Appendix 9

Shadow Flicker Assessment

THUNDERBOLT ENERGY HUB – STAGE 1

Shadow Flicker Assessment

Umwelt (Australia) Pty Limited

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EXECUTIVE SUMMARY

DNV has been commissioned by Umwelt (Australia) Pty Limited on behalf of Neoen Australia Pty Ltd (Neoen, or the "Proponent") to independently assess the expected annual shadow flicker durations associated with the development and operation of the proposed Thunderbolt Energy Hub – Stage 1 ("the Project") located in the Kentucky Area of NSW, approximately 47 km north east of Tamworth and adjacent to the New England Highway. The results of the assessment are described in this document.

Background and methodology

DNV has assessed the expected annual shadow flicker durations for the Project in accordance with the Secretary's Environmental Assessment Requirements [1] (SEARs), the NSW Wind Energy Visual Assessment Bulletin [2] (NSW Visual Assessment Bulletin), and the Draft National Wind Farm Development Guidelines [3] (Draft National Guidelines). The methodology used in this assessment has been informed by these guidelines as well as various standard industry practices, including those adopted in the UK.

The NSW Visual Assessment Bulletin recommends a shadow flicker limit of 30 hours per year at dwellings in the vicinity of a wind farm. In addition, the Draft National Guidelines recommend limits of 30 hours per year on the theoretical shadow flicker duration, and 10 hours per year on the actual shadow flicker duration.

The assessment was carried out for a conceptual layout consisting of 32 wind turbine generators (WTGs) with a maximum rotor diameter of 190 m and a hub height of 165 m, resulting in a tip height of 260 m above ground level (AGL). These dimensions represent the maximum overall tip height and maximum rotor diameter for WTGs considered for the Project. The shadow flicker durations based on these WTG parameters are expected to represent the upper bound for the WTG options currently being considered for the Project. Shadow flicker durations for WTGs with a smaller rotor diameter should typically be lower than those presented here, even if the hub height is marginally higher.

There are 58 dwellings that have been identified within 5 km of the Project, of which 6 are host landholder dwellings, 11 are associated dwellings and 41 are non-associated dwellings. Dwellings within 2900 m of the Project WTGs have been considered for this assessment.

The theoretical shadow flicker durations at dwellings in the vicinity of the Project Area have been determined using a purely geometric analysis. The actual shadow flicker duration likely to be experienced at each dwelling has also been predicted by estimating the possible reduction in shadow flicker due to WTG orientation and cloud cover.

It is recommended that compliance with shadow flicker limits is assessed on the basis of shadow flicker of at least a moderate level of intensity, which is expected to occur up to a distance of around 10 rotor diameters (10D) from a WTG. Shadow flicker below a moderate level of intensity (labelled as "low intensity shadow flicker") may be visible, but is unlikely to cause annoyance and is not typically considered when evaluating compliance with shadow flicker limits.

Outcomes of the assessment

The results of the shadow flicker assessment are summarised in Table 5.

Based on DNV's modelling, no non-associated dwellings are predicted to experience shadow flicker of at least a moderate level of intensity.

For completeness, the shadow flicker assessment has also been performed for host landholder and associated dwellings. Two associated dwellings and two host landholder dwellings are predicted to experience shadow flicker of at least a moderate level of intensity.

The two associated dwellings (H270 and H310) are predicted to experience theoretical shadow flicker durations below the recommended limit of 30 hours per year within 50 m of the dwelling (both 16 hours per year). When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker durations at these dwellings are also predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling (both 6 hours per year). In addition, it is noted that one of these dwellings (H310) has been identified as a vacant dwelling.

The two host landholder dwellings (H017 and H302) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling (33 and 311 hours per year respectively). When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker durations at these dwellings are also predicted to be above the recommended limit of 10 hours per year within 50 m of the dwelling (13 and 117 hours per year respectively). DNV notes that, based on information provided by the Proponent, it is understood that dwelling H302 is vacant. In addition, it is understood that the Proponent has a negotiated agreement in place with the affected host landholders to address impacts associated with the Project.

There may be further reductions in the estimated shadow flicker at some dwellings (for example H017 and H270), due to areas of dense vegetation surrounding the dwelling. However the screening effects of vegetation can require extensive effort to model and have not been included in this assessment.

Based on the results of the shadow flicker assessment and host landholder agreements, the Project is predicted to meet the applicable shadow flicker limits and it is not expected that specific mitigation measures will be required to meet shadow flicker limits.

Blade glint is not expected to be an issue for the Project as it is understood that the Proponent will apply a non-reflective finish to the WTG blades.

1 INTRODUCTION

Umwelt (Australia) Pty Limited on behalf of Neoen Australia Pty Ltd (Neoen, or the "Proponent") has commissioned DNV to independently assess the expected annual shadow flicker durations associated with the proposed Thunderbolt Energy Hub – Stage 1 ("the Project") located in the Kentucky Area of NSW, approximately 47 km north east of Tamworth and adjacent to the New England Highway. The results of this work are reported here.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed wind turbine generators (WTGs) based on the conceptual layout in accordance with the Secretary's Environmental Assessment Requirements [1] (SEARs), the NSW Wind Energy Visual Assessment Bulletin [2] (NSW Visual Assessment Bulletin), and the Draft National Wind Farm Development Guidelines [3] (Draft National Guidelines). The methodology used in this study has been informed by these guidelines as well as various standard industry practices, including those adopted in the UK [4].

2 DESCRIPTION OF THE PROJECT AREA AND PROJECT

2.1 The Project Area

The proposed Project Area is located in the Kentucky Area of NSW, approximately 47 km north east of Tamworth and adjacent to the New England Highway. An overview of the Project Area is presented in Figure 2.

This assessment relates to the Thunderbolt Energy Hub – Stage 1 only (the Project). The Stage 1 Project Area covers approximately 5,918 hectares (ha) and is located to the north of the New England Highway.

The site is characterised by complex terrain with a mixture of open areas and areas of vegetation and trees of varying density.

High-resolution digital elevation data was supplied for the Project by the Proponent [5], which was included in the site model. Areas outside of this map region were covered using publicly available SRTM1 data.

2.2 The Project

2.2.1 Proposed conceptual layout

The conceptual layout includes up to 32 WTGs [6], resulting in a wind farm capacity of up to approximately 192 megawatts (MW) (depending on the selected WTG rated capacity). The WTGs will have a maximum rotor diameter of 190 m and maximum tip height of 260 m above ground level (AGL), based on data supplied by the Proponent. The maximum blade chord length for the proposed WTGs, defined as the dimension through the thickest part of the blade, has been assumed to be up to 5.0 m.

The shadow flicker assessment has considered WTGs with a rotor diameter of 190 m and a hub height of 165 m, which represent the maximum overall tip height and maximum rotor diameter for WTGs considered for the Project. These WTG parameters are expected to represent the upper bound of the shadow flicker durations for the WTG options currently being considered for the Project. Shadow flicker durations for WTGs with a smaller rotor diameter should typically be lower than those presented here, even if the hub height is marginally higher.

Each WTG will have a generating capacity of approximately 5 to 8 MW and each WTG site will consist of a foundation and tower, nacelle, rotor hub and blades. To achieve visual consistency through the landscape, the WTGs will feature uniform colour, design, height and rotor diameter, a matt-white finish and non-reflective material to reduce visibility, and no unnecessary signage or lighting.

WTG base elevations for this layout range from approximately 930 to 1100 m above sea level (ASL). An elevation map of the site with the proposed WTG layout is shown in Figure 3, and the coordinates of the proposed WTG locations are presented in Table 1.

Table 1 Proposed WTG layout for the Project [6]

WTG ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	WTG ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
T01	335661	6594107	934	T17	336574	6597065	1001
T02	341225	6597378	1080	T18	336850	6595039	1040
T03	340719	6596988	1101	T19	337401	6595420	1057
T04	340162	6596552	1080	T20	335739	6595504	978
T05	339556	6596100	1040	T21	335940	6594542	954
T06	338931	6595599	1032	T22	337676	6598098	1009
T07	338473	6595240	1016	T23	336942	6599833	1070
T08	338834	6594805	1005	T24	335883	6599958	1090
T09	338365	6594397	988	T25	335768	6600449	1056
T10	337854	6593964	972	T26	333549	6597099	967
T11	337532	6593412	994	T27	333137	6597539	948
T12	340014	6597494	1070	T28	333131	6598418	1001
T13	339635	6597942	1065	T29	338740	6597656	1040
T14	337718	6595842	1022	T30	339527	6597038	1056
T15	337867	6597269	992	T31	338989	6596546	1017
T16	336629	6596361	979	T32	335555	6596610	948

1. Coordinate system: MGA zone 56, GDA94 datum.

DNV understands that the Project Area is located in a region of high wind farm development activity with several other proposed wind farms nearby, including the adjacent Thunderbolt Energy Hub – Stage 2 development and proposed Tara Springs Wind Farm. Limited detail is available about the proposed Tara Springs Wind Farm as it has not yet entered into the formal NSW approval process (no Scoping Report has been submitted). However, it is likely that the proposed WTGs of the neighbouring Tara Springs Wind Farm, should it proceed, will be too distant from the dwellings potentially affected by shadow flicker from the Project WTGs to lead to cumulative shadow flicker impacts. Additionally, the extent of the Thunderbolt Energy Hub – Stage 2 is also subject to confirmation; the detailed shadow flicker assessment to be undertaken for Stage 2 will require consideration of the associated cumulative impacts. The assessment reported here therefore only includes impacts from the Thunderbolt Energy Hub – Stage 1 WTGs.

2.2.2 Dwelling locations

The locations of dwellings, or 'shadow receptors', in the vicinity of the Project have been provided by the Proponent [7]. There are 58 dwellings that have been identified within 5 km of the Project, of which 6 are host landholder dwellings, 11 are associated dwellings and 41 are non-associated dwellings.

For the purposes of this assessment, DNV has considered all identified dwellings up to 2900 m from the proposed WTGs (which corresponds to 15 times the rotor diameter, or 15D, plus 50 m). There are 23 dwellings within 2900 m of the proposed WTGs. Dwellings situated more than 2900 m from WTG locations are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1. DNV has assumed that all dwellings are inhabited, except where indicated otherwise by the Proponent.

DNV has not carried out a detailed and comprehensive survey of building locations in the area and is relying on information provided by the Proponent.

The coordinates of the dwellings included in the assessment are presented in Table 2, and also presented in Figure 3.

Table 2 Dwellings within 2900 m of proposed WTGs at the Project site [7]

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Landholder status	Nearest WTG	
				Distance (km)	WTG ID
H004	*343635*	*6596914*	*Host Landholder*	*2.5*	*T02*
H017	*334195*	*6599732*	*Host Landholder*	*1.7*	*T28*
H018	339149	6600709	Non-associated	2.4	T23
H027	341318	6593565	Non-associated	2.8	T08
H028	341090	6593361	Non-associated	2.7	T08
H029	339724	6592770	Non-associated	2.1	T09
H055	332742	6600385	Non-associated	2.0	T28
H219	341469	6599624	Non-associated	2.3	T02
H220	341858	6600032	Non-associated	2.7	T02
H221	338474	6602191	Non-associated	2.8	T23
H222	342872	6599122	Non-associated	2.4	T02
H226	335911	6602846	Non-associated	2.4	T25
H270	*334904*	*6598857*	*Associated*	*1.5*	*T24*
H275	*332282*	*6594903*	*Associated*	*2.5*	*T26*
H277	*332736*	*6595809*	*Associated*	*1.5*	*T26*
H279	*332359*	*6594847*	*Associated*	*2.5*	*T26*
H298	*343989*	*6596780*	*Host Landholder*	*2.8*	*T02*
H300[3]	*340929*	*6594484*	*Host Landholder*	*2.1*	*T08*
H302[3]	*338378*	*6595428*	*Host Landholder*	*0.2*	*T07*
H306	*332872*	*6594144*	*Associated*	*2.8*	*T01*
H308	339242	6599999	Non-associated	2.1	T13
H309	339123	6600480	Non-associated	2.3	T23
H310[3]	*333797*	*6595810*	*Associated*	*1.3*	*T26*

1. Coordinate system: MGA zone 56, GDA94 datum.
2. Host landholder dwellings and associated landholder dwellings are indicated by *underlined italic text*.
3. Vacant dwelling.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

In relation to shadow flicker, the SEARs for the Project [1] reference the NSW Visual Assessment Bulletin [2], which states:

> *"…The shadow flicker caused by certain sun angles in relation to the rotation of wind turbine blades on dwellings will be limited to 30 hours per year, and may require mitigation measures such as amended siting and design of turbines to minimise the amount of shadow flicker."*

Although the NSW Visual Assessment Bulletin describes the requirements for assessing and minimising shadow flicker, it does not provide detailed methodologies for these assessments. The Environment Protection and Heritage Council (EPHC), in conjunction with Local Governments and the Planning Ministers' Council, released a draft version of the National Wind Farm Development Guidelines in July 2010 (Draft National Guidelines) [3]. The Draft National Guidelines cover a range of issues across the different stages of wind farm development and provide background information, a proposed methodology, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

In relation to shadow flicker, the Draft National Guidelines recommend that the modelled theoretical shadow flicker duration should not exceed 30 hours per year at any dwelling. The guidelines also recommend that the shadow flicker duration at a dwelling be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of the dwelling.

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the NSW Visual Assessment Bulletin or the Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The impact of shadow flicker is typically only significant up to a limited distance from the WTG. Beyond this distance limit the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This issue is discussed in the Draft National Guidelines, where it is stated that:

> *"Shadow flicker can theoretically extend many kilometres from a wind turbine. However the intensity of the shadows decreases with distance. While acknowledging that different individuals have different levels of sensitivity and may be annoyed by different levels of shadow intensity, these guidelines limit assessment to moderate levels of intensity (i.e., well above the minimum theoretically detectable threshold) commensurate with the nature of the impact and the environment in which it is experienced."*

The Draft National Guidelines suggest a distance limit equal to 265 times the maximum blade chord length, which would correspond to approximately 1000 to 1600 m for modern WTGs (which typically have maximum blade chord lengths of 4 to 6 m).

3.2 Blade glint

In relation to blade glint, the NSW Visual Assessment Bulletin states:

> *"The direct reflection of the sun from the wind turbine structure (glint) is to be minimised through appropriate turbine treatments (such as the use of low sheen and matte finishes)."*

The Draft National Guidelines provide further guidance on blade glint and state that:

> *"The sun's light may be reflected from the surface of wind turbine blades. Blade Glint has the potential to annoy people. All major wind turbine manufacturers currently finish their blades with a low reflectivity treatment. This prevents a potentially annoying reflective glint from the surface of the blades and the possibility of a strobing reflection when the turbine blades are spinning. Therefore the risk of blade glint from a new development is considered to be very low."*

4 ASSESSMENT METHODOLOGY

4.1 Shadow flicker

4.1.1 Overview

Shadow flicker may occur under certain combinations of geographical position and time of day when the sun passes behind the rotating blades of a WTG and casts a moving shadow over neighbouring areas. When viewed from a stationary position the moving shadows cause periodic flickering of the light from the sun, giving rise to the phenomenon of 'shadow flicker'.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of factors, including:

- the direction of the dwelling relative to the WTG
- the distance of the dwelling from the WTG (the further the observer is from the WTG, the less pronounced the effect will be)
- the orientation of the dwelling and windows, etc. relative to the WTG
- the WTG height and rotor diameter
- the time of year and day (the position of the sun in the sky)
- the weather conditions (cloud cover reduces the occurrence of shadow flicker)
- the wind direction (the shape of the shadow will be determined by the position of the sun relative to the blades which will be oriented to face the wind)
- screening effects of vegetation, buildings or other surface obstacles.

Example photographs of WTGs and associated shadows which have the potential to cause flicker are shown in Figure 1 below.

Figure 1 Examples of WTG shadows

4.1.2 Theoretical modelled duration

The theoretical number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun path, topographic variation over the site area, and WTG details such as rotor diameter and hub height.

The proposed WTGs have been modelled assuming they are spherical objects, which is equivalent to assuming the WTGs are always oriented perpendicular to the sun-WTG vector. This assumption will mean the model calculates the maximum duration for which there is potential for shadow flicker to occur, up to a specified distance limit.

In line with the methodology proposed in the Draft National Guidelines, DNV has assessed the shadow flicker at the provided dwelling locations and has determined the highest shadow flicker duration within 50 m of each of the provided dwelling locations.

Shadow flicker has been calculated at dwellings at heights of 2 m, to represent ground floor windows, and 6 m, to represent second floor windows. The shadow receptors are simulated as fixed points, representing the worst-case scenario, as real windows could be facing a particular direction less affected by shadows cast from the WTGs. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute. The shadow flicker map was generated using a temporal resolution of 5 minutes and a spatial resolution of 10 m to reduce computational requirements to acceptable levels.

As part of the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of a shadow cast by a WTG that is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [4], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit.

For the current assessment, DNV has assumed that the shadow length likely to cause annoyance is 10 times the rotor diameter (10D), which corresponds to a distance limit of 1900 m. This distance is generally larger than that proposed by the Draft National Guidelines, where 265 times the maximum blade chord is recommended. The blade chord length assumed for the Project of 5.0 m corresponds to a distance of 1325 m under the Draft National Guidelines. In comparison, the assumed shadow distance of 10D corresponds to a maximum blade chord length of 7.2 m under the Draft National Guidelines.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and therefore it is possible that some people may be affected by shadow flicker intensities below a "moderate level of intensity" assumed beyond this distance limit.

In this report shadow flicker below a moderate level of intensity is referred to as "low intensity" shadow flicker, and is expected to occur beyond a distance of 10D and up to a distance of approximately 15D (corresponding to 2850 m) from the proposed WTGs. Areas and houses that may experience low intensity shadow flicker have been identified. However it is recommended that compliance with shadow flicker limits is assessed on the basis shadow flicker of at least a moderate level of intensity only. Low intensity shadow flicker may be visible, but is unlikely to cause annoyance and is not typically considered when evaluating compliance with shadow flicker limits.

The theoretical shadow flicker model also makes the following assumptions and simplifications:

1. there are clear skies every day of the year
2. the blades of the WTGs are always perpendicular to the direction of the line of sight from the location of interest to the sun (i.e. there are no adjustments to account for the likely wind directions during the year)
3. the WTGs are always rotating
4. there are no screening effects due to vegetation, buildings or other surface obstacles.

Further consideration of the impact of these assumptions is presented below:

- Potential reductions in predicted shadow flicker durations due to the first two of these items are considered in the calculation of the predicted actual shadow flicker duration as described in Section 4.1.4.

- Potential reductions in predicted shadow flicker durations when WTGs are not rotating are not considered in the analysis but are unlikely to have a significant impact on the results, as for most wind farms the amount of time that WTGs are stopped (due to winds above or below the WTG operating range, or WTG downtime) is likely to be small relative to the total operating period of the WTGs over the year; however assuming that the WTGs are always operating may introduce some conservatism.

- Consideration of screening effects can (but does not always) lead to further reductions in the estimated shadow flicker due to vegetation, buildings or other surface obstacles obscuring in the line of sight between WTGs and the dwelling. However this item is not considered in the assessment as such screening can require extensive effort to model.

The settings used to execute the model can be seen in Table 3.

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1900 m
Year of calculation	2033
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (disc for WTG orientation reduction calculation)
Sun modelled as	Disc
Offset between rotor and tower	None
Receptor height (single storey)	2 m
Receptor height (double storey)	6 m
Locations used for determining maximum shadow flicker within 50 m of each dwelling	8 points evenly spaced (every 45°) on 25 m and 50 m radius circles centred on the provided dwelling location

To illustrate typical results, an indicative shadow flicker map for a WTG located in a flat area is shown in Figure 4. The geometry of the shadow flicker map can be characterised as a butterfly shape, with the four protruding lobes corresponding to slowing of solar north-south travel around the summer and winter solstices for morning and evening. The lobes to the north of the indicative WTG location result from the summer months and conversely the lobes to the south result from the winter months. The lobes to the west result from morning sun while the lobes to the east result from evening sun. When the sun is low in the sky, the length of shadows cast by the WTG increases, increasing the area around the WTG affected by shadow flicker.

4.1.3 Factors affecting duration

Shadow flicker duration calculated in this manner overestimates the annual number of hours of shadow flicker experienced at a specified location for several reasons, including:

1. The WTG will not always be oriented such that its rotor is in the worst-case position (i.e., perpendicular to the sun-WTG vector). Any other rotor orientation will reduce the area of the projected shadow and hence the shadow flicker duration.

   The wind speed frequency distribution or wind rose at the site can be used to determine probable WTG orientation and to calculate the resulting reduction in shadow flicker duration.

2. The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover and to provide an indication of the resulting reduction in shadow flicker duration.

3. Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a WTG.

   The length of the shadow cast by a WTG is dependent on the degree that direct sunlight is diffused, which is in turn dependent on the amount of dispersants (humidity, smoke, and other aerosols) in the path between the light source (sun) and the receiver.

4. The modelling of the WTG rotor as a sphere rather than individual blades results in an overestimate of shadow flicker duration.

   WTG blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the WTG blade, and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade.

5. The analysis does not consider that when the sun is positioned directly behind the WTG hub, there is no variation in light intensity at the receiver location and therefore no shadow flicker.

6. The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the WTG, and therefore reduce the incidence of shadow flicker.

7. Periods where the WTG is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the annual shadow flicker duration.

4.1.4 Predicted actual duration

As discussed above in Section 4.1.3, there are a number of factors which may reduce the incidence of shadow flicker that are not taken into account in the calculation of the theoretical shadow flicker duration. An attempt has been made to quantify the likely reduction in shadow flicker duration due to cloud cover and, therefore, produce a prediction of the actual shadow flicker duration likely to be experienced at a receptor.

Cloud cover is typically measured in 'oktas', effectively eighths of the sky covered with cloud. DNV has obtained data from the following Bureau of Meteorology (BoM) stations, presented in Table 4.

Table 4 Sources of cloud data used in the assessment

Weather station	Station ID	Distance to site [approx. km]
Woolbrook (Woolbrook Road) [8]	055136	24.6
Armidale (Tree Group Nursery) [9]	056037	43.2
Armidale (Radio Station 2AD) [10]	056002	43.5
Guyra Hospital [11]	056229	69.4
Barraba (Clifton Lane) [12]	054003	77.1

The number of oktas of cloud cover visible across the sky at these stations is recorded twice daily, at 9 am and 3 pm, and the observations are provided as monthly averages. After averaging the 9 am and 3 pm observations for the stations considered, the results indicate that the average monthly cloud cover in the region ranges between 42% and 55%, and the average annual cloud cover is approximately 53%. This implies that on an average day, 53% of the sky in the vicinity of the Project Area is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is considered to be a reasonable assumption.

Similarly, WTG orientation can have an impact on the shadow flicker duration. The shadow flicker duration is greatest when the WTG rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. Wind direction frequency distributions for the Project Area, derived from wind measurements taken within the Project Area, were provided by the Proponent [13] and used to estimate the reduction in shadow flicker duration due to rotor orientation. The measured wind rose is shown overlaid on the indicative shadow flicker map in Figure 4. An assessment of the likely reduction in shadow flicker duration due to variation in WTG orientation was conducted on an annual basis.

It should be noted that the method prescribed by the Draft National Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover, and not WTG orientation, be included. However, DNV considers that the additional reduction due to WTG orientation is appropriate as the projected area of the WTG, and therefore the expected shadow flicker duration, is reduced when the WTG rotor is not perpendicular to the line joining the sun and dwelling. Due to limitations in the availability of suitable cloud cover data, the methodology used in this assessment also deviates somewhat from the method recommended by the Draft National Guidelines for assessing the reduction in shadow flicker due to cloud cover. However, considering the available cloud cover data, the approach described above is deemed to provide a reasonable estimate of the likely impact of cloud cover on the shadow flicker duration, and this method is regularly applied by DNV in shadow flicker assessments.

While the calculation of the predicted actual shadow flicker duration considers the likely reductions due to cloud cover and rotor orientation, it does not take into account other potential reductions due to low wind speed (or WTG shutdown), vegetation, or other shielding effects around each dwelling, for the reasons explained in Section 4.1.2.

4.2 Blade glint

Blade glint involves the regular reflection of sun off rotating WTG blades. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, angle of the blade and the angle of the sun. The reflectiveness of the surface of the blades is also important. Blade glint is not generally a problem for modern WTGs, provided the blades are coated with a non-reflective paint. Blade glint is not expected to be an issue for the Project as it is understood that the Proponent will apply a non-reflective finish to the WTG blades, and as a result it is not considered further here.

5 ASSESSMENT RESULTS

5.1 Shadow flicker

Shadow flicker predictions were generated at the dwelling locations, as outlined in Table 2.

The theoretical and predicted actual shadow flicker durations at all dwelling locations identified to be affected by shadow flicker are presented in Table 5. The maximum shadow flicker durations within 50 m of the dwellings are also presented in Table 5. Furthermore, the results are shown in the form of shadow flicker maps in Figure 5 and Figure 6. The shadow flicker values presented in these maps represent the worst case between the results at 2 m and 6 m above ground for each modelled grid point.

Based on DNV's modelling, no non-associated dwellings are predicted to experience shadow flicker of at least a moderate level of intensity.

For completeness, the shadow flicker assessment has also been applied to host landholder and associated dwellings.

Two associated dwellings (H270 and H310) are expected to experience some shadow flicker of at least a moderate level of intensity. These dwellings are predicted to experience theoretical shadow flicker durations below the recommended limit of 30 hours per year within 50 m of the dwelling (both 16 hours per year). When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker durations at these dwellings are also predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling (both 6 hours per year). In addition, one of these associated dwellings (H310) has been identified as a vacant dwelling.

Two host dwellings (H017 and H302) are expected to experience some theoretical shadow flicker of at least a moderate level of intensity. These dwellings are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling (33 and 311 hours per year respectively). When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker durations at these dwellings are also predicted to be above the recommended limit of 10 hours per year within 50 m of the dwelling (13 and 117 hours per year respectively). DNV notes that the theoretical shadow flicker duration is substantial at H302, however, based on information provided by the Proponent, it is understood that this house is vacant. In addition, DNV understands that the Proponent has a negotiated agreement in place with these identified landholders to address impacts associated with the Project.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be of a low intensity. As described in Section 4.1.2, it is recommended that compliance with shadow flicker limits be assessed on the basis of the predicted shadow flicker of at least a moderate level of intensity only. However, for informative purposes, DNV has also identified areas and dwellings where low intensity shadow flicker only may be experienced in Figure 5 and Table 5. These results indicate that an additional 10 dwellings have the potential to be exposed to low intensity shadow flicker only, which may be visible but is unlikely to cause annoyance, and therefore has not been considered further.

There may be further reductions in the estimated shadow flicker at some dwellings (for example H017 and H270), due to areas of dense vegetation surrounding the dwelling. However the screening effects of vegetation can require extensive effort to model and have not been included in this assessment.

The WTG parameters used in the assessment should typically lead to conservative shadow flicker durations for the WTG options currently being considered for the Project, which include WTGs up to a maximum rotor diameter of 190 m and maximum tip height of 260 m.

Table 5 Theoretical and predicted actual annual shadow flicker duration (Thunderbolt – Stage 1 WTGs)

Dwelling ID[1]	Easting[2] [m]	Northing[2] [m]	Landholder status	Contributing WTGs	Theoretical annual At dwelling [hr/yr]		Theoretical annual Max within 50 m [hr/yr]		Predicted actual annual[3] At dwelling [hr/yr]		Predicted actual annual[3] Max within 50 m [hr/yr]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
H004 [4]	343635	6596914	Host Landholder	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H017	334195	6599732	Host Landholder	T24 T25	**30.8**	**31.0**	**33.4**	**33.5**	**12.4**	**12.5**	**13.2**	**13.2**
H018 [4]	339149	6600709	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H027 [4]	341318	6593565	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H028 [4]	341090	6593361	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H029 [4]	339724	6592770	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H270	334904	6598857	Associated	T28	14.2	14.1	15.5	15.3	5.2	5.2	5.7	5.6
H298 [4]	343989	6596780	Host Landholder	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H300 [4, 5]	340929	6594484	Host Landholder	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H302 [5]	338378	6595428	Host Landholder	T05 T06 T14 T18 T19	**300.0**	**300.8**	**310.3**	**311.3**	**111.8**	**112.4**	**116.1**	**116.8**
H306 [4]	332872	6594144	Associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H308 [4]	339242	6599999	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H309 [4]	339123	6600480	Non-associated	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H310 [5]	333797	6595810	Associated	T32	0.0	0.0	15.7	15.7	0.0	0.0	6.0	6.1
Recommended duration limits (hr/yr)					**30**	**30**	**30**	**30**	**10**	**10**	**10**	**10**

1. Dwellings that are not predicted to experience shadow flicker have been omitted from this table.
2. Coordinate system: MGA zone 56, GDA94 datum.
3. Considering likely reductions in shadow flicker duration due to cloud cover and WTG orientation.
4. Dwelling may experience some low intensity shadow flicker.
5. Vacant dwelling.

5.1.1 Mitigation

If required, the effects of shadow flicker can be reduced through a number of mitigation measures such as:

- the removal or relocation of WTGs
- the use of smaller (rotor) WTGs
- installation of screening structures or planting of trees to block shadows cast by the WTGs
- the use of WTG control strategies to shut down WTGs when shadow flicker is likely to occur
- suitable agreements with the landholders of dwellings where shadow flicker is predicted to occur above the applicable limits, which include an agreed acceptable shadow flicker duration.

It is understood that the Proponent has a negotiated agreement in place with the identified host landholders and associated dwellings where exceedances of limits are indicated in the shadow flicker modelling.

Based on the results of the shadow flicker assessment and host landholder agreements, it is not expected that specific mitigation measures will be required to meet shadow flicker limits.

5.2 Blade glint

As discussed in Section 4.2, blade glint is not expected to be an issue for the Project as it is understood that the Proponent will apply a non-reflective finish to the WTG blades.

6 CONCLUSIONS

DNV has performed a shadow flicker assessment for the Project. For the purposes of this assessment, DNV has considered all identified dwellings up to 2900 m from the proposed WTGs (which corresponds to 15 times the rotor diameter, or 15D, plus 50 m). DNV has also considered a layout consisting of 32 WTGs with a maximum rotor diameter of 190 m and a hub height of 165 m, resulting in a tip height of 260 m AGL. These dimensions represent the maximum overall tip height and maximum rotor diameter for WTGs considered for the Project, and are expected to represent the upper bound of the shadow flicker durations for the WTG options currently being considered for the Project. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 5.

Based on DNV's modelling, only four dwellings are predicted to experience shadow flicker of at least a moderate level of intensity (two associated dwellings and two host landholder dwellings). Of these, only two are predicted to experience theoretical shadow flicker durations above the applicable limits, both of which are host landholder dwellings.

Two host landholder dwellings (H017 and H302) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling (33 and 311 hours per year respectively). When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker durations at these dwellings are also predicted to be above the recommended limit of 10 hours per year within 50 m of the dwelling (13 and 117 hours per year respectively). DNV notes that the theoretical shadow flicker duration is substantial at H302, however, based on information provided by the Proponent, it is understood that this house is vacant. In addition, it is understood that the Proponent has a negotiated agreement in place with the affected host landholders to address impacts associated with the Project.

There may be further reductions in the estimated shadow flicker at some dwellings (for example H017 and H270), due to areas of dense vegetation surrounding the dwelling. However the screening effects of vegetation can require extensive effort to model and have not been included in this assessment.

Based on the results of the shadow flicker assessment and host landholder agreements, the Project is predicted to meet the applicable shadow flicker limits and it is not expected that specific mitigation measures will be required to meet shadow flicker limits.

Since a non-reflective finish is proposed for the WTG blades, blade glint is not expected to be an issue for the Project.

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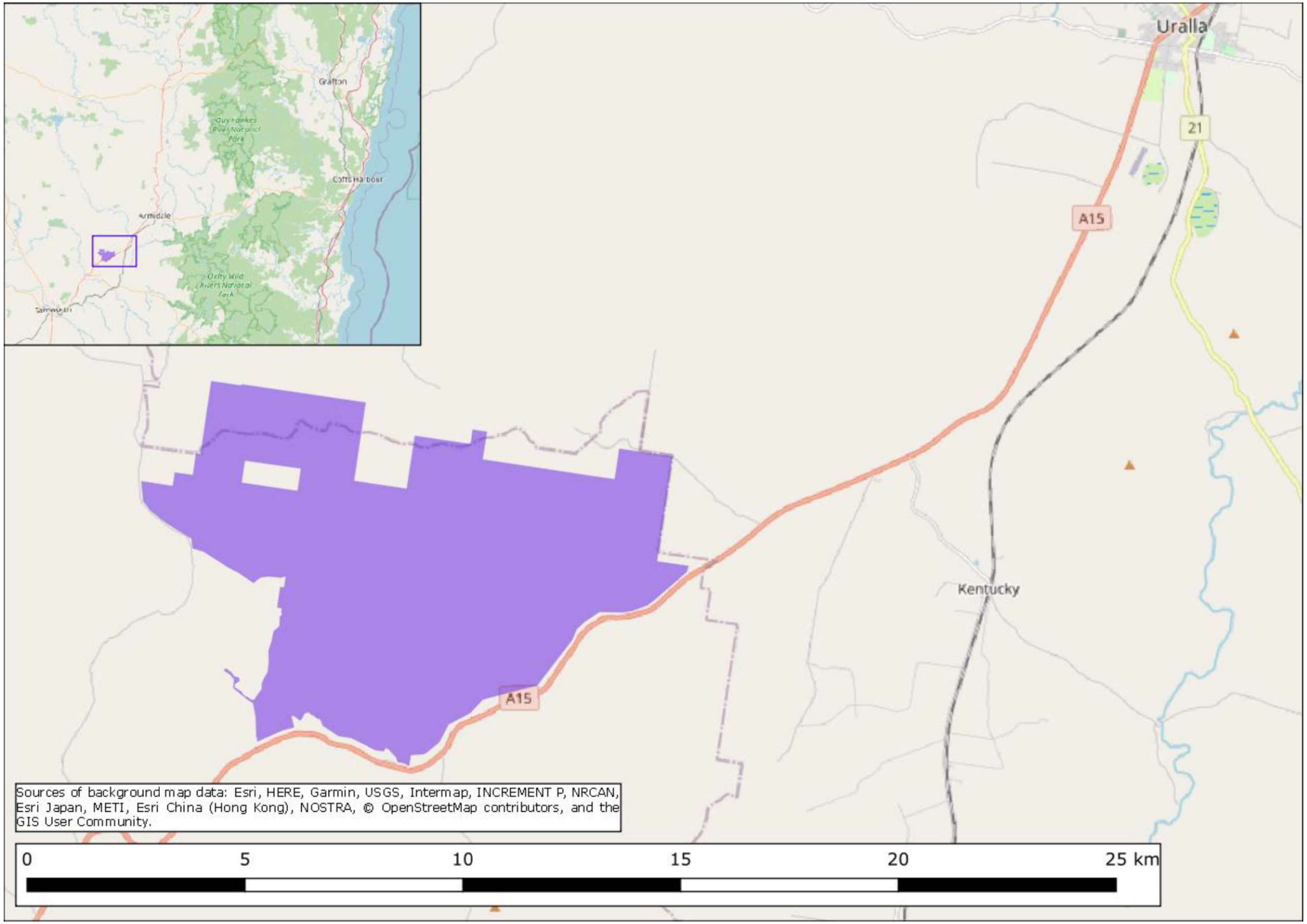


Figure 2 Location of the Project

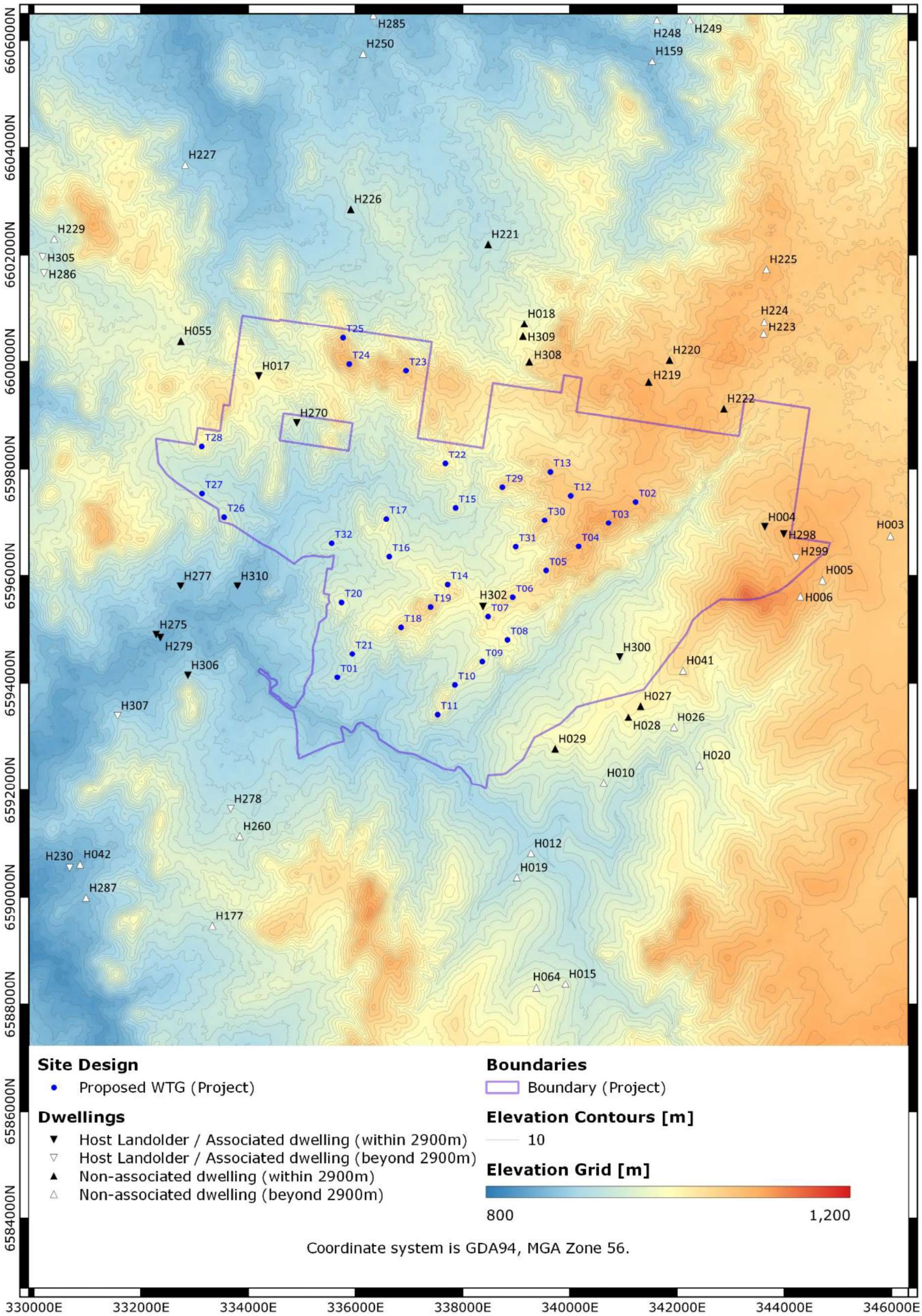


Figure 3 Site layout, showing WTGs, dwellings and elevations

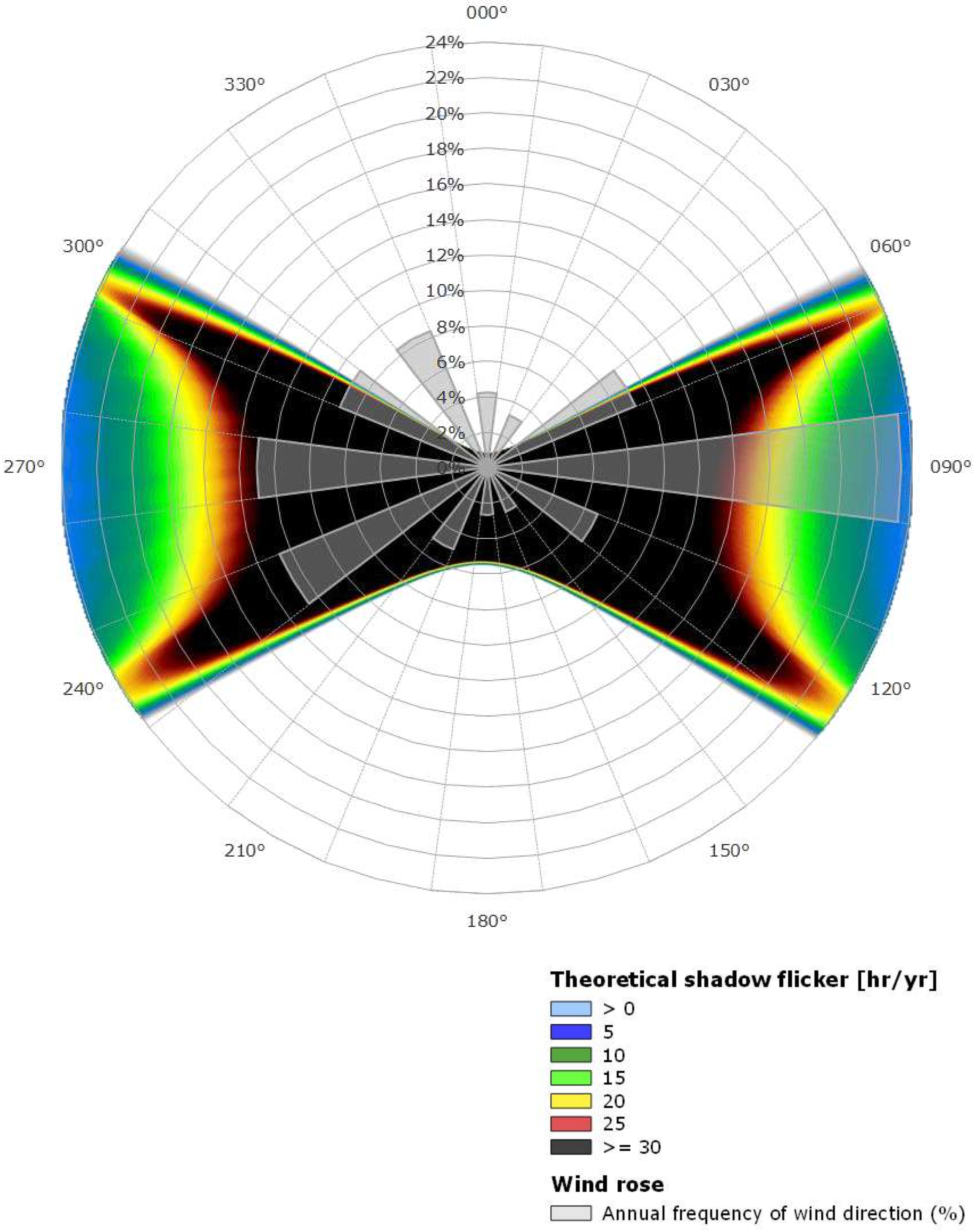


Figure 4 Indicative shadow flicker map and wind direction frequency distribution

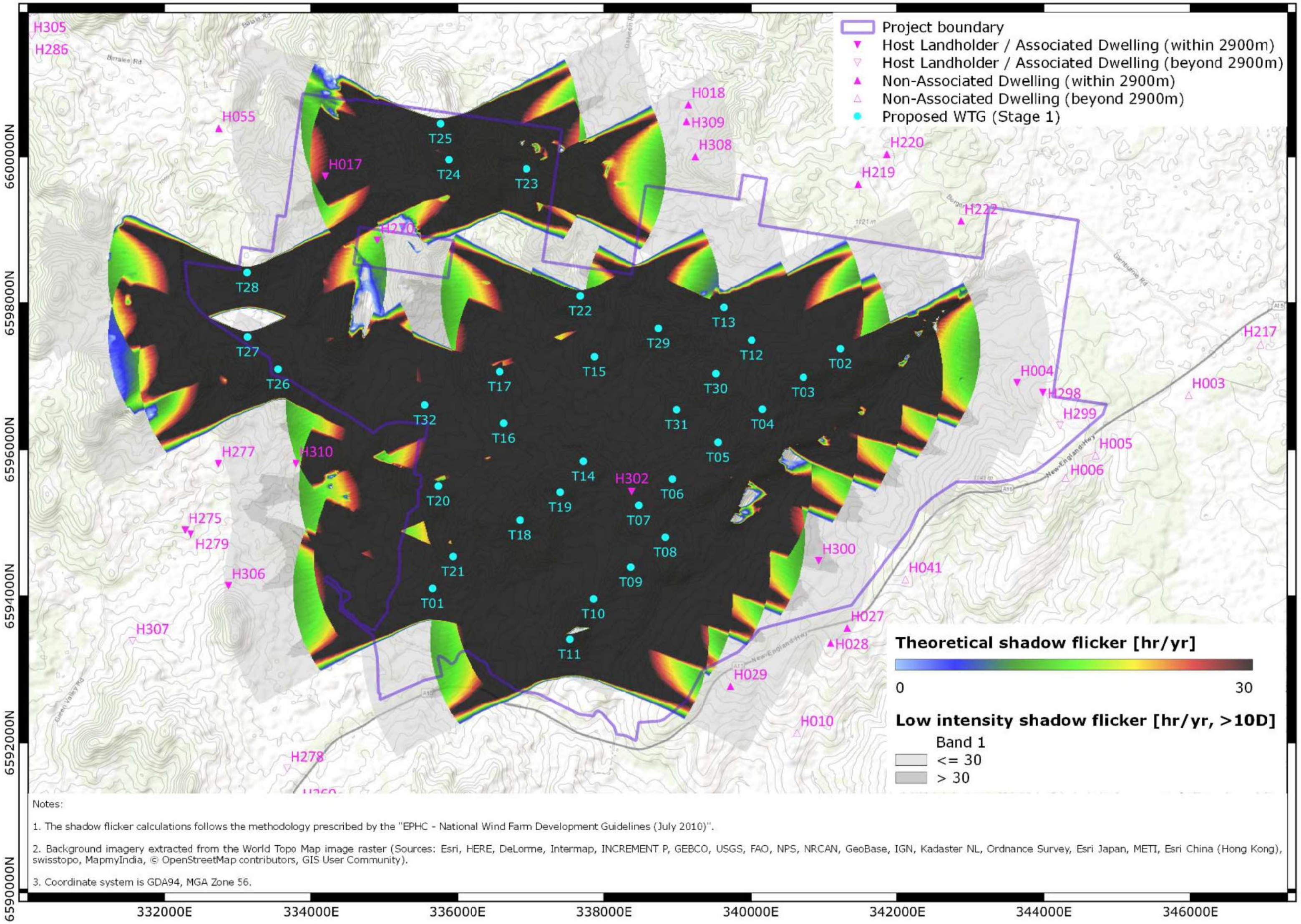
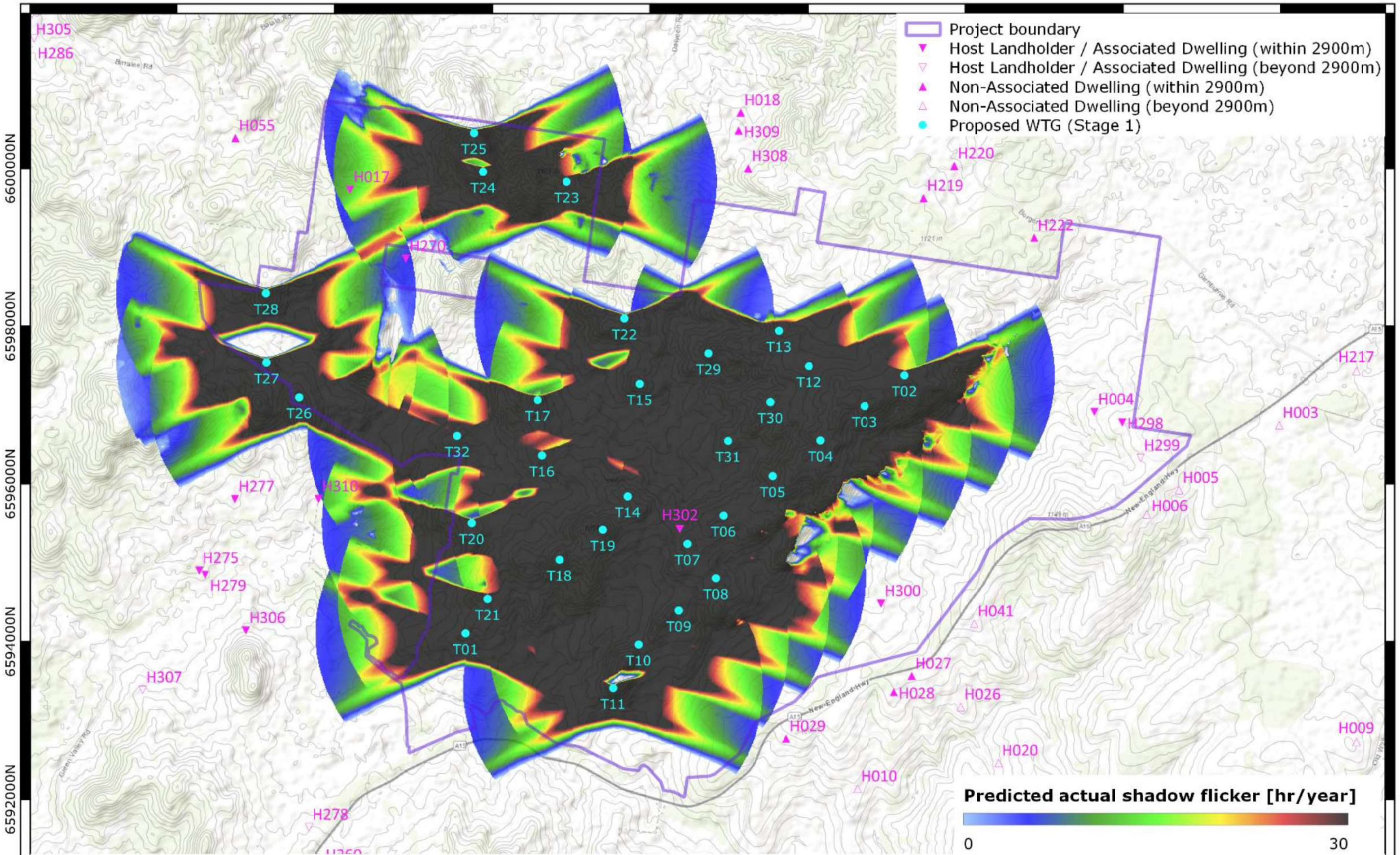


Figure 5 Theoretical annual shadow flicker duration map



Notes:

1. The shadow flicker calculations follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines (July 2010)".
2. The predicted actual shadow flicker duration considers reduction derived from cloud coverage, obtained from surrounding Bureau of Meteorology stations, and rotor orientation, defined by the site monitoring masts wind direction distribution.
3. Background imagery extracted from the World Topo Map image raster (Sources: Esri, HERE, DeLorme, Intermap, INCREMENT P, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, GIS User Community).
4. Coordinate system is GDA94, MGA Zone 56.

Figure 6 Predicted actual annual shadow flicker duration map

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analysing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

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