

TNO report**2019 R10447 | 2.0****Simple Engineering Assessment; The effect of
wind turbines in Dalhem on the Beauvechain
primary radar system****Defence, Safety & Security**

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1 Introduction

The performance of radar systems can be negatively influenced by wind turbines in the vicinity. EUROCONTROL has issued guidelines, on how to assess the potential impact of wind turbines [1]. Within these guidelines different zones around the radar are defined. A Detailed Engineering Assessment (DEA) for the primary radar is required at distances of the wind turbines from 500 m to 15 km (zone 1). In the zone ranging from 15 km to the instrumented range of the primary radar (zone 2), a so-called Simple Engineering Assessment is required.

In this study the impact of wind turbines on the primary radar performance of the Airport Surveillance Radar (ASR) at the Belgian Airbase Beauvechain, following the EUROCONTROL guidelines for Primary Surveillance Radars (PSRs). The newly planned wind turbines will be located at distances larger than 15 kilometres from the radar, therefore a simple engineering assessment is required.

Note that in a simple engineering assessment the size and position of various regions of impact for the primary radar are determined. However, the extent of the interference within these regions is not assessed.

In Chapter 2 the relevant input parameters of the wind turbines and radars are given. In Chapter 3 we perform the line-of-sight analysis to determine whether the wind turbines are visible to the radar. In Chapter 4 we determine the size and position of the regions of potential impact. Chapter 5 deals with the potential issues of false target reports and PSR processor overload.

2 Input Parameters

2.1 Wind turbines

The simple engineering assessment is carried out for a total of six wind turbines. The six newly planned wind turbines are shown in Figure 2.1. The green dots indicate the six wind turbines under investigation.

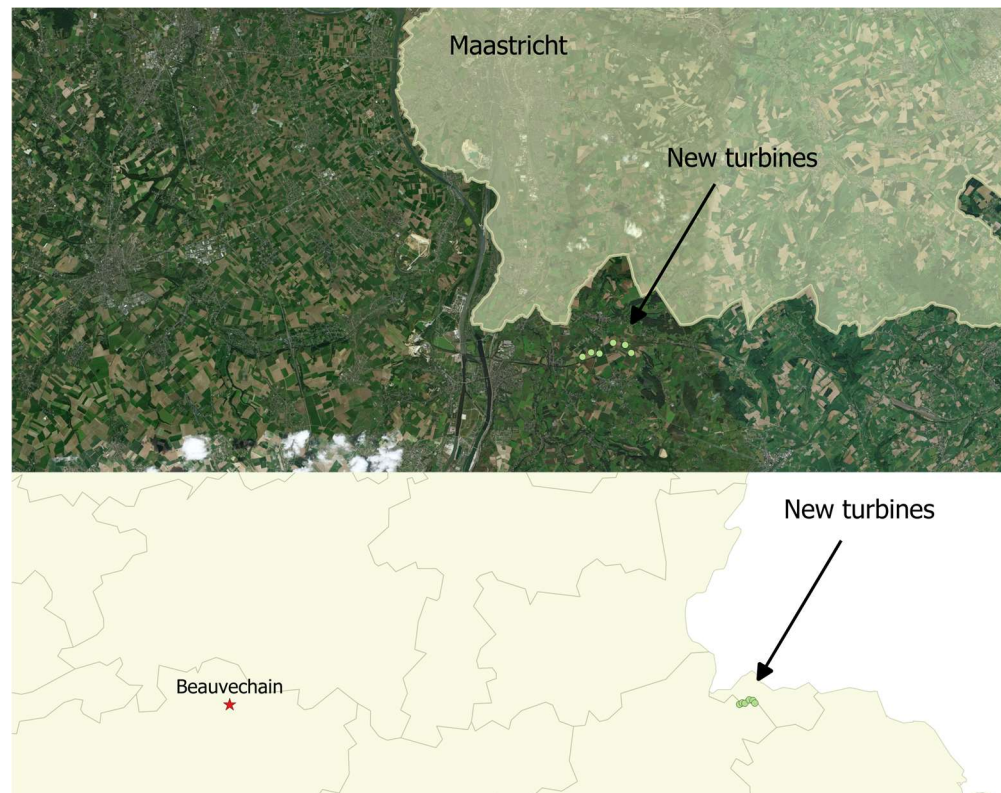


Figure 2.1 The locations of the six newly planned wind turbines in Dalhem. Background image taken from Bing Maps.

The positions and dimensions of the six planned wind turbines are presented in Table 2.1.

Table 2.1 Overview of the positions of the six newly planned wind turbines. The X, Y coordinates have been provided by ENGIE Electrabel. The longitude and latitude have been derived from the Lambert72 coordinates. The terrain height has been derived from the SRTM altitude database.

Nr.	ID	Lambert72 Coordinates		Terrain height w.r.t. EGM96	Lon. WGS84	Lat. WGS84	Hub Height	Tip Height
		X [m]	Y [m]					
1	WT1	247377	160231	103	50,74445	5,74852	87	150
2	WT2	248096	160349	103	50,74539	5,75874	87	150
3	WT3	249130	160706	116	50,74842	5,77348	87	150
4	WT4	248814	160938	116	50,75056	5,76907	87	150
5	WT5	249402	160350	117	50,74517	5,77724	87	150
6	WT6	249433	160395	118	50,74557	5,77769	87	150

2.2 Primary Radar System Beauvechain

We investigate the effects of the wind turbines on the Airport Surveillance Radar at Beauvechain Air Base (Figure 2.2). The air base is equipped with a combined radar system and consists of both a Primary Surveillance Radar (PSR), the Thomson CSF TA-10M and a Secondary Surveillance Radar (SSR). The PSR has been upgraded by Intersoft-Electronics at a later stage.

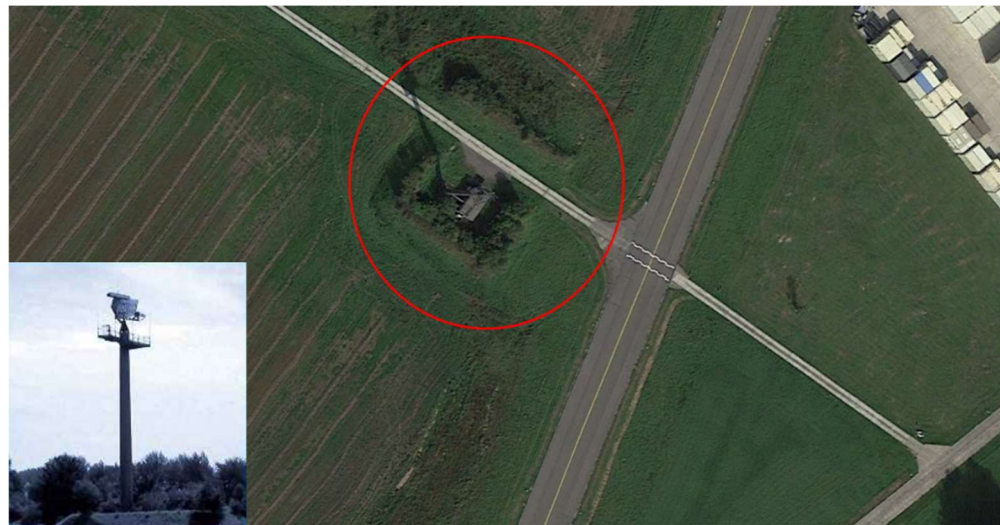


Figure 2.2 The Airport Surveillance Radar at Beauvechain Air Base (image: Google Earth).

In this study only the PSR is under investigation. The radar parameters that are relevant for this study are presented in Table 2.2. This information has been taken from the radar file ASR Beauvechain [2] provided by the Belgium Ministry of Defence and updates received via email [3].

Table 2.2 Relevant radar parameters of the PSR Beauvechain taken from [2] and [3].

PSR Beauvechain	
Antenna position	
<i>Lambert 72</i>	
X [m]	178660
Y [m]	160163
<i>WGS84</i>	
Latitude [°]	50° 45' 04.58" (50.751273) N
Longitude [°]	4° 46' 29.58" (4.774882) E
Antenna Height	
AGL [m]	28
EGM96 [m]	135 (based on ground level of 107 m from SRTM)
Antenna rotation speed	
[RPM]	12
Instrumented range	
[NM]	100
[km]	185
Frequency	
[GHz]	2.775
Beam width (horizontal, 3dB, one-way)	
[°]	1.5° ± 0.2°
Range cell size	
Range	
[m]	21.9
Azimuth	
[°]	0.147°
CFAR algorithm	
Type	CAGO (Cell Averaging Greatest of)
Number of range cells within the early and late window	24 (per window)
Number of guard cells on both sides of CUT	12

3 Line of Sight Analysis

Using the information given in Chapter 2, we have carried out a line-of-sight analysis. In Figure 3.1 we show the terrain profile in the area containing the wind turbines and radar. The lines in the figure connect the radar to the first planned wind turbine WT1. By studying the terrain profile along this line for each wind turbine, we can determine whether the radar in Beauvechain will have line-of-sight to the windfarm.

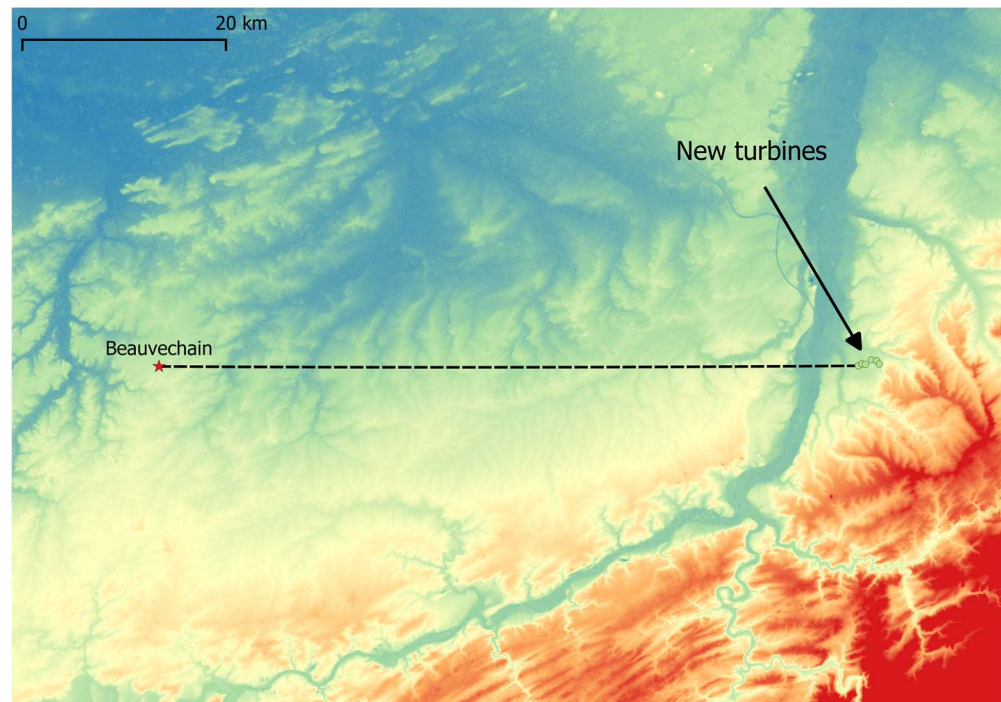


Figure 3.1 The altitude of the terrain between radar and wind turbines taken from the SRTM database. The altitude in this image varies from approximately +0 m (red) to +200 m (blue) ASML. The line-of-sight analysis is performed by studying the terrain profile on the line connecting the radar and each wind turbine.

So-called 'standard propagation' is assumed when determining the line-of-sight. This is modelled by multiplying the earth radius by a factor of 4/3 (the "k-factor").

There are no existing wind turbines in the neighborhood of the new wind farm that are required to be considered for the SEA.

In the figures on the next pages the red ellipses show the first Fresnel zone from the radar antenna to the tip height of the wind turbine and the blue ellipses show the first Fresnel zones from the radar antenna to the hub height of the wind turbines. These ellipses are referred to as the $\frac{1}{4} \lambda$ Fresnel zone, where λ refers to the radar wavelength. Signals travelling between the terminals within the blue and red ellipses are at most 90° out of phase with respect to the signal that takes the shortest path. The black lines show the profile of the ground level between the radar and wind turbine as derived from the SRTM database¹.

¹ For the line-of-sight analysis the data from the Shuttle Radar Topography Mission (SRTM1) is used. This database contains terrain altitude information with respect to the EGM96 geoid. The database was determined by NASA using high-resolution radar carried on the Space Shuttle. The

Figure 3.2 thru Figure 3.7 show line-of-sight diagrams between the location of the radar system and the six newly planned wind turbines locations. The horizontal range is range over ground in kilometres calculated using Vincenty's formulae. The six turbines are located approximately 70 km from PSR Beauvechain.

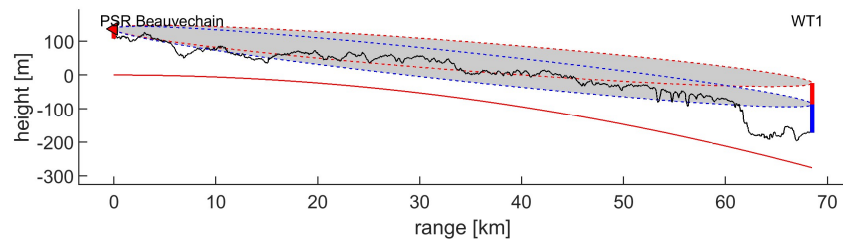


Figure 3.2 Line-of-sight between the PSR of Beauvechain (antenna height: 28 m, ground level: 107 m) and the first newly planned wind turbine WT1 (tip height: 150 m, hub height: 87 m, ground level: 103 m). The ground range from the PSR to the wind turbine is 69 km.

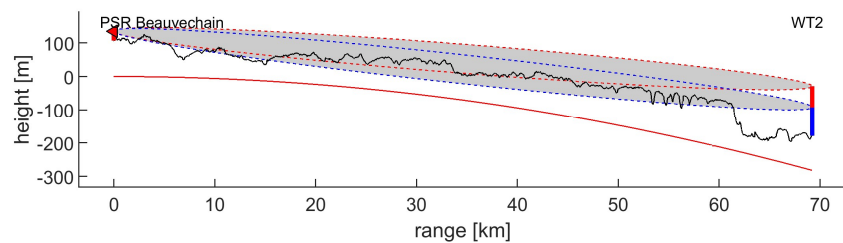


Figure 3.3 Line-of-sight between the PSR of Beauvechain (antenna height: 28 m, ground level: 107 m) and the second newly planned wind turbine WT2 (tip height: 150 m, hub height: 87 m, ground level: 103 m). The ground range from the PSR to the wind turbine is 69 km.

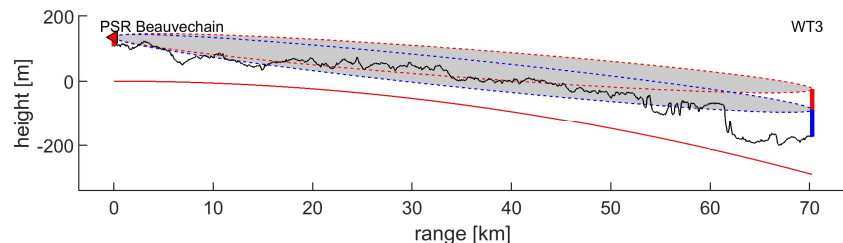


Figure 3.4 Line-of-sight between the PSR of Beauvechain (antenna height: 28 m, ground level: 107 m) and the second newly planned wind turbine WT3 (tip height: 150 m, hub height: 87 m, ground level: 116 m). The ground range from the PSR to the wind turbine is 70 km.

SRTM data has a resolution of 1 arcseconds, which corresponds to a horizontal resolution of about ~20 m at 51 degrees latitude.

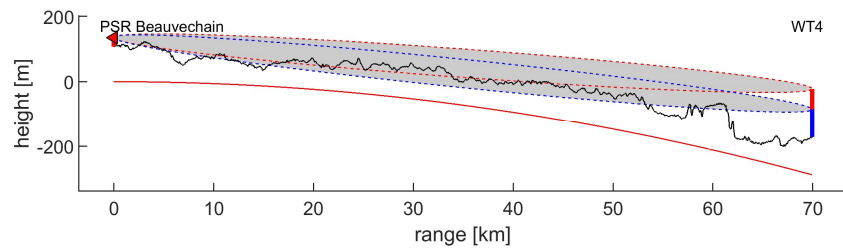


Figure 3.5 Line-of-sight between the PSR of Beauvechain (antenna height: 28 m, ground level: 107 m) and the second newly planned wind turbine WT4 (tip height: 150 m, hub height: 87 m, ground level: 116 m). The ground range from the PSR to the wind turbine is 70 km.

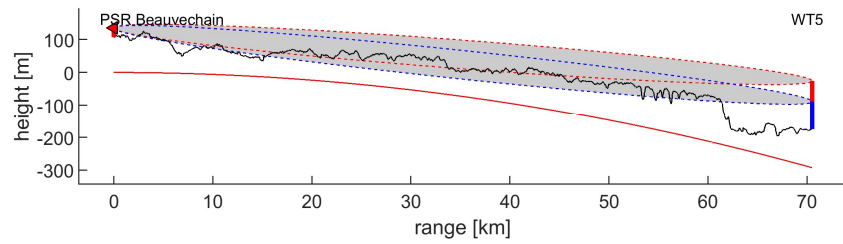


Figure 3.6 Line-of-sight between the PSR of Beauvechain (antenna height: 28 m, ground level: 107 m) and the second newly planned wind turbine WT5 (tip height: 150 m, hub height: 87 m, ground level: 117 m). The ground range from the PSR to the wind turbine is 71 km.

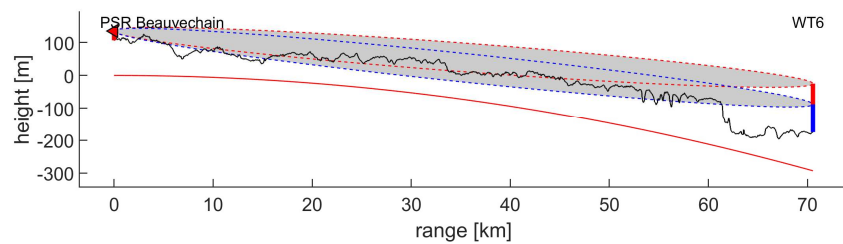


Figure 3.7 Line-of-sight between the PSR of Beauvechain (antenna height: 28 m, ground level: 107 m) and the second newly planned wind turbine WT6 (tip height: 150 m, hub height: 87 m, ground level: 118 m). The ground range from the PSR to the wind turbine is 71 km.

For all wind turbines, the Fresnel zones are not obstructed by the terrain profile, meaning that the radar antenna has line-of-sight to all the planned wind turbines.

4 Regions of Potential Impact

4.1 Introduction

In Chapter 3 we have determined that the radar has line-of-sight to all wind turbines. When this is the case the wind turbines can affect the radar in a number of ways. The EUROCONTROL guidelines [1] prescribe that in the case of a simple engineering assessment, the size of the following two regions must be determined:

1. The shadow region behind the wind turbine, caused by the attenuation due to the wind turbine being an obstacle for the electromagnetic field.
2. The volume located above and around the wind turbine in which the radar detection threshold, generally implemented with CFAR (Constant False Alarm Rate) logic, is affected.

Both regions are shown in Figure 4.1 below. This image was taken from [1], Section 4.3.1. In the next sections the size of the two regions are determined.

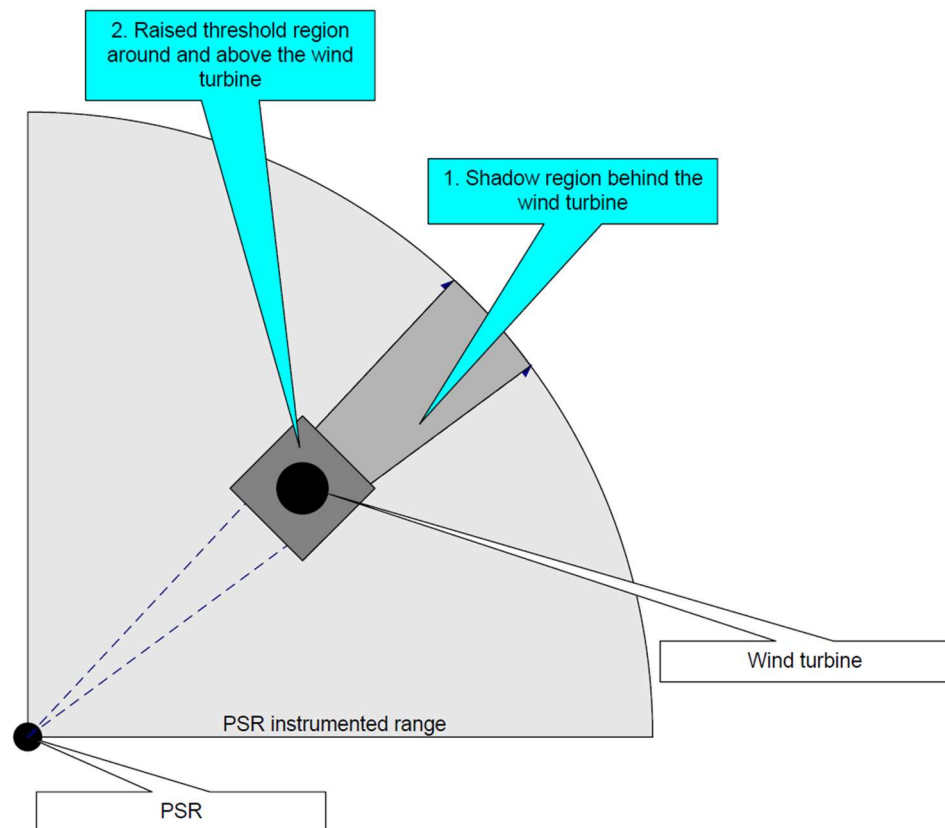


Figure 4.1 Schematic representation of the shadow region behind a wind turbine (1) and the raised threshold region around and above a wind turbine. Image taken from [1].

4.2 Region 1: Shadow region

In this section we determine the size of the shadow regions behind the wind turbine. In Figure 4.2 the shape of the region is shown.

The shadow region extends all the way to the instrumented range of the radar. The length of the shadow region is therefore equal to the instrumented range minus the distance from the radar to the wind turbine.

The width of the shadow region is given by $2\sqrt{(\lambda D)}$, where λ is the radar wavelength and D the distance from the wind turbine. See also Annex A-3 in the EUROCONTROL guidelines [1]. The width is at its maximum at the instrumented range from the radar.

Finally, the height of the shadow region can be calculated according to Equation 1 in Annex A-2 in [1]. Note that this calculation takes the curvature of the earth into account by assuming a spherical earth with radius kR_e , where R_e is the earth radius and k is the standard propagation k-factor equal to 4/3. The calculated height is relative to the EGM96 geoid, which is approximately equal to mean sea level and is accurate within several meters. The height of the shadow region is equal to the tip height at the location of the wind turbine and increases (not taking the ground level into account) to its maximum value at instrumented range from the radar.

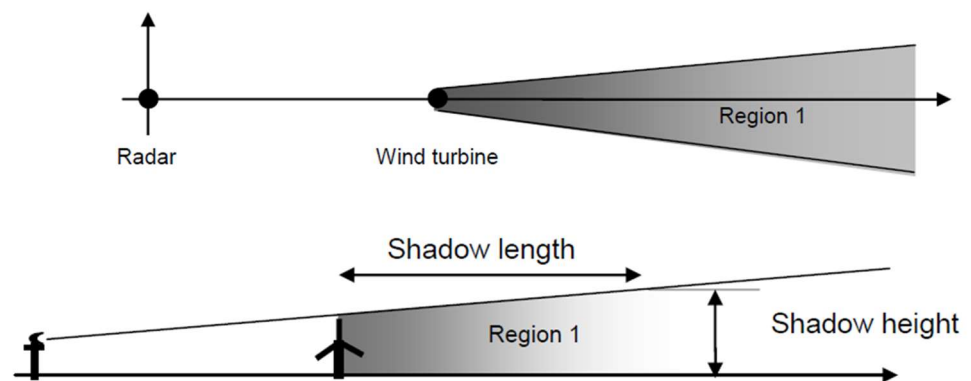


Figure 4.2 Shape of the shadow region. Image taken from Annex A-1 in [1].

4.2.1 Shadow Dimensions

Length, maximum width and maximum height of the shadow regions for the newly planned turbines are provided in Table 4.1.

Table 4.1 Dimensions of the shadow regions of the planned wind turbines.

Nr.	ID	Tip Height [m]	Shadow PSR Beauvechain		
			Length [km]	Max. height w.r.t. sea level [km]	Max. Width [m]
1	WT1	150	116,3	1,72	224
2	WT2	150	115,6	1,71	223
3	WT3	150	114,5	1,73	222
4	WT4	150	114,8	1,73	223
5	WT5	150	114,3	1,72	222
6	WT6	150	114,2	1,73	222

4.2.2 Shadow Locations

The shadows of the planned turbines for PSR Beauvechain are presented in Figure 4.3. The shadows of the planned turbines are indicated with a red colour.

In Figure 4.4 the shadows of the planned turbines are shown. As there are no close existing turbines, these are the only shadows in this area.

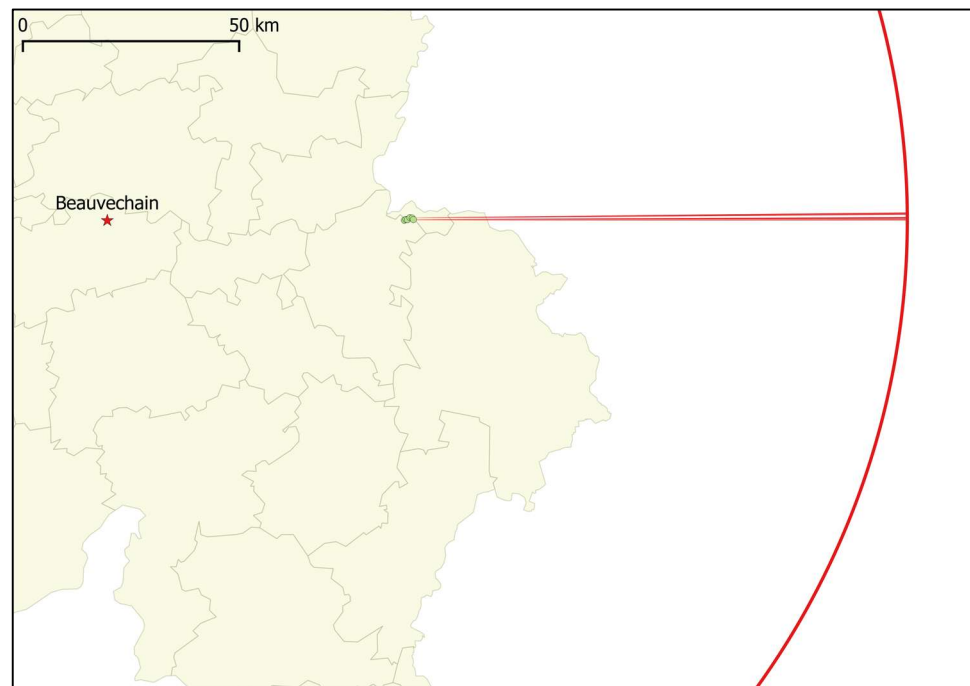


Figure 4.3 The geographic locations of the shadow regions the new turbines as seen from the PSR in Beauvechain. The shadow regions (small red regions) extend from the wind turbine to the instrumented range (100 NM or 185 km) of the radar (indicated with a red circle). The width of the shadow region at instrumented range is approximately 224 m for the new wind turbines. The height of the shadow regions with reference to the EGM96 geoid is maximum 1.7 km above mean sea level.

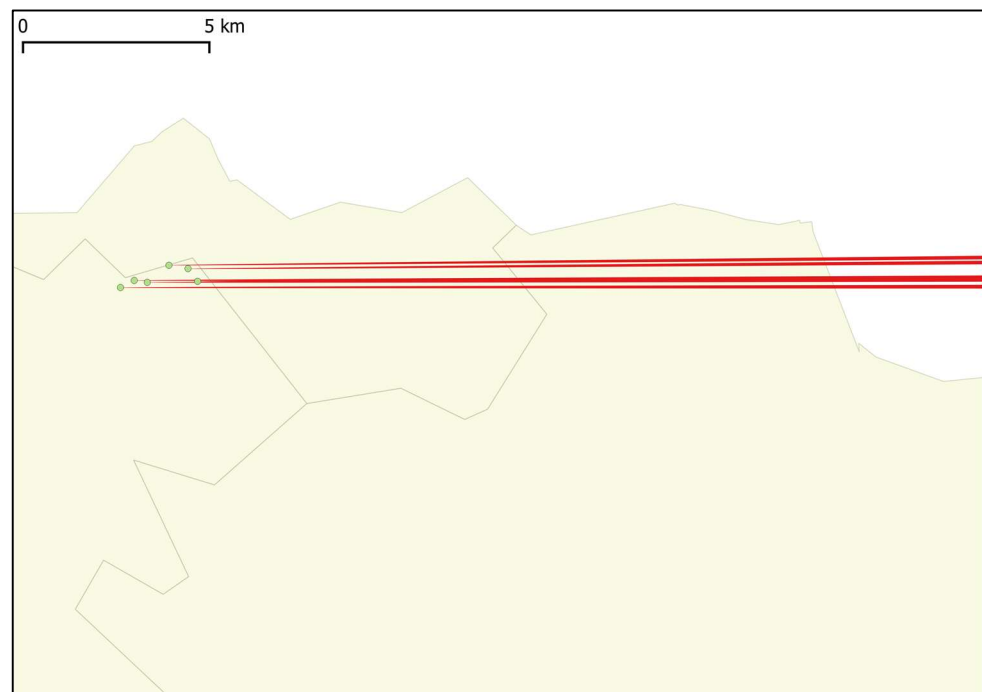


Figure 4.4 The shadow regions of the new turbines (red regions).

4.3 Region 2: Raised threshold regions

The second region of potential impact is the so-called raised threshold region. In this region the possibly large reflection of the wind turbine raises the detector threshold of the radar, lowering the probability of detection of a target.

The size of the region in range is dependent on the exact implementation of the CFAR detection logic in the radar. In general a radar threshold is determined using a number of range cells around the Cell Under Test (CUT).

In the case of PSR Beauvechain (see Table 2.2) the number of range cells around the cell under test has been specified to be 24, of which the 12 closest range cells, the so-called guard cells, are neglected. Given the size of a range cell of 21.9 m, we calculate that a wind turbine can potentially influence the radar threshold from approximately 788 m in front until 788 m behind the wind turbine. The size in azimuth is dependent on the horizontal beam width of the radar. Given the beam width in Table 2.2, at a range of, for example, 25 km the size in azimuth is approximately 1300 m.

The region in which the wind turbine influences the threshold has been calculated for 5 newly planned wind turbines for PSR Beauvechain. The results are presented in Figure 4.5.

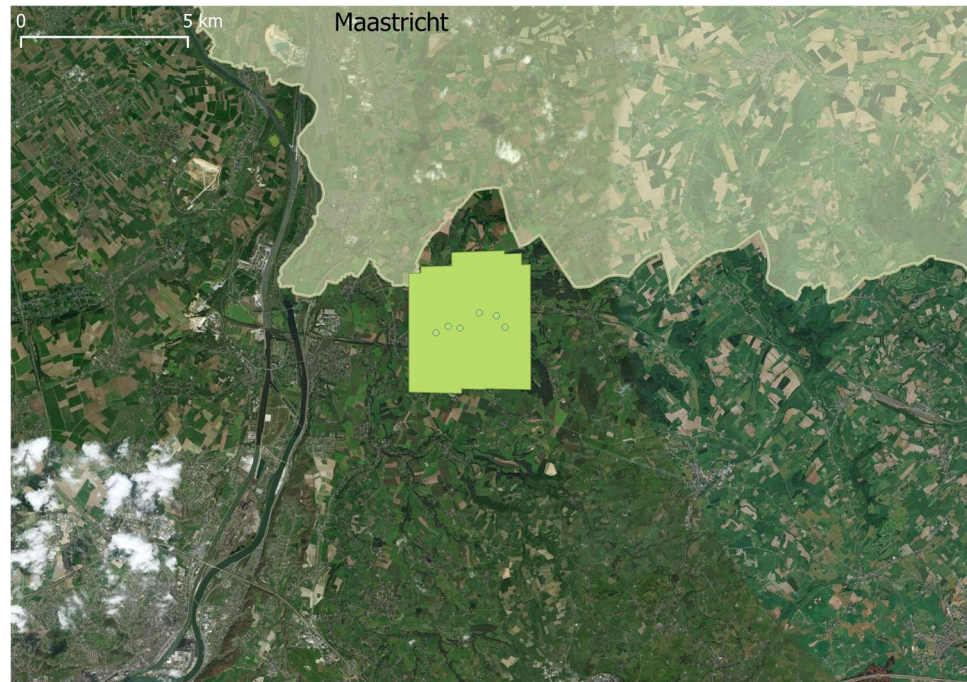


Figure 4.5 The combined raised threshold regions for the planned turbines and PSR Beauvechain. The affected area of the newly planned turbines equals 14.4 km² for Beauvechain.

The pictures above should be interpreted with care, for two reasons. Firstly, the scattering properties of the moving and the non-moving parts of the wind turbines are not being considered. With respect to the non-moving parts: since wind turbine masts are often shaped like truncated cones, wind turbine mast backscatter is not being sensed by the radar, as illustrated in Figure 4.6, given the distance to the wind farm.

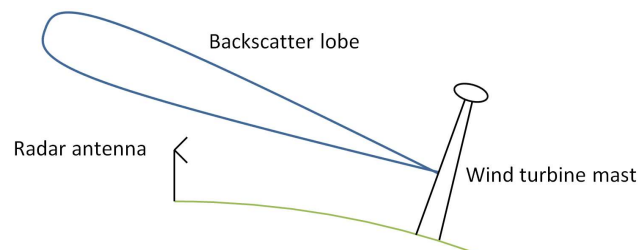


Figure 4.6 Due to the earth curvature as well as the tapering of the wind turbine mast diameter, wind turbine mast backscatter, which is confined in the backscatter lobe, may not be received by the radar. This physical phenomenon is neglected in Figure 4.5.

5 False target reports and processing overload

Modern surveillance radars are equipped with multiple mechanism to obtain detections of flying targets only. To suppress reflections at non-moving objects, adaptive cluttermaps are maintained, potentially within each Doppler filter. Non-moving structures, such as the wind turbine mast and the nacelle will therefore not give rise to false (non-target) plots. A flying target will be detected if its response (echo) also passes the so-called CFAR (constant false alarm rate) circuitry. Radar manufacturers have responded to the detection of wind turbine blade flashes, by adapting the logic of the CFAR process. Rather than the CAGO (cell averaging greatest of) logic, ordered statistics (OS) logic is nowadays often applied, since this processing is better capable to detect aircraft when a wind turbine blade flash occurs. Note that the Belgium Airforce has indicated that the Beauvechain radar are equipped with CAGO CFAR circuitry (rather than OS or like circuitry).

In case the Beauvechain radar would be equipped with a modern receiver such as the Next Generation Signal Processor (NGSP) from Intersoft-Electronics, the radar could benefit from the Vertical Clutter Canceller (VCC) technology. With this technology the radar will be capable of adapting the elevation antenna pattern on receive, range dependent. Thus, wind turbine backscatter can be 'nulled', which improves the detection capability of the radar above wind turbines.

Given a blade flash frequency of 3 Hz, the azimuth beamwidth and the antenna rotation rate, 0,3 blade flashes per scan are expected from the entire windfarm for the ASR Beauvechain. A worst case assumption, which neglects the several anti-wind turbine features of these radars described above, is that these flashes will result in PSR-only plots. Since modern surveillance radars are capable to process several hundred plots per s, the extra plots are considered as being insignificant. Processing overload is therefore not expected.

6 Conclusions

In accordance with EUROCONTROL's description of a simple engineering assessment for primary radar systems, three subjects have been analysed: line-of-sight, the volumes of the regions that are impacted, and the occurrence of false target reports.

It is concluded that the wind turbines are not significantly obstructed by altitude level of the terrain between the radar installation and the wind turbines. The sizes of the volumes in which radar degradation occurs have been specified in Section 4 of the document. The wind turbines in Dalhem will create a volume where PSR Beauvechain is desensitised of approximately 14.4 km² at a distance of more than 70 km from the radar.

Due to the cluttermap processing, it is not expected that static structures of the wind turbines will raise alarms. The probability that an alarm will be induced as a consequence of a wind turbine blade flash has been elaborated in Section 5. The increase of the plot rate due to this phenomenon is expected to be negligible.

7 List of abbreviations

ACP	Azimuth Change Pulse
AGL	Above Ground Level
ASR	Airfield Surveillance Radar
CAGO	Call Averaging Greatest Of
CFAR	Constant False Alarm Rate
CTR	Control
CUT	Cell Under Test
EGM96	Earth Gravitational Model 1996
NASA	National Aeronautics and Space Administration
NGSP	Next Generation Signal Processor
PSR	Primary Surveillance
SSR	Secondary Surveillance Radar
SRTM	Shuttle Radar Topography Mission
TNO	Netherlands Organisation for Applied Scientific Research
VCC	Vertical Clutter Canceller
WGS84	World Geodetic System 1984

8 References

- [1] EUROCONTROL guidelines on How to Assess the Potential Impact of Wind Turbines on Surveillance Sensors, Edition 1.2, September 2014, Ref. nr EUROCONTROL-GUID-0130.
- [2] TA10M Radar file ASR Beauvechain v.D.1.0 received from the Belgium Ministry of Defence.
- [3] E-mail "Re: Request for information (new?)" regarding the update the TA10M recently have received Domien De Ruyck of MRCI-DEOMATIC3D dated 15th February 2018.
- [4] QinetiQ report, Wind Farm Impact on Radar Aviation Interests, FES W/14/00614/00/REP
- [5] A. Theil, L.J. van Ewijk, Radar Performance Degradation due to the Presence of Wind Turbines, IEEE Radar Conference 2007