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Guidelines on the Environmental Risk of Wind Turbines in the Netherlands

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GUIDELINES ON THE ENVIRONMENTAL RISK OF WIND TURBINES IN THE NETHERLANDS

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ABSTRACT: A structural failure of a wind turbine might lead to loss of blade (or parts of it) and thus cause a risk to nearby people and property. In the Netherlands, more densely populated areas are considered to achieve the target set by the Dutch government of implementing 1.500 MW wind power onshore. Because of the public opinion locations close to highways, railways, canals or existing industrial zones are preferred. This development brings about that the risk of wind turbines for the environment becomes more significant as more people might be present near a wind turbine for a longer period. To deal with risks of wind turbine in a rational manner, a handbook with procedures for the risk assessment of wind turbines has been drawn up in order of NOVEM (the Netherlands Agency for Energy and the Environment) [1]. This paper discusses the contents of the handbook and the status of the handbook in the legal framework.

1. INTRODUCTION

In the beginning of the nineties, ECN and consultants in the Netherlands were approached by local authorities and developers of wind farms with the question: *"Is it safe to erect a wind turbine at this location?"* A typical situation is given in Fig. 1A. A fictive site is drawn in Fig. 1B, showing the different types of objects that can be close nearby the intended wind farm and need to be considered in a risk analysis.

Fig. 1A: *An example of turbines placed close to a hazardous plant and a waterway*

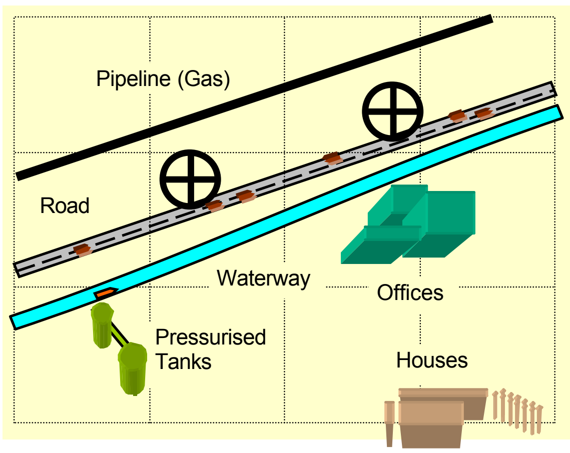


Fig. 1B: *Two wind turbines planned (1) near vulnerable objects like houses and offices, (2) near hazardous installations like pressurised tanks and gas pipelines, and (3) near a road, and a waterway*

In fact, the question consists of two questions:

1. Do the wind turbines form a significant risk for the objects and activities close nearby?
2. If yes, is the sum of that risk and the already existing risks lower than the valid criteria for safety and environmental risk?

To answer these questions, it is necessary to answer the following four questions subsequently:

1. What kinds of risks do wind turbines cause for the environment?
2. To what distance do vulnerable objects[1] need to be considered in the risk analysis?
3. How should the probability of a person or object being hit by a turbine fragment be determined?
4. What are the safety and risk criteria that are valid and should be met?

A project team consisting of experts in the field of wind energy and industrial safety has taken the initiatives to develop a practical and uniform approach to carry out risk analysis for wind turbines. The final result of the project has become the Dutch Handbook for Risk Assessment of Wind Turbines. The project team consisted of the following partners:

- Energy Research Centre of the Netherlands (ECN), Unit Wind Energy
- Nuclear Research Group (NRG), Department of Risk Management and Decision Analysis
- TNO-MEP, Department of Industrial Safety
- KEMA, Department of Renewable Energy
- Ecofys

The handbook has been reviewed and accepted by:

- Ministry of Housing, Spatial Planning and the Environment (VROM)
- Ministry of Transport, Public Works and Water Management (VenW)
- National Institute of Public Health and the Environment (RIVM)
- Dutch Railways (NS)
- Project developers (Siemens Nederland, Nuon, Essent)
- Owners of vulnerable plants (Corus, Gasunie, Dutch Navy)
- Licensing authorities (municipalities and provinces)
- Novem as a representative of the Ministry of Economic Affairs.

In this paper, the Handbook with some technical details will be discussed (Chapter 2). In Chapter 3, the position of the Dutch handbook in the Dutch legislation will be outlined. In Chapter 4, the application of the handbook

[1] *Vulnerable objects are those objects were people stay for a longer period of time like houses, hospitals, etc. An extensive list can be found in the handbook [1].*

will be demonstrated for a tanker passing a wind farm. Finally, some generic conclusions have been drawn for safe siting of wind turbines.

2. HANDBOOK FOR RISK ASSESSMENT OF WIND TURBINES

The handbook has been developed to be a practical guideline for licensing authorities, project developers and consultants in the field risk analysis.

The main body of the handbook first discusses what kind of failure events of turbines (called: *scenarios*) should be considered in a risk analysis. For each scenario, the occurrence frequency has been determined by analysing over 200 severe incidents and accidents in Denmark, Germany and the Netherlands. All data represent approximately 43.000 turbine years. Finally, only 62 incidents appeared to be relevant for the safety of nearby objects. The relevant scenarios and their occurrence frequencies are summarised in Table 1.

Secondly, the main body indicates to what distance from the turbine vulnerable objects should be considered in the risk analysis. The distance equals the maximum throwing distance of a blade during overspeed (= two times rated rotor speed). In general it can be said that for three bladed turbines in the range of 500 kW to 2000 kW, these distances vary from 300 m to 400 m. In the example of Fig. 1 with wind turbines of 1.5 MW and a grid of 200 m, this means that the houses do not have to be considered any further. All other objects are within the maximum throwing distances.

Furthermore, the main body identifies 10 main categories to be considered:

1. Houses and buildings
2. Roads
3. Waterways
4. Railways
5. Industrial areas
6. Underground pipelines
7. Overhead pipelines
8. High tension lines
9. Dikes and dams
10. Paths for communication rays

Table 1: *Frequencies of occurrence of scenarios relevant for risk analysis. The recommended values correspond to the 95% upper limits.*

Scenario	**Expected value**	**Recommended value [1/yr]**
Loss of entire blade	$6.3\cdot10^{-4}$	$\mathbf{8.4\cdot10^{-4}}$
Loss at rated speed		$\boldsymbol{4.2\times10^{-4}}$
*Loss at 1.25*rated speed*		$\boldsymbol{4.2\times10^{-4}}$
*Loss at 2*rated speed*		$\boldsymbol{5.0\times10^{-6}}$
Loss of blade tip	$1.2\cdot10^{-4}$	$\mathbf{2.6\times10^{-4}}$
Collapse of entire turbine at tower foot	$2.0\cdot10^{-4}$	$\mathbf{3.2\times10^{-4}}$
Collapse of rotor and/or nacelle	$5.8\cdot10^{-5}$	$\mathbf{1.3\times10^{-4}}$
Falling down of small parts from nacelle and hub	$1.2\cdot10^{-3}$	$\mathbf{1.7\times10^{-3}}$

For each category the handbook explains:

- what calculation method should be used;
- which safety and risk criteria should be applied; and
- how the results of the risk analyses should be assessed.

In addition to the main body of the handbook, it consists of four annexes with background information.

Annex A: Analyses of incidents and accidents
In this annex, the incidents reported in the German WMEP database from ISET, a Danish database, owned by Energie og Miljødata, and a Dutch database have been analysed in order to determine the data given in Table 1. The annex contains among others the process used for the data analyses, considerations if incidents are a risk for the environment or not, and throwing distances reported by eyewitnesses.

Annex B: Generic data and conclusions
In many cases, especially in the start-up phase of a wind farm project, the exact type of turbine to be used is not known. For that reason, the authors have collected generic turbine data like hub height, rotor diameter, rotor speed, throwing distances of blades, and risk contours as a function of the rated power. The data is based on three bladed, commercially available wind turbines in the range of 500 to 2000 kW. By applying the generic data and conclusions, labour intensive work can be avoided in many cases.

Annex C: Calculation method
This annex contains a method to determine the probability that a blade (or any other turbine component) may hit a person or object. The method assumes that the centre of gravity of the blade follows a ballistic curve; lift and drag have been neglected (underpinned with a benchmark exercise). The method further includes the size of the blade (or any other component), the size of the object or area, and if relevant the velocity of e.g. a car or train.

Annex D: Risk criteria and assessment
This annex in fact is tailor made for the Dutch situation. In the Netherlands, two basic criteria developed by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) are valid:

Individual Risk (IR) = the probability that a person will die from an accident at a plant (or any other hazardous activity) if he is permanent at a certain place without protection. The maximum value for the IR is 10^{-6} per year. (The IR is usually presented as contours with equal IR values around a plant or turbine.)

Group Risk for Plants (GR_I) = the probability per year that a group of persons of at least a certain size will die from an accident at a plant or any other hazardous activity. The maximum value is 10 persons with a probability of 10^{-5} per year, 100 persons with a probability of 10^{-7} per year, and so on.

Derived from these two basic criteria, the Ministry of Transport, Public Works and Water Management (VenW) has established a similar Group Risk for Transport Routes (GR_T).

In the mid-nineties, the Ministry of VenW and Dutch Railways (NS) have developed their own risk criteria in order to assess the risks for persons passing a wind farm placed on (or close nearby) their premises. The risks are more or less similar to the IR and GR, however they take into account the fraction of time that the persons are in the vicinity of the turbines. The risk criteria from VenW and NS are called the individual risk for passengers (IPR) and societal risk (MR = *maatschappelijk risico* in Dutch).

The above mentioned criteria appear to be applicable if a blade or any other component directly hits a person, or a group of persons. However, no guidance is given on how to assess the risks if a wind turbine is placed close to a tank with toxic gasses. If a blade hit the tank, it may lead to loss of containment and make many victims. In the handbook, these risks are considered as indirect risks.

The handbook in fact distinguishes four situations to assess the direct and indirect risks, see Fig. 2 through 5.

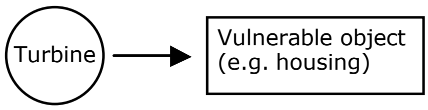


Fig. 2: *Situation 1, the wind turbine causes a direct risk for vulnerable objects*

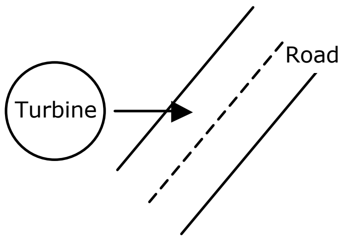
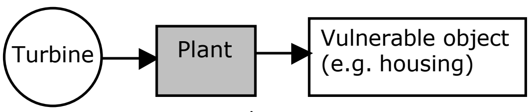


Fig. 3: *Situation 2, the wind turbine causes a direct risk for passing persons*



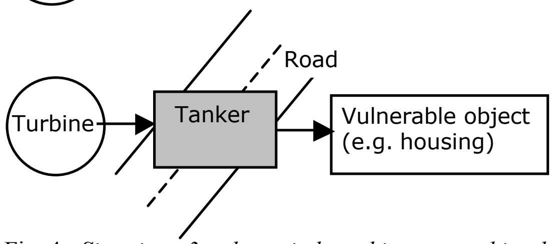


Fig. 4: *Situation 3, the wind turbine may hit the hazardous plant and cause an indirect risk for vulnerable objects*

Fig. 5: *Situation 4, the wind turbine may damage a tanker with an hazardous gas or liquid and cause an indirect risk for vulnerable objects*

In the handbook, a method has been developed to assess the indirect risks in situation 3 and 4. In all cases, the IR, GR_I, and GR_T should be met. The additional risk, caused by the wind turbine should not lead to the situation that the already existing risks from the plant (or tanker) will exceed the IR, GR_I, and GR_T. In many cases, it can be sufficient to demonstrate that the probability of hitting e.g. a tanker is much lower (say < 1%) than the already existing probability of loss of containment as given in generic guidelines for risk assessment (e.g. CPR 18E, ref [2]). This method avoids the execution of a time consuming quantitative risk analysis (QRA) of the entire plant.

3. DUTCH LEGISLATION

In the Netherlands, the following documents deal specific with safety of wind turbines.

1. NVN 11400-0: "*Wind turbines – part 0: regulations for type certification – Technical requirements*", 1999
   This document can be considered as the safety standard for wind turbines. In the handbook it is assumed that wind turbines have been certified in accordance with this standard.
2. *Besluit Voorzieningen en Installaties Milieubeheer*, Algemene Maatregel van Bestuur, Staatsblad 2001 487, 18 oktober 2001 (*Decision Facilities and Installation Environmental Management,* General Measures of Government)
   This document is a law, which deals with environmental problems. It deals a.o. with noise levels of wind turbines, but also with safety issues. The handbook in fact deals in depth with the safety issues since a type certificate is not a 100% guarantee that no accidents will happen.
3. Ministry of Transport, Public Works and Water Management: "*Draft policy rule for siting of wind turbines on or near public works*", 2001
   This document is still a draft. However it is used already to for safe siting of wind turbines near public roads and waterways.

During the preparation of the handbook it appeared that at present, the law does not cover situation 3 and 4 (see Chapter 2). The Ministry of Housing, Spatial Planning and the Environment recommends to apply the handbook if needed to fill up the gap in legislation.

4. TANKER PASSING A WIND FARM (EXAMPLE)

In this chapter, an example is given on how a risk analysis should be performed to assess the risks for a tanker with toxic gasses passing a wind farm.

Assumptions:

- Size of the tanker: 15 m long, 2,5 m width
- Velocity of tanker: 80 km/hr (braking distance 67 m)
- Wind farm: 20 turbines, 1.5 MW, d = 74 m
- Length of farm: 9.5 km (spacing = 6.5·d)
- Distance between turbine and road = ½ d = 37 m

The situation is sketched in Fig. 6.

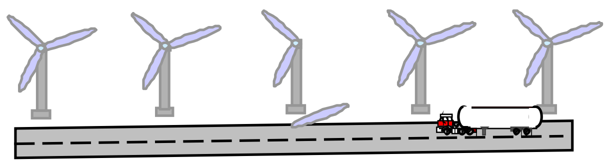


Fig. 6: *Tanker passing a wind farm*

Determination of probability of hitting the tanker

The maximum throwing distance at 2 times the rated speed is 370 m so the road is within the vulnerable area. The scenario's to be considered for each turbine are given in Table 1. The probability of a blade or any other component hitting the tanker (including the braking distance) is determined in accordance with Annex C of the handbook, $p = 5.9 \cdot 10^{-10}$. In order to compare the results with the data given in [2], the probability should be expressed per km road: $p = 6.2 \cdot 10^{-11}$ per km. From [2] it has been derived that the generic probability of loss of containment of this type of tanker is $4.32 \cdot 10^{-9}$ per km. If we assume that any hit leads to leakage (which is a very conservative assumption) the added risk is 1.4%. In reality not all blades that hit the tanker will lead to leakage so the added risk is less than 1%. In general it can be said that placing turbines near a highway does not influence the safety for tankers.

5. CONCLUSIONS

Similar to the calculations for the tanker, generic conclusions for three bladed turbines have been drawn in Annex B. For example the IR contours as a function of the turbine size are given, the reason why ice throw and loss of tip brakes are not an issue for risk and safety in most cases, etc. In Fig. 7, an example is given of the IR contours for a 2 MW turbine. Fig. 7A shows the IR contours resulting from the individual scenarios. Fig. 7B shows the sum of all IR values.

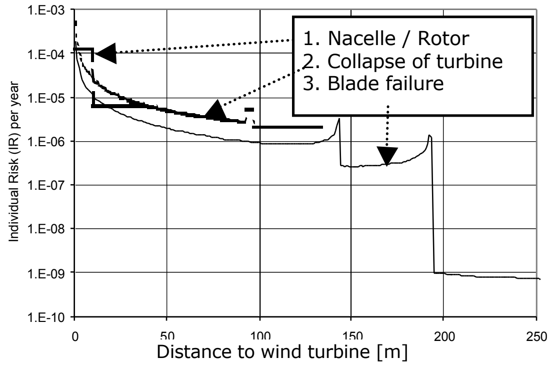


Fig. 7A: *Individual Risk (IR) resulting from the individual scenarios for a 2 MW wind turbine*

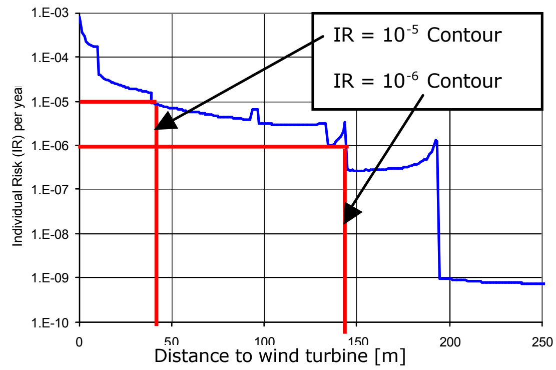


Fig. 7B: *Individual Risk (IR) for a 2 MW wind turbine, including all scenarios of Table 1*

In the handbook, such contours have been plotted for turbines in the range of 500 kW up to and including 2 MW. From these plots the IR = 10^{-5} and IR = 10^{-6} contours as a function of the turbine size have been determined, see Table 2. The IR = 10^{-5} contour equals half the rotor diameter. The IR = 10^{-6} contour equals the maximum throwing distance of a blade at rated rotor speed.

Table 2: *IR contours as a function of turbine size*

Type of turbine				
Rated power [kW]	500	1000	1500	2000
IR = 10^{-6} contour [m]	111	124	134	144
IR = 10^{-5} contour [m]	20	28	37	39

The handbook has already proven its value. A lot of the knowledge and insights gained within the project have been applied already in many cases. The handbook provides a rational basis for assessing the risks of wind turbines for their environment. It provides a uniform approach, supported by all parties involved and has lead to a faster licensing procedure.

ACKNOWLEDGEMENT

The Handbook Risk Assessment of Wind Turbines [1] will be published in Dutch in May 2002. It can be ordered by NOVEM who financially supported the project.

REFERENCES

[1] Braam, H. et al: *"Handboek Risicozonering Windturbines" (Handbook Risk Assessment of Wind Turbines)*, Novem, to be published in May 2002.

[2] Committee for the Prevention of Disasters: "*Guidelines for Quantitative Risk Assessment*", CPR 18E, The Hague 1999, ("Purple Book")