of these stakeholders indicated that the obstacle data in the Aeronautical Information Publication (AIP), did not meet their operational requirements regarding obstacle accuracy and integrity. This particular stakeholder supplemented the AIP published obstacle data, with cadastral information to develop a tailored obstacle data set. Of interest is that the geographical area covered by this HEMS operator is identical to the survey.

[31] *WIND FARMS IMPACT ON RADAR AVIATION INTERESTS - FINAL REPORT, FES W/14/00614/00/REP, DTI PUB URN 03/1294*

A4.4.1 Enhanced vision

Due to their expected lifetime, LED lights are increasingly used for obstacle lighting. An industry concern relates to the effectiveness of light enhancing equipment such as Night Vision Goggles (NVG) with LED lights.

There are different classes of NVG which registers lights within certain wavelengths such as 645 to 900 nanometres. Depending on the night vision goggles used, this means that certain types of NVG could potentially filter out certain obstacle lights, such as LED. Red coloured obstacle LED can operate outside NVG spectra.

This is especially relevant as NVG are regularly used in HEMS or State flight rotor wing operations at night in close proximity to the ground and obstacles. Irrespective of how the NVG is used in an operational environment, this study will identify if the current regulatory provisions take this sufficiently into consideration.

A4.5 Obstacles and aviation

ICAO Annex 15 (Aeronautical Information Services) defines obstacles as:
“All fixed (whether temporary or permanent) and mobile objects, or parts thereof, that:

1. are located on an area intended for the surface movement of aircraft; or
2. extend above a defined surface intended to protect aircraft in flight; or
3. stand outside those defined surfaces and that have been assessed as being a hazard to air navigation.

An obstacle in aviation denotes an object that is considered a potential hazard to the safe passage of aircraft in different types of operations. However, the criteria in sense of obstacle risk differs greatly depending on the type of obstacle. It is important to realise that the typical obstacles, at the time when the current regulations were drafted, were mainly static objects with height properties that defined their risk.

Traditionally, obstacles are categorised as either aerodrome obstacles or air navigation (en-route) obstacles. This broad categorisation is reflected also in how and by whom these obstacles and the risk they pose for aviation are being ‘managed’ from regulatory perspective.

A4.5.1 Aerodrome obstacles

An aerodrome obstacle is one that is located on an area intended for the surface movement of aircraft, or extends above a defined surface intended to protect aircraft in flight – referred to as the Obstacle Limitation Surface (OLS).

These OLS can extend to distances greater than 15 kilometres from the runway thresholds. When an obstacle infringes one of the prescribed limitation surfaces, an aeronautical study is required to demonstrate that the obstacle does not negatively affects the existing safety level and the regularity of flight operations. The usual risk mitigation method chosen is to require steeper descent/climb gradients or raise the minimum altitude at which aircraft can fly without visual reference to those obstacles or the operating environment. These risk mitigations have an effect on the accessibility of the aerodrome.

As per Basic Regulation, the ultimate responsibilities for aerodrome safeguarding typically lies with the Member State in which the aerodrome is located. In most cases, the Competent Authority of that Member State will attribute part of this responsibility to the Aerodrome Operator in line with the philosophy of Regulation (EU) 139/2014 on Management Systems for Aerodrome Operators.

Due to the traditional obstacle categorisation (aerodrome or air navigation obstacle) uncertainty can exist for obstacles that are located *outside* the aerodrome perimeter, but still extend above the defined surfaces intended to protect aircraft in flight. The result being an obstacle for which none of the stakeholders takes responsibility in terms of safety management. This study will try to identify if such uncertainty can exist, and to which it has an effect on the safeguarding of the aerodrome.

A4.5.2 Air Navigation (en-route) obstacles

The en-route obstacles are typically those obstacles that are gathered through the implementation of the, per ICAO Annex 15 article 225A, defined data collection surfaces.

The ICAO area 1 surface is basically set-up 100 meter above ground level for the whole territory of the State. Therefore, in ICAO philosophy all objects higher than 100 meters are considered to be obstacles for aviation and should be assessed and/or authorized, irrespective if the obstacle would be considered as hazardous.

Typically under EASA, the Competent Authority would be responsible for this process. Compliance is usually achieved by a national requirement to notify the Competent Authority of existing or proposed en-route obstacles (permanent or temporary) exceed a height of 100 metres (328 feet) Above Ground Level (AGL). The ICAO requirement would apply to all land-based obstacles but also to all obstacles in territorial waters. This study will try to identify how this process is functioning for wind turbines on land.

A4.5.3 Terrain and Obstacle Data Management

ICAO States are required to publish obstacle data within their Aeronautical Information Publication (AIP). The requirement is to provide this information in a simple, tabular form, classified in one of three ways:

- Obstacles impacting the en-route phase of flight;
- Obstacles at the aerodrome and impacting the circling area;
- Obstacles at the aerodrome and impacting the approach/take-off phases of flight.

Whilst this provided sufficient information for the navigation techniques in use when these ICAO requirements were first developed, more extensive terrain and obstacle data sets are required for modern navigational procedures, terrain awareness systems and a different airspace utilisation concept.

Particularly how this obstacle data is used is of interest in the scope of this study. The following paragraphs explore the specifics of this.

Obstacle accuracy

In essence the main interest in Instrument Flight Procedure Design is on the most limiting obstacle, referred to as the “dominant obstacle”.

This requires improved data quality by validating that information is provided by accountable and qualified data originators through a standard digital data exchange and processing of information and it allows for a timely and accurate distribution of information.

This study will include recommendations on the current regulatory provisions for obstacle data management in relation to wind turbines and the responsible stakeholders.

Instrument Flight Procedure (IFP) Design

Data relating to terrain and obstacles is used by IFP designers, who then apply obstacle clearance criteria to calculate minimum safe altitudes, and minimum descent altitude/height or decision altitude/height, according to the approach procedure type. These minimum altitudes and climb requirements are intended to ensure that aircraft do not collide with ground or obstacles.

Some parts of these obstacle assessment surfaces do not permit penetration by obstacles, whilst other areas do allow some penetration to occur. These surfaces tend to be aligned along the extended centreline of the runways and around the aerodrome in the circling area.

The surfaces depend on the approach type being flown and are defined in ICAO Annex 14 and ICAO PANS-OPS.

Electronic Charts

Electronic maps are intended to increase situation awareness of the pilot by providing a correlation between geographic details, navigational position and data on obstacles in a single display format.

Electronic charts:

- Provide a visualisation of the obstacle and terrain information in electronic form rather than as paper chart;
- Combine the existing specifications of the Aerodrome Obstacle Chart Types A, B and former Type C as well as the Precision Approach Terrain Chart with terrain and obstacle data; and
- Can replace of the Aerodrome Obstacle Chart — ICAO Types A and B and the Precision Approach Terrain Chart — ICAO.

For electronic maps, not only the dominant obstacle, but also objects which do not penetrate an assessment surface, and are not strictly 'ICAO obstacles' are of interest. Information on each individual obstacle, and how the obstacle is managed, is needed for this purpose. This results in larger obstacle data sets containing additional attributes/metadata.

The production of the electronic terrain and obstacle charts is subjected to numerical and qualitative requirements. Although these requirements are mainly applicable for surveying and data processing organizations and certified hardware products to visualize this data, they define to what extend and accuracy an obstacle survey should be conducted. This is important in the context of who should be responsible for the survey, and who should bear the costs.

Requirements that regulate the functionalities of software applications such as moving maps including obstacle information for handheld devices do not exist. Some software products are produced by recognized industry leaders and manufacturers, but the access to the 'handheld' electronic chart market is not regulated with a Certification Standard in the same extend as the certified installed electronic chart products. This results in a variety of chart symbols being used for wind turbines on electronic charts.

Pressure altimeters

Pressure altimeters are calibrated to ISA conditions. Any deviation from ISA will result in error proportional to the ISA deviation and the height of the aircraft above the pressure datum. For this purpose, the calculated minimum safe altitudes/heights must be adjusted when the ambient temperature on the surface is much lower than that predicted by the standard atmosphere. Failure to correct for this deviation can negatively affect the true vertical clearance. The approximate error is 4 percent height increase for every 10°C below ISA temperature[32].

[32] *For example, if the OAT is - 40 °C then for a 2.000 ft indicated altitude the true altitude is 1.520 ft*

The subscale of the altimeter is set manually to a pressure reference. Setting an incorrect pressure reference can also affect the true vertical clearance. The approximate error is 10 meter per 1 hPa difference in ISA[33].

[33] *For example, if the subscale is incorrectly set 10hPa too low, the true altitude is 300 ft lower as indicated.*

A5 Appendix – Stakeholder input

Over the course of the project various stakeholders were consulted. These meetings mostly aimed to verify the causal map developed and risks identified. In addition, the meetings provided input on areas of focus during the study.

A5.1 Interviews with Member States

Member States were encouraged by EASA to contribute to the study through various means. It was originally planned to forward an online survey to all Member States to capture information. However, after developing the survey, it was decided that the level of technical expertise required was to such an extent that an interview would better fit the purpose. A total of 6 different Civil Aviation Authorities actually participated in these interviews. The purpose of the interviews was to obtain information on the challenges associated with assessing the safety impact of wind turbines in the vicinity of aerodromes from a regulator's perspective that exist at a national level.

In order to allow comparison of the information shared, the interview was structured identical and based on the following three main areas of interest.

A. Challenges related to ADR or national regulations
B. Existing of risk mitigation and safety assessment methods
C. Experience in shared responsibilities regarding obstacle management

The regulatory assessment performed at the start of the project was the main driver to focus on these three areas of interest. The key points of the most relevant information received from these interviews is included in the following sub-paragraphs. The minutes of meeting of the interviews are included in this report as an appendices.

The information below reflects the views of the interviewed people, and not necessarily the organisation that employs them or the position of EASA.

A5.1.1 Challenges related to ADR and/or national regulations (A)

Key point A.1
The cumulative effects of wind turbines are not considered in existing regulations. Whatever regulation is applicable, it is simply applied to each individual wind turbine. For multiple wind turbines in a certain area, their whole combined safety effect is perceived greater than the sum of their individual parts by some of the participants.

Key point A.2
The national regulations for marking and lighting only cover wind turbines with certain dimensions. Turbines that fall outside these criteria, but still pose a hazard for aviation are difficult to regulate.

Key point A.3
The current regulations only assess the wind turbine as a static obstacle whilst it has dynamic properties in sense of turbulence and radar interference depending on rotor and nacelle orientation. These are not covered in the existing regulatory framework.

Key point A.4

At present, no regulatory guidance material for automated dependent lighting systems (ADLS) exists, which makes it difficult to implement such systems. Automated lighting systems using ADSB are not compatible with certain state flight principles regarding covert operations and the carriage of onboard equipment required to activate the system.

Key point A.4
The regulatory criteria for the acceptance of obstacles infringing protection surfaces are missing. Although article 8 of EU 139/2014 requires consultations, no guidance on how such consultation process should be conducted is provided.

Key point A.5
The existing CS ADR.DSN.Q.851 regarding marking and lighting of obstacles is considered too general, and particularly missing information on NVG compatible lighting requirements.

Key point A.6
In some Member States adherence to the requirements regarding marking and lighting are assigned to the Aerodrome Operator (AO). In reality the AO has very limited power to ensure compliance, and the responsibility should be attributed to the obstacle owner instead, and enforced by the Competent Authority.

Key point A.7
Wind turbines in vicinity of different FIR boundaries require coordination between Member States on the assessment, particularly when the turbine is located on the boarder of one country, and the aerodrome is located in a neighbouring country. This process is not regulated.

A5.1.2 Existing risk mitigation and safety assessment methods (B)

Key point B.1
In general, all authorities are of the opinion that the highest risk profile related to wind turbines in aviation exists for low level VFR traffic in degraded meteorological conditions.

Key point B.2
Some authorities focus on pilot information and sensibilization as a risk mitigation measure.

Key point B.3
Some authorities apply requirements for an obstacle free corridor with a specific minimum width (for example 3 km) to ensure that aerodromes are not becoming landlocked, particularly for VFR flights during lower meteorological conditions.

Key point B.4
There is no standardised tool or method for risk assessment available. The experience from multiple authorities suggests that safety studies performed by wind turbine sector lack in quality and independence.

Key point B.5
The majority of authorities apply height and location restrictions for wind turbines as the main risk mitigation method. One CAA is actively involving flight operational expertise from local established and certified operators in the process of establishing risk mitigation methods.

Table A5.1-1 Examples of assessment criteria applied by various States

State	Assessment trigger	Assessment by	Assessed topics
#1	Height > 50 m (rural) Height > 100 m (populated)	CAA MIL	Low Level Flying Radar/COMM interference Aerodrome accessibility
		AO	Visual surface segment inspection
#2	Height > 1000' AGL	CAA ANSP	Min. Radar Vector altitude OLS penetration Radar/COMM interference
		AO	Visual surface segment inspection
#3	Height > 25 m or penetration of OLS	CAA MIL ANSP	Consultation between MIL, ANSP and AO (when within 50 km of that aerodrome).
		AO	Responsible for obstacle management, CAA provides assistance.
#4	Height > 60 m	CAA	Impact assessment on CNS and IFP structure.
#5	Height: > 100 m or Range: < 5 km of aerodrome < 16 km from radar	CAA ANSP	Assessment on procedures Impact to NAVAIDS ICAO obstacle criteria

A5.1.3 Experience in shared responsibilities regarding obstacle management (C)

Key point C.1
In some countries, the Aerodrome Operator is responsible for a check on obstacles (line of sight) in the Visual Surface Segment only. In other countries, the AO has been made fully responsible.

Key point C.2
The process to ensure obstacle databases are accurate is exhaustive and a continuous process that involves multiple parties where each make mistakes. The shared responsibility regarding obstacle management between the parties involved should be covered by a documented arrangement to function correctly.

Key point C.3
A holistic approach has proven successful where geographical areas are pro-actively assessed on potential wind turbine locations and their maximum height. The principle of a 'one-stop-shop' concept to create a central expertise or coordination point within a Member State's government for wind energy planning is seen as a clear benefit.

A5.2 Interview with Operators

A certified Helicopter Emergency Medical Services (HEMS) operator operating mainly VFR day and night in the lower airspace structure within a geographical area that is densely occupied with wind turbines participated in this study.

Paragraphs below describe the operators experience with respect to low level day and night flights in the vicinity of wind turbines, and using Night Vision Goggles (NVG). It is important to realize that these concerns are based on their expertise resulting from specific requirements applicable in one Member State only, using specific equipment. The concerns brought forward are translatable, but only reflect one particular opinion.

Binary approach

In the country of this operator, the requirements for lighting and marking of wind turbines are published on a national level in a specific "information leaflet" with a regulatory status. Lighting and marking requirements for wind turbines are based on the dimensions of the wind turbine. Although these requirements create clarity, following them blindly can result in a binary approach with respect to what marking and lighting is applied in each individual assessment. With multiple wind turbines with different sizes close to each other, each of these turbines is lighted differently.

Applying requirements like this can arguably have a counterproductive effect on safety. Some turbines might, in accordance with the regulation, require no lighting whereas in reality installing lights would be highly desirable from safety perspective and vice versa. In view of the HEMS operator, addressing these valid safety concerns is difficult due to a rigidity when enforcing compliance requirements. Due to the title "information leaflet" of the requirement, legal challenges by wind turbine owners on enforcement is achievable. This approach makes it very challenging for the HEMS operator to address safety concerns with respect to wind turbine lighting.

Density of wind turbines

The density of wind turbines in some specific geographical area increased to such an extent that it negatively impacts the mission capability of the HEMS provider during certain conditions.

For these high density areas the necessary operational restrictions, implemented by the HEMS operator to ensure safety, delay the response time of requested airborne medical assistance. An involvement of the HEMS operator providing operational expertise might have resulted in other risk mitigations with no operational (for the HEMS operator) impact.

Usually, HEMS operations are granted on the basis of public governmental agreements containing performance criteria, such as maximum response times. In essence, the effect of government decisions on wind turbine lighting indirectly reduces the HEMS mission capability in regions where that same government wants to ensure HEMS response times for reasons of public health. The net result is an ethical safety dilemma for the HEMS organisation to choose between risk acceptance, or a decreased mission capability. This situation might be avoided had the HEMS operator been part of a flight operational assessment on the location or lighting of the wind turbine.

AIP data

The data contained in the AIP regarding obstacles is considered insufficient for the type of operations conducted. The cadastral register contains more information, particularly for the lower obstacles such as high-voltage cables, masts, etc.

The AIP information, and particularly the NOTAMS, do not take the different construction phases of wind turbines into consideration. This results in outdated or incorrect obstacle information presented as per NOTAM.

Safety Assessments

In view of the HEMS operator, the process of wind turbine safety assessments should be performed independently, without direct links between wind turbine exploiter and consultancy firm. When agencies are hired directly by an applicant for a wind turbine permit, the lack of independency results often in biased reports directed for the purpose of obtaining a permit.

NVG

With the type of NVG in use, the key element in identifying the presence of a wind turbine through the NVG optics is not the installed obstruction light, but rather the shape of the turbine against the background light.

During night flying, the operational practice established within this operator is to switch between NVG and naked-eye-sight to obtain a visual reference that is as complete as possible. There is however a significant impact of the background lights in relationship with the wind turbine and its location. A wind turbine might be obscured by the background lights.

Figure A5.2-1 - Contrast in respect to obstacle lighting (left turbine unlighted clearly visible, right turbine lighted but barely visible, middle turbine almost invisible)

A cautionary remark should be made here as the NVG capabilities are depending on the device age/generation, the quality of the tube within the unit, as well as the overall capabilities of the device itself and the conditions under which it is being used. It is likely that NVG operators using equipment with a different specification will have a different experience.

A5.3 VFR safety survey

As part of this study, as survey targeting VFR pilots was launched in May 2023. The goal of the study was to identify if unreported or unidentified safety issues regarding wind turbines could exist within this group.

Additional goals of the survey were to identify:

- Experience with turbulence induced by wind turbines on small aircraft;
- Average flight altitudes for VFR flights around wind turbines;
- Accuracy of knowledge on wind turbines (dimensions and height);
- Usage of obstacle related data during pre-flight preparation; and
- Operational methods to identify obstacle risk during low level flight.

Attached to this report is an overview of the survey questions. The survey consisted of a total of 36 questions, divided in different parts. The questions used for the survey were a mix of Likert, multiple-choice and net promotor score types.

The survey was completed by 128 respondents, with an average time to complete of 16:21 minutes.

A5.3.1 Respondents

In terms of license privileges, the majority of the respondents (70%) held a non-commercial fixed wing pilot license such as a PPL or RPL. A vast majority of the responses (97%) was generated from within one Flight Information Region inside the EU. In terms of normal flight altitude, excluding take-off and landing, 57% flies their aircraft between 1.000 and 1.500 feet AGL mostly for leisure flights (74%).

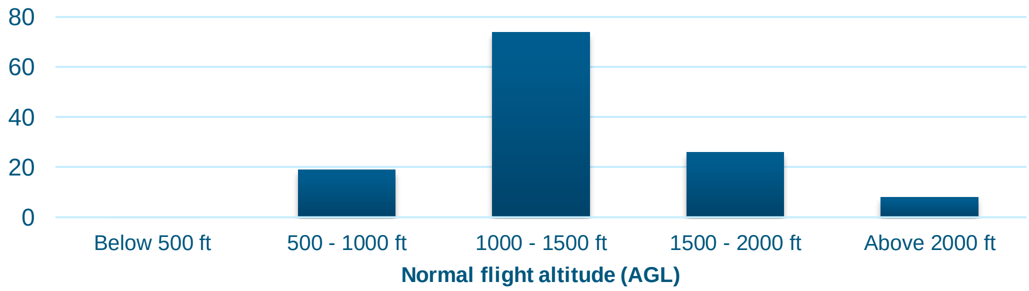


Figure A5.3-1 - Flight profile of survey respondents

A majority of respondents (92%) indicated that wind turbines are present in their normal area of flight operations.

When asked on the specifics of having these wind turbines present in their normal area of operations, the majority of the respondents replied that experiencing the effects from wind turbines was not unexpected. This is an important statement from a safety point of view, as the (mental) preparation for an event – before the event occurs – has proven vital to generate operational recovery methods for pilots.

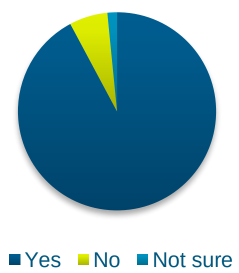


Figure A5.3-2 - Presence of wind turbines in normal area of operation

A5.3.2 Encounters with wind turbines

In essence, the statement that encounters are not unexpected should be taken into account when assessing the further questions. For example, the majority of respondents indicated that they were not uncomfortable with the remaining vertical obstacle separation margins, nor that corrections on the aircraft's course were required to prevent collision. There is a high likelihood that their assessment on lateral and vertical obstacle clearance are influenced by their knowledge on, or experience with, the presence of wind turbines in that area.

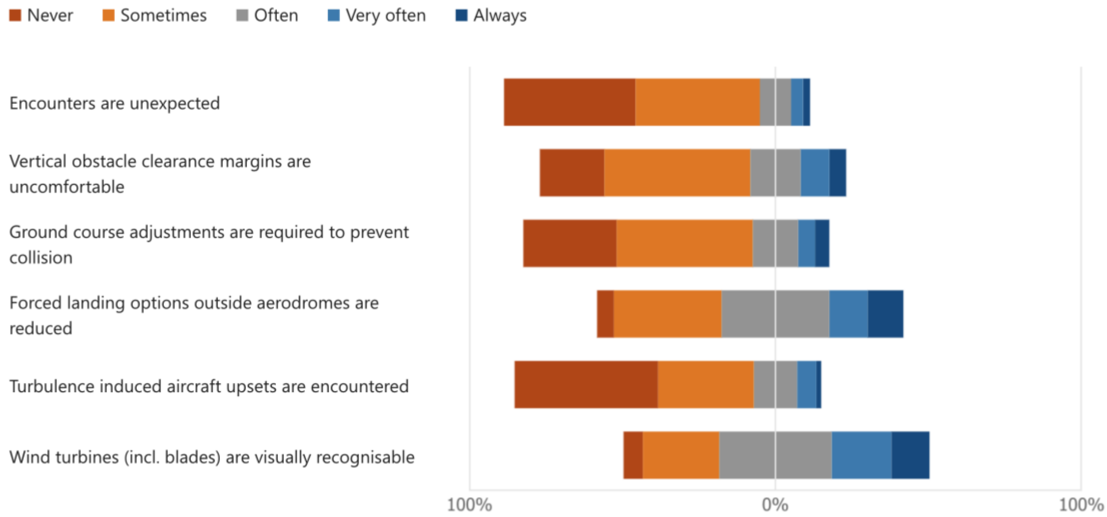
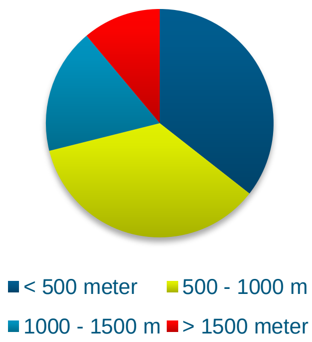


Figure A5.3-3 – Wind turbine turbulence encounters

Roughly 1/3 of the respondents indicated that they experienced wind turbine induced turbulence during their flights. In sense of lateral distance between the aircraft, this turbulence was mostly (71%) experienced in a lateral distance up to 1.000 meters from the wind turbine. Expressed in the dimension of the rotor diameter (D), this lateral distance would translate to 8 x D for an average rotor diameter of 120 meters. The height of the encounter is described to be at the level of the turbine nacelle.

The accuracy of these numbers is difficult to verify, as assessing distances from an aircraft in flight is difficult. This empirical data does show that most wind turbine induced turbulence, based on the operational experience of the respondents, is mostly restricted to the height of the turbine rotor and in relatively close proximity to the turbine.



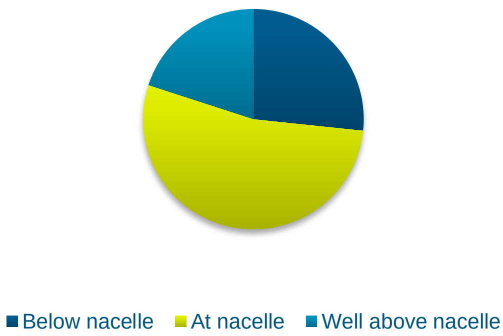


Figure A5.3-4 – Empirical assessment of turbulence encounters in distance and height relative to wind turbine

A5.3.3 Effects of encounters

When asked on their experience on the severity of wind turbine induced turbulence, the majority of respondents (78%) answered that these turbulence encounters never, or only sometimes have influence on the aircraft. The term 'aircraft upset event' was used in the survey. To ensure respondents understood the question, a second control question was asked. The control question verified that 87% of the turbulence encounters would not qualify as an aircraft upset. This is important information as it indicates that the aircraft, when encountering turbulence from wind turbines, remains from a practical experience level, inside normal control parameters for light aircraft.

Two elements of the survey were replied in a more balanced trend. Around 60% indicated that the presence of wind turbines reduces options to select an area for a forced landing in case of engine failures. The respondents typical flight profile (recreational leisure flying), is mostly conducted with small single engine piston (SEP) aircraft. Although engine failures are in general uncommon in aviation, the SEP segment typically has a higher probability for such event.

The presence of safe areas for forced landing scenario's is particularly important in close proximity to aerodromes. It is likely that the lack of unobstructed areas suitable for a forced landing, will have an impact on the VFR patterns of single engine aircraft. For example, if an area north of the aerodrome has more obstructed and unsuitable areas, it can be expected that the southern area will see a denser pattern of aircraft flying.

Recognizability plays an important role in collision prevention, particularly for flights conducted in accordance with visual flight rules (VFR) where the pilot in command is solely responsible for maintaining separation with terrain and obstacles. The respondents were asked to identify and rank, in their opinion, the most important methods to visually identify obstacles such as wind turbines during flight.

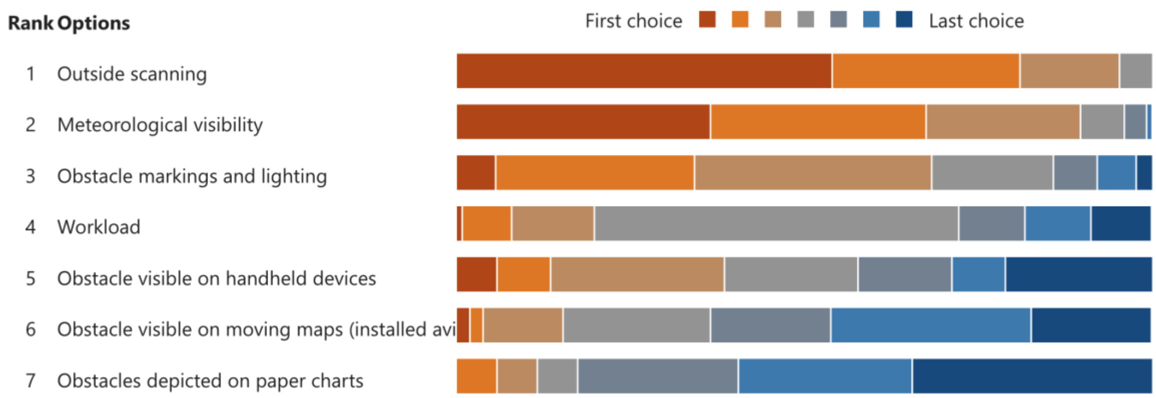


Figure A5.3-5 - Ranking of important elements for visual recognition of wind turbines in day VFR conditions

This ranking matches the expectation and follows the general principles regarding separation methods for VFR flights. The preference of handheld devices over installed avionics could be explained by the accessibility and affordability of these devices.

Important in the context of this survey is that the geographical area covered concerns mostly one Member State. In this Member State, the national requirements do not require wind turbines to be marked with red/orange colours. Obstacle lighting requirements exist and their specifications depend on the height and location of the wind turbine.

A5.3.4 Source of obstacle information

When asked on the main source of information for obtaining obstacle information, the use of handheld devices (tablets, smartphones, etc.) was by far (63%) the biggest source. The alternatives being either AIP publication, installed avionics and paper navigation charts with a combined 36%.

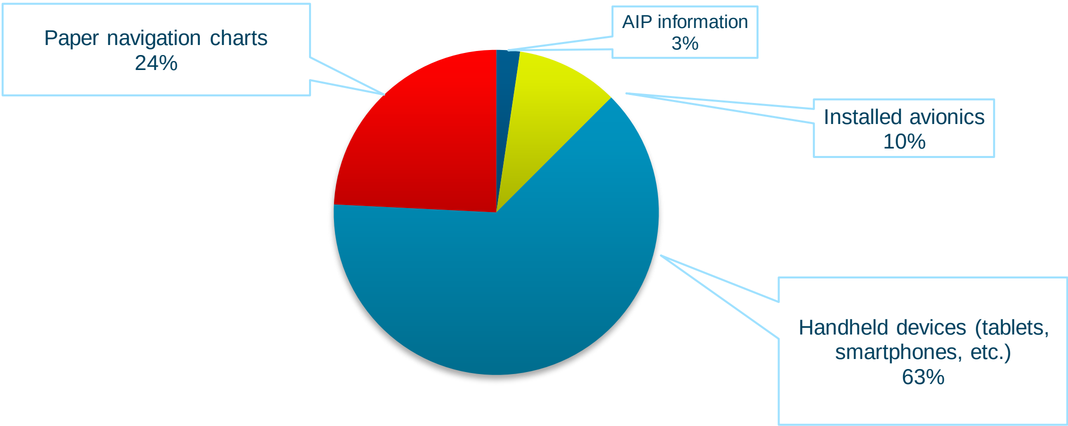


Figure A5.3-6 - Main sources of information for obstacle information for VFR pilots

SIG Aviation

A6 Appendix – VFR Safety survey questions

Wind turbines and particularly their height, location and rotor induced turbulence could present a risk for aircraft flying at lower altitudes to and from aerodromes. In addition there might be a possible impact on radar and communication equipment that could affect air navigation services provided. This survey is part of an EASA study on the safety of wind turbines in relation to aviation.

This survey is intended to include the input from airspace users in this aeronautical safety study. A separate survey, specifically for aerodromes, regulators and ANSP's has been communicated directly through EASA.

For information on this survey, please contact info@sig-aviation.nl

A6.1 Section 1 – General

Number	Question	Subtext
1	In what FIR do you mostly fly?	This survey is launched in various EU Member States. Using the different Flight Information Regions helps to differentiate between those Member States.
2	What type of license do you have?	This survey does not focus on 'amount of experience' but rather on the type of activity conducted with a license privilege. Selecting the type of license helps in establishing a typical profile for you within this survey.
3	What is the minimum altitude that you normally fly, excluding take-off and landing?	Depending on your normal area and type of operation, different flight altitudes are possible. This question helps to determine your risk exposure in relation to wind turbines.
4	What type of flights do you mostly conduct?	This question helps to further determine your risk exposure in relation to wind turbines.

A6.2 Section 2 – Wind turbines

Number	Question	Subtext
5	Are there wind turbines located in your normal area of operation?	For the purpose of this survey, the normal area of operation is meant to be the geographical area where you conduct the majority of your flights.
6	In your perception, what is the maximum height (top-blade in feet above ground) of the average wind turbine installed on land:	The word 'perception' is taken deliberately to ask you what YOU NOW THINK, without using sources to verify your answer.
7	With respect to wind turbine encounters during flight, and in relation to your experience:	The causal map developed in this safety study contains three main undesirable events in relation to wind turbines and aviation. With this question we try to assess the likelihood of these events to occur.
8	What is your main source for obtaining obstacle information (position/height)?	Part of the safety study is to assess the usability of aeronautical data (including obstacle data on wind turbines) to increase awareness on these obstacles. This question helps to identify what information source you are normally using.
9	Did you ever experience turbulence induced by wind turbines?	For the purpose of this survey, turbulence induced by wind turbines is meant to be a clear disturbance of the smooth air in the downwind area of a wind turbine that resulted in a physical disturbance of the aircraft.
10	In your memory, what was the lateral distance (in meters) from the wind turbine during this event?	Turbulence induced by man-made obstacles such wind turbines dissipate over distance from the object causing the disturbance. Although there are aerodynamic flow models available, this question aims to include operational experience in the survey. This is particularly important as the rotor of a wind turbine might have a different effect on the dissipation of any turbulence caused.

11	In your memory, at what height compared to the wind turbine was the aircraft approximately during this event?	The nacelle of the wind turbine is the center of the rotor. The diameter of the rotor is two times the rotor blade length.
12	Did this event occur during take-off, landing or in a traffic pattern?	This question aims to identify if turbulence generated by wind turbines can also exist in areas where aircraft are typically at a higher risk due to their lower altitude and airspeed.
13	How would you describe the magnitude of this event?	This question aims to assess the severity of turbulence induced by wind turbines.
14	Do you fly using Visual Flight Rules (VFR) during daylight?	This question will differentiate the survey questions more on your operational experience.
15	For VFR flights IN DAYLIGHT and in your opinion, what is most important to visually identify obstacles during VFR flights? (rank the options below from high importance to low importance)	
16	Do you operate Single Engine?	
17	To what extent do you consider wind turbines (location/height) in forced landing scenarios while flying Day VFR?	
18	Do you fly using Visual Flight Rules (VFR) outside the Universal Daylight Period (UDP)?	This question will differentiate the survey questions more on your operational experience.

19	**For VFR flights OUTSIDE the UNIVERSAL DAYLIGHT PERIOD and in your opinion, what is most important to visually identify obstacles during VFR flights? (please rank the options below from high importance to low importance)**	
20	Do you operate Single Engine at night?	
21	To what extent do you consider wind turbines (location/height) in forced landing scenarios while flying Night VFR?	
22	Do you have an IFR rating?	This question will differentiate the survey questions more on your operational experience.
23	For IMC flights and in your opinion, what is most important to reduce the collision risk with obstacles during flight? (please rank the options below from high importance to low importance)	
24	Is the following statement true? "Wind turbine avoidance is included in the Enhanced Ground Proximity Warning System (EGPWS) functionalities."	An EGPWS system contains a database. This question aims to assess your practical knowledge on EGPWS system limitations.
25	Do you operate Single Engine (SE)-IFR?	This question differentiates the survey based on your experience.
26	To what extent do you consider wind turbines (location/height) in forced landing scenarios while flying SE-IMC?	

A6.2.1 Helicopter Emergency Medical Service (HEMS)

Number	Question	Subtext
27	Do you operate outside UDP?	
28	Do you operate with an Enhanced Vision System (EVS) or Night Vision Goggles (NVG's)?	Are the ICAO obstacle avoidance lights, installed on wind turbines and obstacles, visible using the EVS/NVG?
29	Are the ICAO obstacle avoidance lights, installed on wind turbines and obstacles, visible using the EVS/NVG?	

A6.2.2 Aerodromes

Number	Question	Subtext
30	What is the ICAO code of your home-base?	This will help to identify possible hotspots and examples for the safety study.
31	Are there wind turbines located within a radius of 8 kilometers from this aerodrome?	
32	In your estimation, how many wind turbines are installed within this 8 kilometer radius from the aerodrome?	
33	With respect to flight safety, how concerned are you regarding these wind turbines in the vicinity of this aerodrome?	
34	How would you rate the accuracy of obstacle information, including wind turbines, published in the official AIP and aerodrome pages?	

A6.2.3 Final

Number	Question	Subtext
35	How would you rate this survey?	
36	Do you have additional considerations to be included in this safety study?	

A7 Appendix – Expanded causal map with deeper relationships

A7.1 Expanded causal branch – Collision with a wind turbine

A7.1.1 Wind turbine not visually identified

For flights conducted under Visual Flight Rules (VFR), the obstacle clearance is a result of visually identifying an obstacle and by applying VFR separation minima to that obstacle by the pilot.

For VFR flights, the following factors influence the pilot's ability to identify a wind turbine and react to it during flight:

1) Interpretation of the obstacle position and height;
2) Awareness on presence of collision risk; and/or
3) Effective visual scanning by the pilot.

In instrument meteorological conditions there is no possibility for pilots to visually identify obstacles. In this regime, the pilot maintains a minimum altitude either provided on an Airway, Instrument Flight Procedure or by Air Traffic Controller (ATCO) instructions. The ATCO uses the aircrafts position and a chart with minimum safe altitudes to provide this service.

Background information

VFR flights can only be conducted in meteorological conditions that allow the pilot to visually avoid terrain, obstacles and other aircraft. These conditions are specified as Visual Meteorological Conditions (VMC). A reduction in these weather minima is possible only for a sub-category of VFR referred to as Special VFR. Permission to operate under Special VFR within a Control Zone, is given to a flight by means of an Air Traffic Control clearance.

IFR flights can be conducted in both VMC and Instrument Meteorological Conditions (IMC) and require a suitable airspace classification, specific aircraft instrumentation and equipment and a pilot qualification to operate IFR. In airspace classes F and G only flight information service is provided to the pilot. Flight information service is intended to provide useful advice to the pilot, such as collision hazard. Flight Information service is provided by Flight Information Service Officers (FISOs), but the terrain separation responsibility solely resides with the pilot.

Awareness on presence of collision risk

Identifying risks before flight is essential to ensure flight safety as it enables the proactive management of potential risks. Particularly when the minimum safe altitude is high compared to the aircraft altitude, for example for VFR flights in an obstacle rich environment.

VFR flights are typically performed by pilots with a recreational or private pilot license. Due to the nature of VFR flights, combined with the typical pilot profile and experience level, the workload for the pilot can become high. In addition, the typical VFR pilot is not trained on using other than rudimental navigation equipment or monitoring maps. During flight, there is very limited time available for VFR pilots to scan charts and maps for obstacle data.

For IFR flights in uncontrolled airspace, the pilot would typically use the minimum safe altitude published for that sector to ensure obstacle clearance is guaranteed.

These mitigations only function on the assumption that the wind turbine location and height are accurately recorded in the obstacle database, and this information is reflected in charts and minimum altitudes.

Effective visual scanning by the pilot

Performing a visual scan of the outside environment for obstacles, such as wind turbines, is a primary means to avoid collision during VFR flights.

The main negative contribution to this method is the workload of the pilot. There is a maximum to the level of human performance to manage workload efficiently. This maximum level depends on the experience of the pilot, the tasks being performed, the aircrafts status and the operating environment.

The cause-and-effect relationships for the visual recognition of wind turbines are further visualised in the figure below.

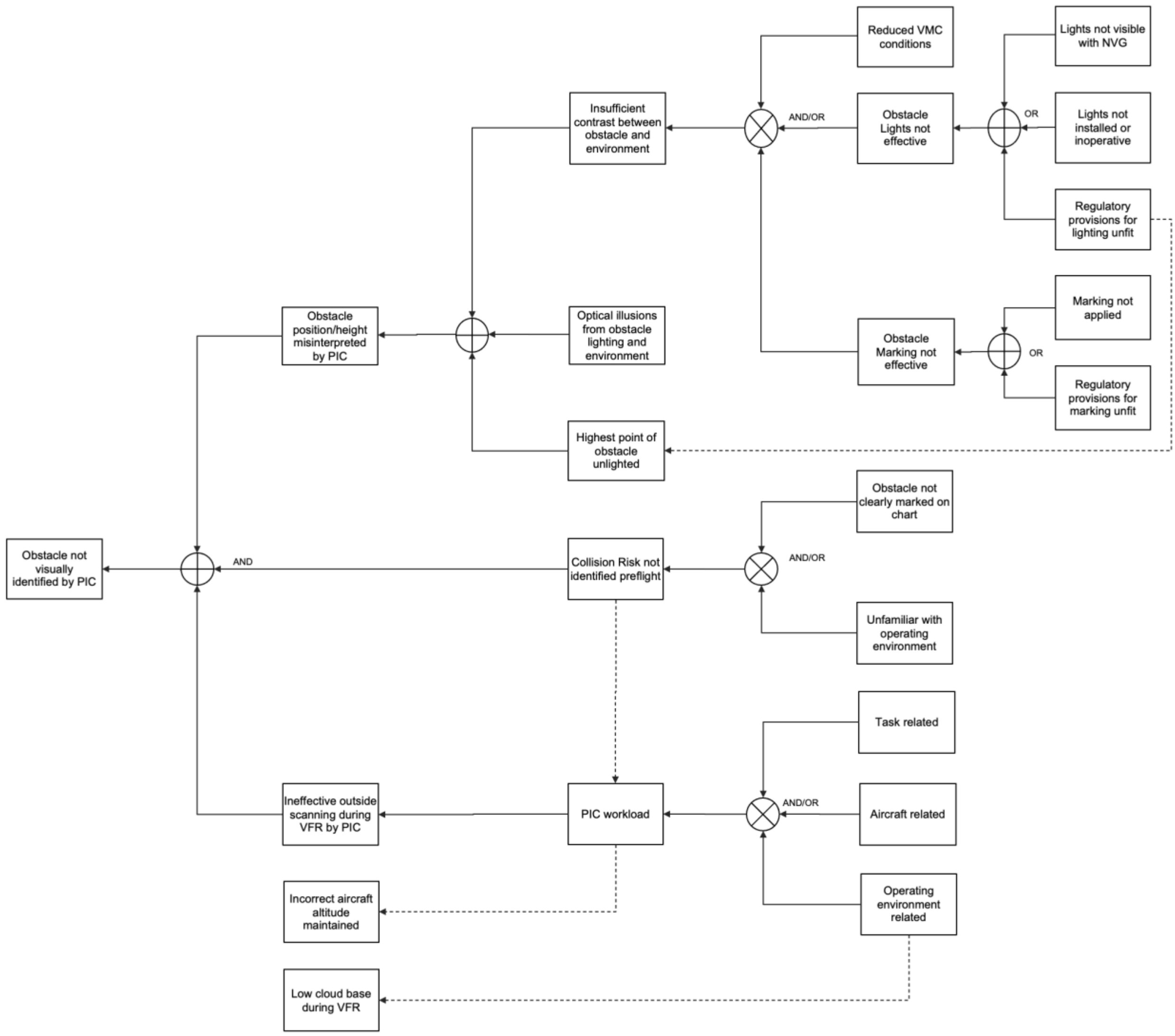


Figure A7.1-1 Wind turbine not visually identified

A7.1.2 Insufficient vertical clearance

Inadequate vertical clearance between aircraft and wind turbine can result in a collision. The actual vertical clearance is a function of the altimeter setting and corrections applied to the altimeter. Errors in the altimeter setting or corrections [Pressure altimeters] will result in a different altitude above ground than as indicated on the altimeter. This can result in a lower than anticipated obstacle-clearance separation.

For VFR flights the minimum distance between clouds and the aircraft depends on the airspace category. The majority of VFR flights takes place in class G airspace. For this airspace class the requirement[34] is to 'remain clear of clouds' without any vertical clearance margin given. This requirement allows VFR flights just below, and just above a cloud base.

When meteorological conditions deteriorate, the need to stay below a cloud base can place the aircraft's altitude below the minimum desired for obstacle clearance. For the scenario where a VFR flight is performed just above a cloud base in class G airspace, an obstacle such as a wind turbine might be obscured by that cloud base. There are cases known where only the rotor of a wind turbine protrudes through the top of the cloud base, and the nacelle remains hidden.

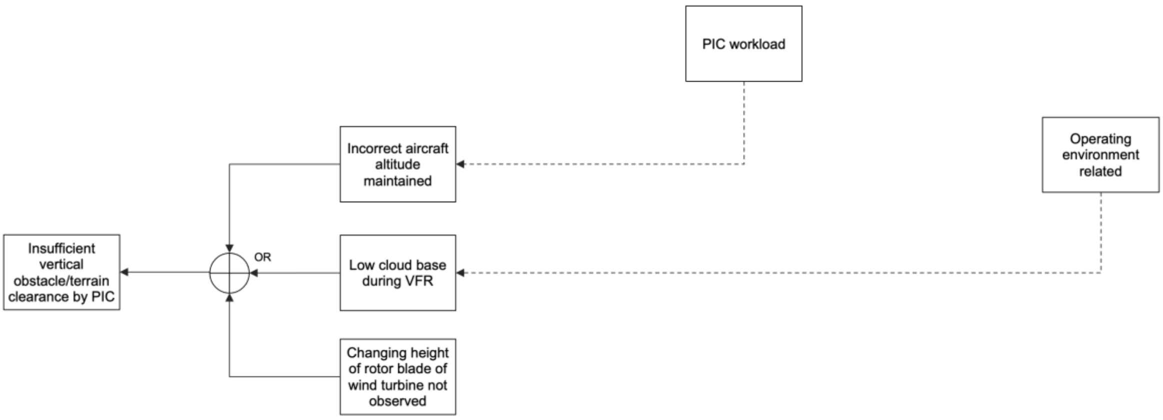


Figure A7.1-2 Insufficient vertical clearance

[34] *SERA.5001 VMC visibility and distance from cloud minima*

A7.1.3 Incorrect separation margins applied

For each aerodrome with instrument approaches, obstacle limitation surfaces (OLS) are established to ensure that the instrument approach procedure can be designed safely, taking into account the location and height of obstacles around that aerodrome. Criteria for flight procedure design are contained in the Procedures for Air Navigation Services — Aircraft Operations (ICAO, PANS-OPS, Doc 8168). In total ICAO defines nine different obstacle limitation surfaces.

Objects which penetrate the obstacle limitation surfaces should result in an increase in the obstacle clearance altitude/height or a required gradient for an instrument flight procedure or any associated visual circling procedure. The majority of the EASA certified aerodromes will have instrument approaches published and OLS established. These OLS offer a significant safety protection.
Flights that do not follow instrument approach or departure procedures are required to maintain a minimum safe altitude until sufficient reference to terrain is present to allow for a visual approach.

The minimum heights[35] for VFR flights are specified in SERA.5005(f) and the minimum levels for IFR flights are specified in SERA.5015(b):

- VFR flights shall not be flown[36] at a height less than 150 m (500 ft) above the highest obstacle within a radius of 150 m (500 ft) from the aircraft [37].
- IFR flights shall be flown at a level which is not below the minimum flight altitude established by the State, or, where no such minimum flight altitude has been established at a level which is at least 300 m (1.000 ft)[38] above the highest obstacle located within 8 km of the estimated position of the aircraft.

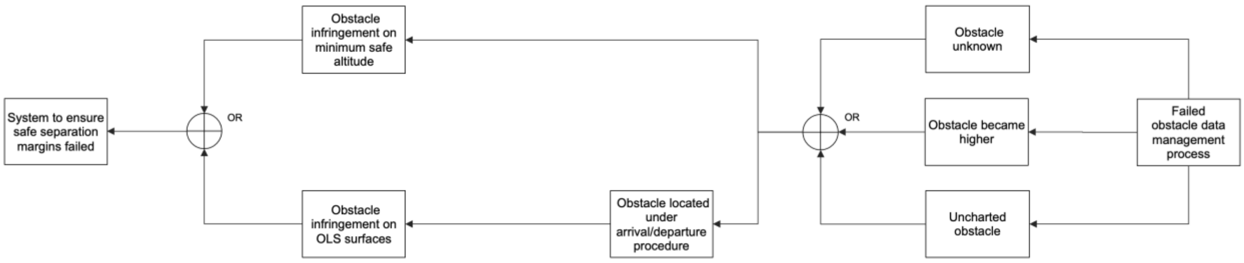


Figure 7.1-3 Incorrect separation minima

A7.1.4 Aircraft position error unnoticed

Accurate knowledge on the aircraft position is increasingly important for flights at a lower altitude or in reduced meteorological conditions. Unnoticed position errors can result in CFIT accidents.

For the purpose of this study, three subbranches of interest have been identified. Two of those branches mainly address flights under IFR:

1) Interference from wind turbines with radar; and
2) Reduced navigational performance operations.

[35] SERA.3105 Minimum heights
[36] Except when necessary for take-off or landing, or except by permission from the competent authority.
[37] Over congested areas of cities, towns or settlements or over an open-air assembly of persons a minimum height of 300 m (1000 ft) and a radius of 600 meter applies.
[38] Over high terrain or in mountainous areas, a level which is at least 600 m (2 000 ft) above the highest obstacle located within 8 km of the estimated position of the aircraft applies.

Wind turbines can appear as an echo on the display of primary surveillance radars used for air traffic control. The magnitude of the radar return mainly depends on the orientation of the rotor and can cause distraction for the air traffic controller. It can also mask the position of aircraft resulting in an aircraft position uncertainty for the air traffic controller.

The probability of radar detection can be reduced in three ways:

- In a shadow region directly behind the turbine.
- In a volume located above and around the wind turbine.
- In a larger volume located above and around the wind turbine if the radar has signal processing or tracking techniques which can be affected by wind turbines.

Secondary Surveillance Radar (SSR) systems are more commonly used in civil aviation. The SSR relies on a radar transponder, that reply to an interrogation signal by transmitting encoded data. This data contains an identity code, the aircraft's altitude and further information depending on its chosen mode. Monopulse secondary surveillance radar (MSSR), Mode S, TCAS and ADS-B are similar modern methods of secondary surveillance. SSR is affected by a shadow region behind the wind turbine where the transfer of information can be degraded.

Despite the existence of satellite navigation, the navigation systems onboard aircraft also use information from ground-based radio transmitters. As wind turbines can reflect the VHF signals in a form of form multipath propagation, signal components from other beacons can cause errors in the aircrafts navigation system.

During stronger crosswind conditions, the aircrafts heading and it’s ground track will differ from each other. If this drift remains uncorrected by the pilot, this might drift the aircraft unknowingly in the direction of wind turbines resulting in an unexpected closer proximity between aircraft and wind turbine. This scenario is mostly present for VFR flights.

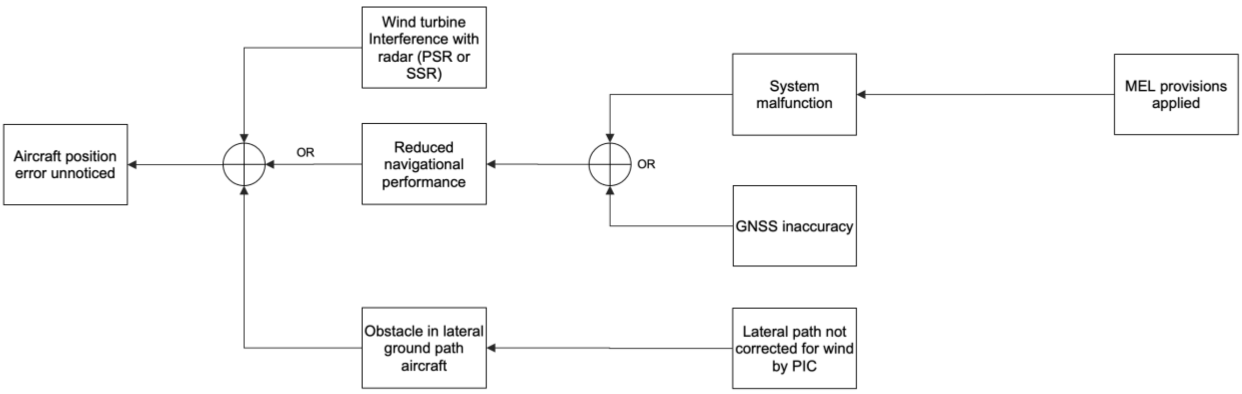


Figure A7.1-4 Aircraft position error unnoticed

A7.1.5 Proximity warning of obstacles

A Terrain Awareness Warning System is designed to alert pilots if their aircraft is in immediate danger of flying into the ground or an obstacle. The newer versions of this system are referred to as Enhanced-GPWS (EGPWS). They make use of terrain and obstacle data.

A precondition for this safety mitigation to function is the availability on an accurate obstacle data set. Without this accuracy, the system cannot provide early alerts and, therefore, more time for the pilot to take corrective action.

The Minimum Safe Altitude Warning (MSAW) is a ground-based safety net used by ATCOs to issue timely warnings of aircraft proximity to terrain or obstacles, in a similar manner as the onboard EGPWS. The system uses the aircraft's transponder data, which contains the aircraft's pressure altitude and position data. Warnings are issued to the ATC system if the altitude is lower than, or predicted to be lower than, the minimum safe altitude. An accurate obstacle data set, and correct aircraft 3D position are required for this safety net to function.

The Approach Path Monitor (APM) is a ground-based safety net which issues warnings of aircraft proximity to terrain or obstacles during the final approach of the aircraft to the ATCO. Its purpose is to increase safety and it serves as a function in air traffic control systems. The logic employed is the same as for MSAW.

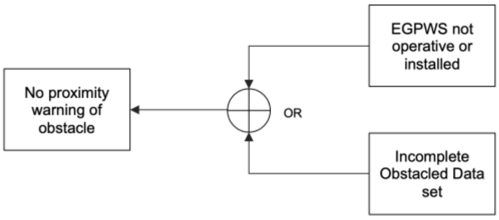


Figure A7.1-5 No proximity warning on obstacle

A8 Appendix – ECCAIRS Safety Reporting Data

ECCAIRS (European Co-ordination Center for Accident and Incident Reporting Systems) provides a digital platform to integrate European Civil Aviation Authorities and Safety Investigation Authorities to enable the implementation of the provisions defined in Regulation (EU) 376/2014. Its objective is to ensure that the necessary safety intelligence is available to support the safety management efforts.

ECCAIRS data is collected with different attributes giving information about an incident or an accident. As part of this study, a query was performed through EASA, on selected attributes related to wind turbines.

A8.1 Attributes used

This query used the following attributes:

1) Obstructions for occurrences on water
   Information on obstructions present on the water, e.g. wind turbines.
2) Minimum Safe Altitude Warning (MSAW) System alerting
   The generation of minimum safe altitude warnings is a function of an ATC radar data processing system. The objective of the MSAW function is to assist in the prevention of controlled flight into terrain accidents by generating, in a timely manner, a warning of the possible infringement of a minimum safe altitude.
3) Issues related to the conspicuity of the aircraft on Primary radar
   Primary Surveillance Radar (PSR) transmits a high-power signal, some of which is reflected by the aircraft back to the radar to determine its position.
4) Lowest flight level displayed for sector
   The lowest flight level displayed for an ATC sector.
5) GPWS warning/alerts
   Warnings are provided by the GPWS for excessive terrain closure rate, unsafe terrain clearance while not in landing configuration and excessive descent below the instrument glide path.
6) Minimum horizontal separation estimated
   The minimal horizontal distance during an incident involving two aircraft as estimated by the investigation taking into account all available evidence (witnesses, recordings).
7) Minimum vertical separation estimated
   The minimal vertical distance during an incident involving two aircraft as estimated by the investigation taking into account all available evidence (witnesses, recordings).
8) The aircraft height at the time of the occurrence
   The aircraft vertical distance, measured from a specified datum at the time of the occurrence.
9) Potential descriptive factor subject
   This field is used to report on safety issues or potential safety issues that relate to the occurrence irrespective whether these issues were causal or contributory to the occurrence.
10) Avoiding action taken by aircraft in an incident involving a loss of separation
    Information on whether any avoiding action was taken by the aircraft during an incident involving a loss of separation, and whether it was adequate/late.

The data set used contained 10 years of data and produced in total 544 events that triggered on any of the attributes above.

A8.2 Wind turbine related events

A further query searched for the presence of a "wind turbine", in various forms and spellings of this word, in the narrative of the event. This resulted in a correlation of in total 6 events with wind turbines. One event was removed from the table below as the wind turbine played no contributing factor, but was mentioned to provide information on the type of work conducted.

From the five events, three are considered to be serious safety breaches by the author. These events all consider large aircraft.

Table A8.2-1 ECCAIRS data related to wind turbines

Date	Occurrence class	Operational type	Description[39]
10/12/2013	LOC-I Loss of control - inflight	Unscheduled commercial air transport (fixed wing) – large aircraft	On departure in gusty turbulent conditions on a night VFR departure, both pilots became focussed on the wind drifting the aircraft closer to the large adjacent wind turbines. Distraction for approx. 1 minute caused crew to miss a mandatory reporting point.
31/07/2015	ATM ATM/CNS	Scheduled Commercial Air Transport (fixed wing) – large aircraft	Number of aircraft lose their primary only returns and show a secondary only contacts. This was perhaps in the area of radar blanking to the north due the wind farm.
29/03/2016	CFIT Controlled flight into or toward terrain	Unscheduled commercial air transport (fixed wing) – large aircraft	Whilst on the arrival route in direction of a waypoint with a mandatory altitude of 1400 feet AMSL, we noticed 2 large wind turbines in the vicinity. EGWPS Pull up command was briefly activated during climbing left turn in go-around manoeuvre. After second approach and landing, whilst in the airport building, crew noticed a staff memo which showed a picture of a half-built wind turbine in the vicinity of the approach at the location of the EGPWS command. The altitude of the turbine indicated in the memo was 1306 feet.
12/06/2018	ATM ATM/CNS NAV: Navigation error	Scheduled Commercial Air Transport (fixed wing) – large aircraft	ATCO cleared aircraft to altitude 3000 feet. Mode C on aircraft was showing altitude 2600 feet descending. Crew immediately instructed to check and climb to altitude 3000 feet. The area they were operating in has high ground with a windfarm and masts that are up to 1938 feet AMSL. The aircraft was descending at a relatively high rate for the stage of flight and levelled out at 2000 feet QNH before climbing again to 3000 feet. Despite dropping outside CAS and below the minimum vectoring area the MSAW did not activate.
29/11/2018	Other	Scheduled Commercial Air Transport (rotor wing) – large aircraft	Wind farm red obstacle lighting missing from 10 out of the 11 offshore wind turbines near the coast. Only the turbines that were turning/in motion had the red aviation obstruction light illuminated.

A cautionary note should be made in respect to the ECCAIRS data in respect to the information on light aircraft. The ECCAIRS system is 'fed' by reports that are filed either voluntarily or under a mandatory occurrence reporting scheme. The mandatory reporting of occurrences is mostly driven by commercial organizations active in the aviation domain.

[39] *The description has been redacted and de-identified.*

The lack of data regarding light aircraft interactions with wind turbines in ECCAIRS does not necessarily mean that interactions did not occur. The presence of fear for repercussions, a sense of shame or lack of knowledge on reporting purposes and system can significantly influence the number of reports filed.

Logic dictates that the majority of safety events related to wind turbines occur in the lower airspace structure. The absence of reports from General Aviation in ECCAIRS on wind turbine interactions is therefore not in line with expectations. The conclusion is that the voluntarily reporting on safety events with wind turbines is lacking and not displaying the actual number of interactions.