Blade Throw Risk Assessment: Wombelano Wind Farm

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Executive Summary

The risk associated with blade throw at the proposed Wombelano Wind Farm is assessed as being broadly acceptable, with the likelihood of a fatality being estimated at one fatality per 9million years of operation per wind turbine.

For hazards with fatal consequences, a recurrence period of one-million years is generally considered to be “broadly acceptable”.

The estimate is based on the number of catastrophic blade failures in Australia divided by the number of operating years of wind turbines in Australia. The spatial extent is adjusted to reflect the mode of failure: blade fragment being thrown up to 500 m versus the blade dropping to the ground, constrained to within 150 m of the wind turbine. An estimate is made of the likelihood of the impact point being populated based on typical farming practice, a conservative view of traffic volume, and the presence of wind farm maintenance personnel.

1. Introduction

In their preliminary response to the Proponent's planning submission for the Wombelano Wind Farm (WWF), the Department of Environment, Land, Water and Planning (DELWP) noted that either a larger buffer between Wind Turbine Generators (WTGs) and the property boundary or a risk assessment would be beneficial to address the risk of blade throw impact on neighbouring properties and adjacent roads.

It is the view of the Proponent that the lives of those on the wind farm site are of equal value to the lives of those not on the site. In any case, the Proponent has a duty of care to maintain a safe workplace. Thus, this assessment does not distinguish between "on site" and "off site".

Risk is assessed as a combination of likelihood and consequence. Where a hazard has fatal consequences, such as WTG blade throw, the likelihood must be extremely low for the residual risk to be considered acceptable.

The boundary between "broadly acceptable" and "tolerable" risks is generally taken as a 1 in one million years' fatality. The boundary between "tolerable" and "unacceptable" is generally taken for the public at large as a 1 in 10,000 years' fatality.[1] These values assist in providing appropriate benchmarking.

An assessment of the likelihood of a fatality due to blade throw is presented below.

2. Methodology

The following methodology is employed to determine the acceptability of blade throw risk:

1. Identify the number of operating years of WTGs in Australia.
2. Identify and classify the number of blade failures in Australia.
    a. Classification is based on whether blade drop is observed or whether there is fragmentation. Antcliff & Curtis[2] reported that for blade drop, the farthest impact was 150 m, whereas for fragment, the farthest impact was 500 m.
3. Assess the likelihood of people being within impact radius.
    a. This is based on typical farming and wind farm maintenance practice.
4. Assess the likelihood of injury/fatality associated with blade failure.
    a. For an area within 150 m of the WTG, this is taken as the likelihood of blade drop plus the likelihood of blade fragmentation.
    b. For an area within 500 m of the WTG, this is taken as the likelihood of blade fragmentation.
5. Assess whether likelihood of injury/fatality falls below accepted community standards.

3. Analysis

3.1 Operating years of WTGs in Australia

As tabulated in Appendix 1: List of Wind Farms and Years of Operation, 3635 wind turbines have been identified as operating in Australia. This corresponds to 26,128 years of WTG operation, as of 2021.

[1] Robinson, C., Gupta, S., Morrison, A. (2013) *Den Brook Wind Farm Risk Assessment*. MMI. Report MMU311-R-01, Issue 02.
[2] Antcliff, A., Curtis, M., C.T. (2020) *Blade Throw Risk Assessment: Hills of Gold Wind Farm*. ERM.

Data was sourced from Wikipedia pages, AEMO reports and project websites.

3.2 Identifying Blade Failures

Blade failures are generally not well advertised; however, catastrophic failures are generally reported. Five catastrophic blade failures have been identified in Australia. These are described and classified in Table 1. It is noted that there is very little detail on the incidents, including Root Cause Analyses and failure modes. However, there is some broad data to suggest that manufacturing defects and lightning are two key causes of failure. There have been no injuries or fatalities associated with these events.

It is identified that two failures are described as "blade drop", while the remaining three events are classified as "fragmentation".

It is noted that most cases where blade defects are observed, catastrophic failure will not occur as these will be detected and rectified in the wind farm Operations and Maintenance program.

This results in a return period of less than one catastrophic failure event resulting in fragmentation in 8,700 years of operation, or 0.000115.

This results in a return period of less than one catastrophic failure event resulting in blade drop in 13,000 years of operation, or 0.0000765.

Table 1

Event	Date	Description	Classification	Source
Windy Hill WF (QLD)	July 2005	Blade "sheared off" from wind turbine.	General Failure: Unsure – Assume fragmentation.	Herald Sun, 29 July 2005.
Wonthaggi WF (VIC)	March 2012	Blade cracked. Fibreglass delaminated. Blade fill strewn around vicinity of WTG. Lightning suspected. Manufacturing defect.	General Failure: Fragmentation.	Wonthaggi Wind Farm - Wikipedia Various media reports.
Lal Lal WF (VIC)	September 2019	Blade broke and fell to the ground. Prior to incident, there was severe weather including lightning.	Lightning Failure: Blade drop.	Lal Lal Wind Farms Press Release: 23 September 2019
Bald Hills WF (VIC)	June 2020	No reliable details on cause.	General Failure: Assume fragmentation.	Turbine Trouble For Bald Hills Wind Farm - South Gippsland Sentinel-Times (sgst.com.au)

Dundonnell WF (VIC)	October 2020	A single blade separated from the hub of a turbine and fell to the ground. Soon after mechanical completion.	General Failure: Blade drop.	Tilt Press Release: 6 October 2020 Dundonnell wind farm stops production after blade falls off turbine | RenewEconomy (wpengine.com)

3.3 Likelihood of People within Impact Radius

Based on Antcliff & Curtis[3], a maximum throw for blade fragments is 500 m. Thus, 500 m radius around the WTGs is considered to be the impact radius for the fragmentation analysis; for blade drop, they noted a maximum impact radius of 150 m, which is used for the blade drop analysis.

It is noted that no dwellings are located within 1200 m of WTGs; there are sheds 225 m from the nearest WTG.

Fragmentation

Through the operation of the wind farm, it is estimated that the fragmentation impact radius would be occupied approximately 20% of the time, with vehicles passing, farming activities on the wind farm site and at adjacent farms, and wind farm maintenance work, as shown in Table 2.

Table 2: Fragmentation: 500 m radius.

Activity	**Estimate**	**Total**
Vehicles Passing	100 per day, driving at 60 km/h for 1 km through impact zone: 100 minutes/day.	608 h/yr
Farming work	8 hours per day for 2 working weeks of ploughing and seeding. 8 hours per day for 2 working weeks of harvesting. 8 hours per day for 2 working weeks of mustering and shearing for 4 people. 1 hour per day for remaining 46 working weeks.	710 h/yr
Wind farm maintenance work	8 hours per day for 2 working weeks for 4 people.	320 h/yr
TOTAL		**1638 h/yr** **18.7%**

Blade Drop

For simplicity, the occupancy of the region for "Farming work" is assumed to be proportioned by area to the assumptions made in Table 2, that is, Blade Drop Impact Area divided by Fragmentation Impact Area, which equals 0.09. The rate of cars passing is assumed to be the same, except that, as can be seen in Figure 1, the farthest a road passes through the 150 m buffer zone around a WTG is 150 m (north-eastern-most WTG), so the likelihood of a passing vehicle is reduced to 15% of that

[3] Antcliff, A., Curtis, M., C.T. (2020) *Blade Throw Risk Assessment: Hills of Gold Wind Farm*. ERM.

observed in the fragmentation scenario. Wind farm maintenance work is assumed to be constant. As shown in Table 3, this results in an occupancy of just over 5%.

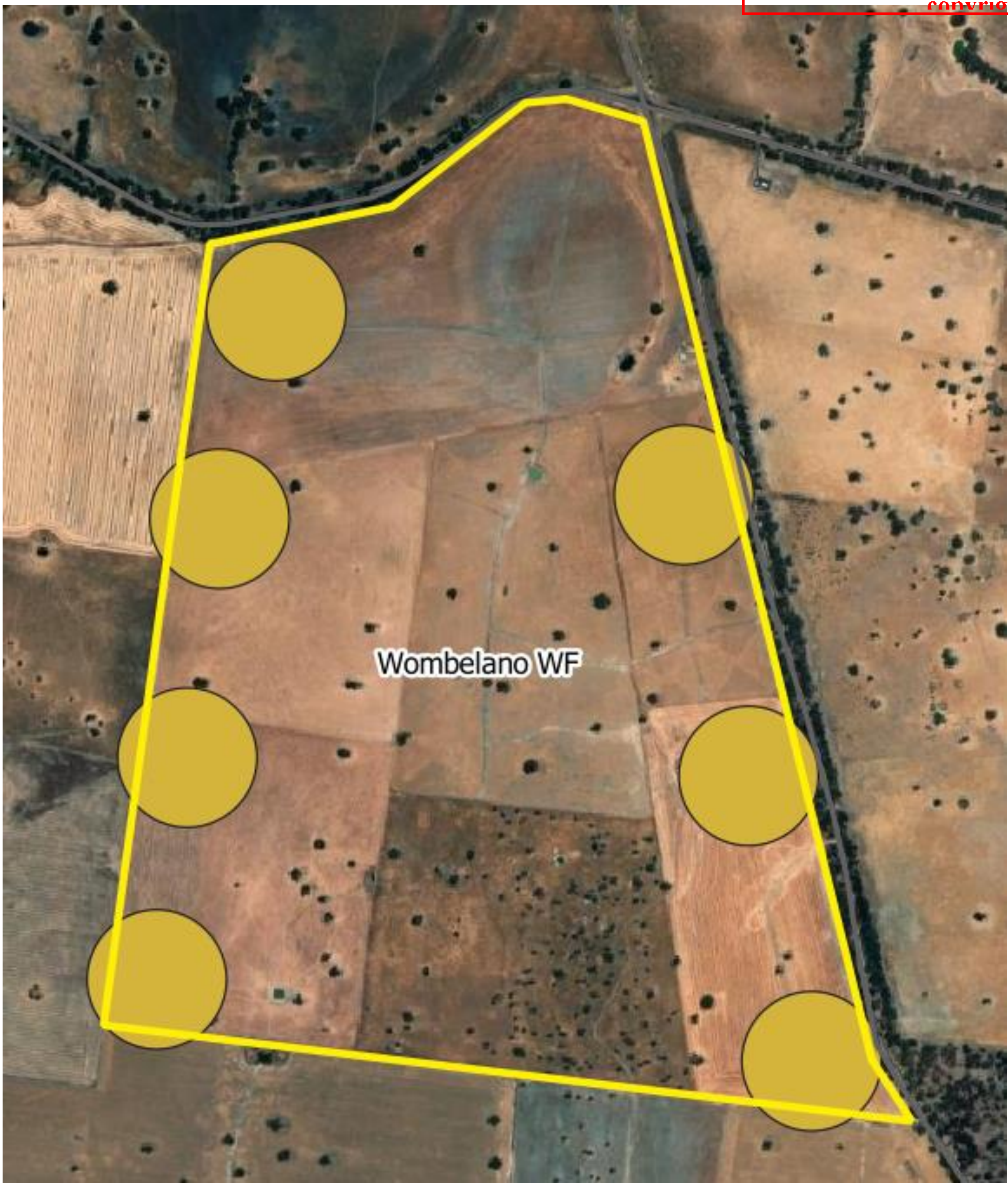

Figure 1: 150 m buffers around WTGs at WWF.

Table 3: Blade drop: 150 m radius.

Activity	**Estimate**	**Total**
Vehicles Passing	100 per day, driving at 60 km/h for 0.13 km through impact zone: 100 minutes/day.	91 h/yr
Farming work	Proportional to population density of 500 m radius: $(150^2/500^2)$*710 hours = 0.09 * 710 hours	63.9 h/yr

Wind farm maintenance work	8 hours per day for 2 working weeks for 4 people.	320 h/yr
TOTAL		**475.1 h/yr 5.42%**

3.4 Likelihood of Person Impacted by Blade Failure

Given a person is in the impact zone during a blade failure event, the likelihood of that person being struck is difficult to estimate. Some studies have used Monte Carlo simulations to derive a probability density function, with the likelihood of a blade landing in a specific location generally decreasing as that location is farther from the WTG[4]. The result of this simulation for a wind turbine with 158 m rotor is shown in Figure 2, which has very similar parameters to the proposed Vestas V162 proposed at WWF. Figure 2, using 12.5 m distance bins, shows that within 50 m of a WTG, the likelihood of impact is approximately 75% higher for the 50 m to 200 m range. Beyond 200 m there is a steady decline in likelihood of impact.

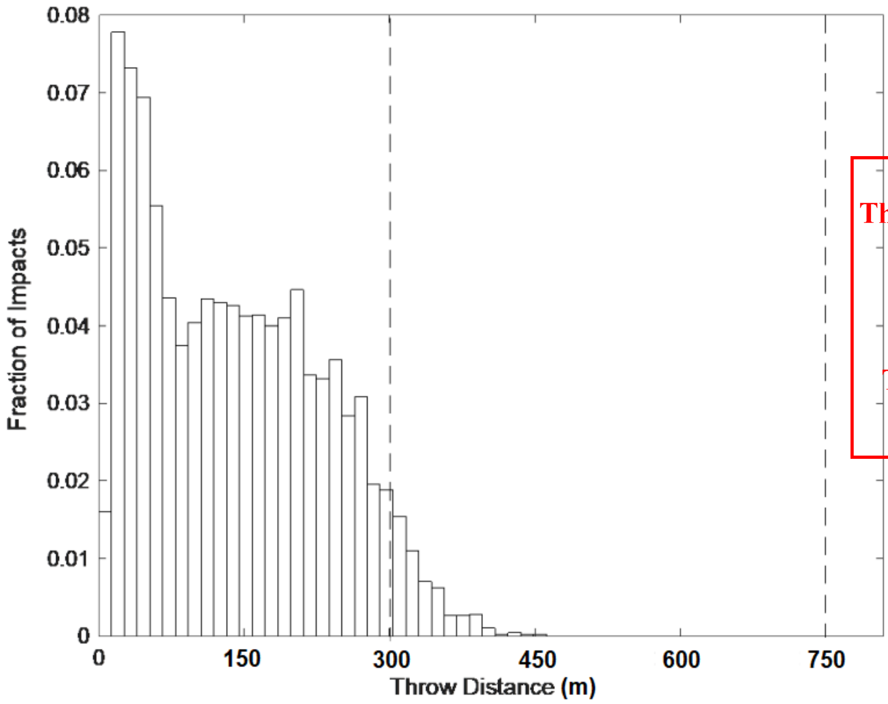

Figure 2: Histogram of blade fragment throw distance based on Monte Carlo simulations. Taken from Persimia (2020) with throw distances converted from feet to metres.

For simplicity and conservatism, it is assumed that the distance from the WTG is not a relevant parameter, provided that the distance is less than 500 m for fragmentation and 150 m for blade drop, that is, the person is within the respective impact zone. To further the conservatism, it is assumed that the throw distance, rather than being binned in 12.5 m steps, per Figure 2, is binned in 25 m steps, resulting in twenty distance sectors for fragmentation and six distance sectors for blade drop.

It is assumed that failure will occur in one of sixteen directional sectors of 22.5° and that it is equally likely that anyone within the impact zone will be within any one of those sectors.

[4] Rogers et al. (2011) *A method for defining wind turbine setback standards*; Persimia (2020) *Panther Grove Ice Shed and Blade Throw Risk Assessment.*

Combining the distance sectors and direction sectors results in 320 impact sectors for fragmentation and 96 impact sectors for blade drop.

Thus, the resulting likelihood of a person being impacted by fragmentation, I_F, is taken as:

$P(I_F)$ = *P(Fragmentation)* × *P(Person in impact zone)* × *P(Person in impact sector)*

= 0.000115 × 0.187 × (1/320)

= 6.71E-8 or 1 in 14.9million years

The resulting likelihood of a person being impacted by blade drop, I_{BD}, is taken as:

$P(I_{BD})$ = *P(Blade Drop)* × *P(Person in impact zone)* × *P(Person in impact sector)*

= 0.0000765 × 0.0542 × (1/96)

= 4.32E-8 or 1 in 23.1million years

The total impact risk *P(Impact)* is then the sum of the two scenarios:

P(Impact) = $P(I_F) + P(I_{BD})$

= 6.71E-8 + 4.32E-8

= 1.103E-8 or 1 in 9million years

It is noted that there is a detailed root cause analysis undertaken and detailed inspections of unimpacted blades after catastrophic blade failures. Because of this, if one blade fails, it is highly unlikely that further blades on the site will fail. Nonetheless, for conservatism, the likelihood is multiplied by the number of proposed WTGs, that is seven. This results in a likelihood of an event being 7.724E-7 or a return period of 1.295million years.

3.5 Assessment of Whether Likelihood is Acceptable by Community Standards

At a recurrence period of 1 in 1.295million years for a fatal event, based on the described conservative model, the likelihood can be described as “Broadly Acceptable” as the recurrence period is greater than one million years.

4. Conclusion

The risk to life of blade drop or blade fragment throw at a wind farm is extremely low, with the return period of a fatal event calculated in this study as being one event in 1.295million years of operation, which can be described as “Broadly Acceptable”.

Appendix 1: List of Wind Farms and Years of Operation

	No of WTGs	Year of Commencement	Years of Operation	WTG Years
Agnew	5	2020	1	5
Albany 2	6	2011	10	60
Albany WF	12	2001	20	240
Ararat Wind Farm	75	2017	4	300
Badgingarra	37	2019	2	74
Bald Hills Wind Farm	52	2015	6	312
Beros Rd	19	2019	2	38
Biala Wind Farm	31	2021	0	0
Blayney Wind Farm	15	2000	21	315
Boco Rock Wind Farm	67	2015	6	402
Bodangora Wind Farm	33	2019	2	66
Bulgana	56	2019	2	112
Canunda Wind Farm	23	2005	16	368
Capital Wind Farm	67	2009	12	804
Cathedral Rocks Wind Farm	33	2007	14	462
Cattle Hill Wind Farm	48	2019	2	96
Challicum Hills Wind Farm	35	2003	18	630
Clements Gap Wind Farm	27	2010	11	297
Collgar Wind Farm	111	2011	10	1110
Coober Pedy	2	2017	4	8
Coonooer Bridge	6	2016	5	30
Coopers Gap Wind Farm	123	2020	1	123
Crookwell 1	8	1998	23	184
Crookwell 2	46	2018	3	138
Crowlands Wind Farm	39	2018	3	117
Cullerin Range	15	2009	12	180
Diapur	2	2020	1	2
Emu Downs Wind Farm	48	2006	15	720
Ferguson	3	2021	0	0
Flinders Island	1	2017	4	4
Granville Harbour Wind Farm	31	2018	3	93
Gullen Range Wind Farm	73	2013	8	584
Gunning WF	31	2011	10	310
Hallett 1	45	2008	13	585
Hallett 2	34	2010	11	374
Hallett 4	63	2011	10	630
Hallett 5	25	2012	9	225
Hampton Wind Park	2	2001	20	40
Hepburn	2	2012	9	18
Hornsdale 1	32	2017	4	128
Hornsdale 2	32	2017	4	128
Hornsdale 3	35	2018	3	105
Huxley Hill 1	3	1998	23	69

Huxley Hill 2	2	2003	18	36
Karakin	10	2013	8	80
Kiata	9	2018	3	27
Lake Bonney 1	46	2005	16	736
Lake Bonney 2	53	2008	13	689
Lake Bonney 3	13	2010	11	143
Lal Lal Wind Farm	60	2019	2	120
Lincoln Gap Wind Farm	59	2018	3	177
Macarthur Wind Farm	140	2013	8	1120
Maroona	2	2018	3	6
Moorabool Wind Farm (North & South)	104	2020	1	104
Mortons Lane Wind Farm	13	2013	8	104
Mount Barker	3	2011	10	30
Mount Emerald Wind Farm	53	2018	3	159
Mount Gellibrand Wind Farm	44	2018	3	132
Mount Mercer Wind Farm	64	2014	7	448
Mount Millar Wind Farm	35	2006	15	525
Mumbida Wind Farm	22	2013	8	176
Murra Warra II Wind Farm	38	2021	0	0
Murra Warra Wind Farm	61	2019	2	122
Musselroe Wind Farm	56	2013	8	448
Nine Mile Beach	1	2003	18	18
Oaklands Hill Wind Farm	32	2012	9	288
Port Gregory	5	2019	2	10
Portland 1	20	2007	14	280
Portland 2	29	2008	13	377
Portland 3	22	2009	12	264
Portland 4	23	2015	6	138
Rottnest	1	2004	17	17
Salt Creek WF	15	2018	3	45
Sapphire Wind Farm	75	2018	3	225
Sassafras	1	2008	13	13
Silverton Wind Farm	58	2019	2	116
Snowtown 1	47	2009	12	564
Snowtown 2	90	2014	7	630
Starfish Hill Wind Farm	22	2003	18	396
Stockyard Hill Wind Farm	149	2020	1	149
Sumich West Hills	10	2013	8	80
Taralga Wind Farm	51	2015	6	306
Ten Mile Lagoon	9	1993	28	252
Thursday Island	2	1997	24	48
Timboon West	2	2018	3	6
Toora	12	2002	19	228
Walkaway Wind Farm	54	2006	15	810
Warradarge	51	2020	1	51
Waterloo 2	6	2017	4	24

Waterloo Wind Farm	37	2011	10	370
Wattle Point Wind Farm	55	2005	16	880
Waubra Wind Farm	128	2009	12	1536
White Rock Wind Farm (Stage I)	70	2017	4	280
Willogoleche Wind Farm	32	2019	2	64
Windy Hill	20	2000	21	420
Wonthaggi WF	6	2005	16	96
Woodlawn Wind Farm	23	2012	9	207
Woolnorth Studland Bay	25	2007	14	350
Woolnorth Wind Farm	37	2004	17	629
Yaloak South	14	2018	3	42
Yandin WF	51	2020	1	51
TOTAL	**3625**			**26,128**