Appendix K. Alberton Wind Farm, Shadow Flicker and Blade Glint Assessment (DNVGL, 15 September 2017)

ALBERTON WIND FARM

Shadow Flicker and Blade Glint Assessment

Synergy Wind Pty Ltd.

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1 EXECUTIVE SUMMARY

DNV GL has been commissioned by Synergy Wind Pty Ltd ("Synergy") to independently assess the expected annual shadow flicker duration in the vicinity of the proposed Alberton Wind Farm. The results of the work are reported here.

Shadow flicker involves the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and an observer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative position of the sun throughout the year, the wind turbines at the site, local topography and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations neighbouring the proposed Alberton Wind Farm.

However, this analysis method tends to be conservative and typically results in over-estimation of the number of hours of shadow flicker experienced at a dwelling [1]. Therefore, an attempt has been made to quantify the likely reduction in shadow flicker duration due to turbine orientation and cloud cover, and hence produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

Synergy has commissioned DNV GL to assess the shadow flicker based upon a preliminary layout consisting of 34 wind turbines [2] which was modified by DNV GL to satisfy infrastructure and environmental constraints, in addition to reducing impacts at some surrounding dwellings. The turbine coordinates considered in the assessment are listed in Table 2. It has been advised by Synergy that shadow flicker should be calculated such that turbines T01 – T30 and T31 – T34 are at hub heights of 130 and 110 m, respectively, with a rotor diameter of 140 m for both hub height options [4].

Synergy has also provided the locations of 102 dwellings [2]. Of these dwellings, 17 have been identified as stakeholder dwellings and 85 as third-party dwellings which are listed in Table 1 and shown in Figure 2. It is noted that some of the dwelling locations are in very close proximity to turbine locations, which is likely to lead to high shadow flicker and other impacts. The closest dwelling is approximately 355 m from a turbine, and there are seven dwellings within 600 m of a turbine.

The Victorian Planning Guidelines [6] recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling. In addition, the EPHC Draft National Wind Farm Development Guidelines [7] recommend a limit on the theoretical shadow flicker duration of 30 hours per year, and a limit on the actual shadow flicker duration of 10 hours per year.

The Victorian Planning Guidelines, as well as planning guidelines in a number of other jurisdictions [8, 9], refer to the EPHC Draft National Wind Farm Development Guidelines [7] for guidance on the methodology for assessing shadow flicker durations. This assessment was based on the methodology recommended in the Draft National Wind Farm Development Guidelines. Calculations were carried out assuming houses had either one or two stories; with window heights of either 2 m or 6 m, respectively. The relevant shadow flicker duration at a dwelling was taken as the maximum calculated duration occurring within 50 m of the dwelling.

The results are presented in Table 4 and indicate that, of the dwellings identified by Synergy for study, there are locations within 50 m of 30 dwellings that are predicted to experience some shadow flicker. Ten of these locations are predicted to experience a theoretical shadow flicker duration in excess of the recommended limit of 30 hours per year within 50 m of the dwelling location, all of which are stakeholder dwellings. It should be noted that the theoretical shadow flicker durations at some stakeholder dwellings are very high, with the highest theoretical duration being over 280 hours (or over nine times the recommended limit). Theoretical shadow flicker durations at third-party dwellings are within the limit of 30 hours.

When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to turbine orientation and cloud cover, nine dwellings are expected to experience shadow flicker durations in excess of the recommended limit of 10 hours per year within 50 m of the dwelling location, all of which are stakeholder dwellings. Again, the predicted actual shadow flicker durations at many of the stakeholder dwellings are high, with the highest predicted actual duration at a being approximately 57 hours. Predicted actual shadow flicker durations at third-party dwellings are within the limit of 10 hours.

Synergy has however notified DNV GL that the dwelling with the highest impact, R02, is to be unoccupied if turbines are constructed [5]. This is also the case for dwelling R14. Excluding these dwellings, the highest theoretical shadow flicker duration is approximately 125 hours, and the highest predicted actual shadow flicker duration is approximately 32 hours, which are still approximately 4 and 3 times the recommended limits respectively.

It is noted that DNV GL staff have not visited the Alberton site as part of this assessment, and have not examined local conditions at each of the dwellings considered. Therefore it is possible that local screening from trees or structures, or window orientations, may further reduce actual shadow flicker durations.

However, unmitigated shadow flicker impacts from the Project are likely to present a problem for some stakeholder dwellings in the vicinity of the wind farm. The effects of shadow flicker may be reduced through a number of mitigation measures such as the installation of screening structures or planting of trees to block shadows cast by the turbines, the use of turbine control strategies; which shut down turbines when shadow flicker is likely to occur, or relocation of turbines.

If the turbine selected for the site has dimensions smaller than those considered here, but still within the turbine envelope, then shadow flicker durations in the vicinity of the site are likely to be lower than those predicted here.

Blade glint involves the reflection of light from a turbine blade, and can be seen by an observer as a periodic flash of light coming from the wind turbine. Blade glint is not generally a problem for modern turbines provided non-reflective coatings are used for the surface of the blades.

2 DESCRIPTION OF THE PROPOSED WIND FARM SITE

2.1 The Project

Synergy is developing the proposed Alberton Wind Farm, located approximately 4 km west of the town of Alberton and 7 km east of the town of Welshpool, in Victoria. The terrain at the proposed Alberton wind farm can be described as flat, with turbine base elevation varying between approximately 0 m and 20 m above sea level. The site area can generally be described as open farmland interspersed with areas of tall trees and wind breaks; with extensive areas of forestry southeast and northwest of the proposed layout.

Elevation data for the site area and immediate surrounds was extracted from Shuttle Radar Topography Mission (SRTM) 1 arc-second elevation data [10] and 5 metre resolution ELVIS data [16]. The elevation contours for the proposed Alberton Wind Farm are displayed in Figure 2.

2.2 Proposed Wind Farm Layout

The proposed turbine layout for the Alberton Wind Farm is comprised of 34 wind turbine generators [2].

DNV GL has modelled the shadow flicker using a hypothetical turbine with two hub height options; 130 m for turbines T01 to T30 and 110 m for turbines T31 to T34. A 140 m rotor diameter configuration has been used in both cases, as requested by Synergy [4]. These turbine dimensions are intended to encapsulate worst-case scenario based on turbine dimension limitations at the site. The results generated based on these dimensions are expected to be conservative if the adopted turbine dimensions are within the turbine configuration bounds as defined below:

- For turbines T01 to T30
    - A rotor diameter of 140 m or less;
    - A maximum blade chord of 5.3 m;
    - An upper blade tip height of 200 m or less;
    - A lower tip height of 60 m or greater;
- For turbines T31 to T34
    - A rotor diameter of 140 m or less;
    - A maximum blade chord of 5.3 m;
    - An upper blade tip height of 180 m or less;
    - A lower tip height of 40 m or greater;

A list of coordinates of the proposed turbine locations are given in Table 2.

2.3 House Locations

A list of dwellings neighbouring the wind farm was supplied to DNV GL by Synergy [2].

The coordinates of dwellings in the vicinity of the wind farm are presented in Table 1. DNV GL has assumed that all listed locations are potential inhabited residential locations. It should be noted that DNV GL has not carried out a detailed and comprehensive survey of house locations in the area and is relying on information provided by Synergy.

It is noted that some of the dwelling locations are in very close proximity to turbine locations, which is likely to lead to high shadow flicker and other impacts. The nearest dwelling is approximately 355 m from a turbine, and there are seven turbines within 600 m of a turbine. Of these dwellings, Synergy has indicated that R02 and R14 will not be inhabited if the turbines are to be constructed.

3 PLANNING GUIDELINES

The Victorian Planning Guidelines [6] currently state;

> *"The shadow flicker experienced immediately surrounding the area of a dwelling (garden fenced area) must not exceed 30 hours per year as a result of the operation of the wind energy facility".*

In addition, the EPHC Draft National Wind Farm Development Guidelines released in July 2010 [7] include recommendations for shadow flicker limits relevant to wind farms in Australia.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration should not exceed 30 hours per year, and that the actual or measured shadow flicker duration should not exceed 10 hours per year. The guidelines also recommend that the shadow flicker duration at a dwelling should be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a dwelling.

As details of the 'garden fenced area' for a dwelling are not readily available, DNV GL assumes that the evaluation of the maximum shadow flicker duration within 50 m of a dwelling (as required by the Draft National Guidelines) will be equivalent to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be conservative, however, it is acknowledged that in rural areas, the 'garden fenced areas' may extend beyond 50 m from a dwelling and additional guidance can be provided if areas of concern are highlighted.

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

The Draft National Guidelines provide background information, a proposed methodology and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine [11] or approximately 1000 to 1400 m for modern wind turbines (which typically have rotor diameters of 100 to 140 m). 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 therefore suggest a distance equivalent to 265 maximum blade chords[1] as an appropriate limit, which corresponds to approximately 1000 to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 to 6 m).

The Draft National Guidelines also provide 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."*

[1] The maximum blade chord is the thickest part of the blade.

4 SHADOW FLICKER AND GLINT ASSESSMENT

4.1 Shadow Flicker 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 wind turbine 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:

- Direction of the property relative to the turbine;
- Distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be);
- 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);
- Turbine height and rotor diameter;
- Time of year and day (the position of the sun in the sky);
- Weather conditions (cloud cover reduces the occurrence of shadow flicker).

4.2 Theoretical Modelled Shadow Flicker 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 wind farm site and wind turbine details such as rotor diameter and hub height.

The wind turbines have been modelled assuming they are spherical objects, which is equivalent to assuming the turbines are always oriented perpendicular to the sun-turbine vector. This assumption will mean the model calculates the maximum duration for which there is potential for shadow flicker to occur.

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

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 would be facing a particular direction. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute; meaning that, if shadow flicker is predicted to occur in any 1-minute period, the model records this as 1 minute of shadow flicker. The shadow flicker map was generated using a temporal resolution of 5 minutes 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 wind turbine that is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [11], while the Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit. Synergy has nominated a hypothetical turbine rotor diameter of 140 m with maximum blade chord length of 5.3 m for this study. DNV GL has implemented a maximum shadow a length of 265 chord lengths, or 1405 m. Under the Draft National Guidelines, this will be conservative for any turbine with a maximum blade chord of less than 5.3 m.

The model also makes the following assumptions and simplifications:

- There are clear skies every day of the year;
- The turbines are always rotating;
- The blades of the turbines are always perpendicular to the direction of the line of sight from the location of interest to the sun.

These simplifications mean that the results generated by the model are likely to be conservative.

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

To illustrate typical results, an indicative shadow flicker map for a turbine located in a relatively flat area is shown in Figure 1. 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 turbine location result from the summer solstice and conversely the lobes to the south result from the winter solstice. 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 turbine increases, increasing the area around the turbine affected by shadow flicker.

4.3 Factors Affecting Shadow Flicker 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.

1. The wind turbine will not always be yawed such that its rotor is in the worst-case orientation (i.e. perpendicular to the sun-turbine 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 turbine 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 wind turbine.

   The length of the shadow cast by a wind turbine 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 wind turbine rotor as a sphere rather than individual blades results in an overestimate of shadow flicker duration.

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

4.4 Predicted Actual Shadow Flicker Duration

As discussed above in section 4.3, there are a number of factors which may reduce the incidence of shadow flicker, such as cloud cover and variation in turbine orientation, that are not taken into account in the calculation of the theoretical shadow flicker duration. Exclusion of these factors means that the theoretical calculation is conservative. An attempt has been made to quantify the likely reduction in shadow flicker duration due to these effects and therefore produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

Cloud cover is typically measured in ‘oktas’ or eighths of the sky covered with cloud. DNV GL has obtained data from four Bureau of Meteorology (BoM) stations, located a distance of approximately 47 to 75 km from the site [12, 13, 14, 15], with twice-daily approximations of the percentage of cloud cover visible across the sky. The results show that the average annual cloud cover values obtained from readings at 9 am and 3 pm for the four available stations, at Morwell, Wilsons Promontory, East Sale Airport and Erica, range between 4.9 and 5.9 oktas. From those measurements, is was estimated that, on an average day 67% of the sky in the vicinity of the wind farm 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 a reasonable assumption.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker impact is greatest when the turbine 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. A wind direction frequency distribution previously derived by DNV GL from data collected by a mast on site has been 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 1.

An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation and cloud cover was conducted on an annual basis, which indicated that a reduction of approximately 73% to 87% can be expected at the affected dwelling locations.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shutdown has not been considered. It is therefore likely that the predicted actual shadow flicker durations presented here can still be regarded as a conservative assessment.

4.5 Blade Glint

Blade glint involves the regular reflection of sun off rotating turbine 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. As discussed, blade glint is not generally a problem for modern wind turbines, provided the blades are coated with a non-reflective paint, and it is not considered further here.

5 RESULTS OF THE ANALYSIS

A shadow flicker prediction was carried out at all dwelling locations, or "receptors", located within 1.5 km of the proposed Alberton Wind Farm, as outlined in Table 1. The theoretical predicted shadow flicker durations at all dwellings identified to be affected by shadow flicker are presented in Table 4, along with the maximum predicted theoretical shadow flicker durations within 50 m of these receptors. The maximum theoretical and predicted actual shadow flicker durations between 2 m and 6 m heights are presented in Figure 3 and Figure 4 respectively.

These results indicate that 30 dwellings in the vicinity of the proposed Alberton Wind Farm are predicted to experience some shadow flicker based on the methodology recommended in the Draft National Guidelines. Of these dwellings, ten stakeholder dwellings are predicted to be affected by theoretical shadow flicker durations exceeding the Victorian Guidelines recommended limit of 30 hours per year within 50 m of the house locations. It should be noted that the theoretical shadow flicker durations at some of the stakeholder dwellings are very high, with the highest theoretical duration being over 280 hours (or over nine times the recommended limit). Theoretical shadow flicker durations at third-party dwellings are within the limit of 30 hours.

An assessment of the level of conservatism associated with the theoretical results has been conducted by calculating the possible reduction in shadow flicker duration due to turbine orientation; based on the wind rose measured at the site, and cloud cover; based on data obtained from a number of nearby stations from the Australian Bureau of Meteorology. These adjusted results are presented as predicted actual shadow flicker durations in Table 4. Consideration of turbine orientation and cloud cover led to the expected reduction in the predicted shadow flicker durations by approximately 73% to 87% at the dwellings affected by shadow flicker.

After reductions due to turbine orientation and cloud cover are taken into account, nine stakeholder dwellings that exceeded the 30-hour limit are predicted to be subject to an actual shadow flicker duration above the limit of 10 hours within 50 m of the dwelling location, as recommended in the Draft National Guidelines. Again, the predicted actual shadow flicker durations at some of the stakeholder dwellings are predicted to be high, with the highest predicted duration being approximately 57 hours (or more than five times the recommended limit). Predicted actual shadow flicker durations at third-party dwellings are within the limit of 10 hours.

Excluding dwellings R02 and R14 which Synergy has indicated will not be inhabited should the project be constructed, the highest theoretical shadow flicker duration is 125.3 hours, and the highest predicted actual shadow flicker duration is 32.4 hours, which are still approximately 4 and 3 times the recommended limits respectively.

It is noted that DNV GL staff have not visited the Alberton site as part of this assessment, and have not examined local conditions at each of the dwellings considered. Therefore it is possible that local screening from trees or structures, or window orientations, may further reduce actual shadow flicker durations.

It should also 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 turbine orientation, be included. However, DNV GL considers that this additional reduction due to turbine orientation is appropriate as the projected area of the turbine, and therefore the expected shadow flicker duration, is reduced when the turbine rotor is not perpendicular to the line joining the sun and dwelling.

5.1 Mitigation Options

Unmitigated shadow flicker impacts from the Project are likely to present a problem for residents in the vicinity of the wind farm. The effects of shadow flicker may be reduced through a number of mitigation measures such as the installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies which shut down turbines when shadow flicker is likely to occur; further discussed below in section 5.1.1.

It should be noted that the results presented here have been generated based on a turbine configuration such that turbines T01 to T30 have a hub height of 130 m, and turbines T31 to T34 have a hub height of 110 m; with all turbines having a rotor diameter of 140 m. If the turbine eventually selected for the site has a rotor diameter smaller than that considered here, then shadow flicker durations in the vicinity of the site are expected to be lower than those predicted here.

5.1.1 Shadow Flicker Protection Systems

It is noted that the predicted shadow flicker durations at a number of stakeholder dwellings are high, and are well above recommended shadow flicker limits. Synergy has indicated that they intend to mitigate shadow flicker durations at some stakeholder dwellings using a shadow flicker protection system. Such systems have been deployed extensively on multiple wind turbines and wind farm sites throughout Europe, however DNV GL understands that they have not yet been deployed within Australia. The protection system could be used to ensure that shadow flicker durations experienced at affected stakeholder dwellings remain below agreed limits.

Shadow flicker protection systems [17] typically consist of a control module that can calculate whether it is theoretically possible for shadow flicker to occur at a sensitive location, and light sensors to detect whether there is direct sunlight at the site. Examples of typical system components can be seen in Figure 5.

Once the maximum permitted shadow flicker exposure duration is exceeded, the wind turbine(s) causing the shadow flicker will be shut down for the duration of the shadow fall. All shadow flicker occurrences and shutdown periods can be recorded. The settings in the shadow flicker shutdown module that determine turbine shutdown periods are customisable depending on parameters such as the position of the sun, meteorological data, time of day and year, wind speed and temperature, etc.

6 CONCLUSION

An analysis has been conducted to determine the annual duration of shadow flicker experienced at dwellings in the vicinity of the proposed Alberton Wind Farm, based on the methodology proposed in the Draft National Guidelines. The results of the assessment are presented in the form of shadow flicker maps in Figure 3 and Figure 4. The shadow flicker results for each house location predicted to be affected by shadow flicker are also listed in Table 4.

It is noted that some of the dwelling locations are in very close proximity to turbine locations, which is likely to lead to high shadow flicker and other impacts. The nearest dwelling is approximately 355 m from a turbine, and there are seven dwellings within 600 m of a turbine.

The assessment of theoretical shadow flicker duration shows that 30 of the dwellings identified by Synergy are predicted to experience some level of theoretical shadow flicker within 50 m of the house location. Ten stakeholder dwellings are predicted to be affected by theoretical shadow flicker durations of greater than the Victorian Guidelines recommended limit of 30 hours per year within 50 m of the house locations. In general the theoretical shadow flicker durations at some of the stakeholder dwellings are very high, with the highest theoretical duration being over 280 hours (or over nine times the recommended limit). Theoretical shadow flicker durations at third-party dwellings are within the limit of 30 hours.

Approximation of the degree of conservatism associated with the worst-case results has been conducted by calculating the possible reduction in shadow flicker duration due to turbine orientation and cloud cover. The results of this analysis, also presented in Table 4, show that nine stakeholder dwellings are predicted to experience actual annual shadow flicker durations within 50 m of the dwelling location that are in excess of the recommended 10 hours/annum limit outlined in the Draft National Guidelines. Again, the predicted actual shadow flicker durations at some of the stakeholder dwellings are high, with the highest predicted actual duration being approximately 57 hours (or more five times the recommended limit). Predicted actual shadow flicker durations at third-party dwellings are within the limit of 10 hours.

Synergy has however notified DNV GL that dwellings R02 and R14 (both of which receive high shadow flicker durations) will not be inhabited if turbines are to be constructed. Excluding these dwellings, the highest theoretical shadow flicker duration is 125.3 hours, and the highest predicted actual shadow flicker duration is 32.4 hours, which are still approximately 4 and 3 times the recommended limits respectively.

It is noted that DNV GL staff have not visited the Alberton site as part of this assessment, and have not examined local conditions at each of the dwellings considered. Therefore it is possible that local screening from trees or structures, or window orientations, may further reduce actual shadow flicker durations.

However, unmitigated shadow flicker impacts from the Project are likely to present a problem for some stakeholder dwellings in the vicinity of the wind farm. The effects of shadow flicker may be reduced through a number of mitigation measures such as the installation of screening structures or planting of trees to block shadows cast by the turbines, the use of turbine control strategies which shut down turbines when shadow flicker is likely to occur, or relocation of turbines.

Blade glint is not likely to cause a problem for observers in the vicinity of the wind farm provided non-reflective coatings are used on the blades of the turbines.

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Table 1: Dwelling locations within 1.5 km of turbines at the proposed Alberton Wind Farm

Receptor ID	Easting[1] [m]	Northing[1] [m]	Landowner Status	Nearest turbine	Distance to nearest turbine [km]
R01	458025	5721403	stakeholder	T01	0.8
R02[2]	458511	5721773	stakeholder	T02	0.4
R03	459349	5723517	stakeholder	T07	0.6
R05	464013	5723672	stakeholder	T11	0.7
R08	465556	5724498	stakeholder	T14	0.7
R09	466041	5724449	stakeholder	T14	1.0
R10	466058	5727464	stakeholder	T24	0.9
R11	466580	5728555	stakeholder	T28	1.0
R12	466861	5725604	stakeholder	T25	0.6
R13	467098	5724123	stakeholder	T31	0.6
R14[2]	467310	5724158	stakeholder	T31	0.4
R15	467727	5729528	stakeholder	T28	0.5
R16	468091	5725646	stakeholder	T29	0.5
R17	468272	5724349	stakeholder	T34	0.5
R18	468387	5725686	stakeholder	T29	0.8
R19	469205	5724777	stakeholder	T34	0.9
D10	457420	5721301	third-party	T01	1.5
D13	458737	5723585	third-party	T03	1.0
D22	463348	5724709	third-party	T09	1.0
D29	463958	5724677	third-party	T14	1.5
D30	463373	5724339	third-party	T11	1.1
D31	464056	5724474	third-party	T14	1.3
D33	464278	5724560	third-party	T14	1.2
D34	464339	5721714	third-party	T13	1.5
D35	464393	5724553	third-party	T14	1.1
D45	465158	5726702	third-party	T24	1.5
D46	465557	5725302	third-party	T14	1.4
D47	465624	5725326	third-party	T14	1.5
D48	465662	5725284	third-party	T14	1.4
D49	465666	5725357	third-party	T17	1.4
D50	465711	5728791	third-party	T20	1.4
D51	465724	5724867	third-party	T14	1.1
D52	465957	5727564	third-party	T24	1.1
D53	466440	5728061	third-party	T24	1.4
D54	466491	5727792	third-party	T24	1.1
D55	466729	5728009	third-party	T24	1.3
D56	466778	5728057	third-party	T28	1.2
D57	466848	5721988	third-party	T19	1.0
D58	466928	5727796	third-party	T24	1.1

Receptor ID	Easting[1] [m]	Northing[1] [m]	Landowner Status	Nearest turbine	Distance to nearest turbine [km]
D59	467134	5728108	third-party	T28	1.0
D60	467278	5722331	third-party	T27	1.0
D61	467900	5727786	third-party	T28	1.4
D62	468021	5722533	third-party	T33	1.0
D63	468183	5727934	third-party	T28	1.4
D64	468186	5727032	third-party	T25	1.3
D65	468397	5729317	third-party	T28	1.0
D66	468579	5722356	third-party	T33	1.2
D67	468582	5730329	third-party	T30	1.0
D68	468737	5730295	third-party	T30	1.2
D70	468913	5730054	third-party	T30	1.4
D72	469159	5725201	third-party	T34	1.2
D73	469510	5724603	third-party	T34	1.0
D74	469711	5724415	third-party	T34	1.1
D75	469822	5724534	third-party	T34	1.3
D76	469938	5724573	third-party	T34	1.4
D77	470008	5724610	third-party	T34	1.5
D81	467680	5726999	third-party	T25	1.0
D82	465354	5727002	third-party	T24	1.3
D83	465338	5726904	third-party	T24	1.3
D84	460504	5723858	third party	T07	1.1

[1] Coordinate system: UTM zone 55 South, WGS84 datum.
[2] Dwelling to be uninhabited if project is construted.

Table 2: Proposed turbine layout for the Alberton Wind Farm site

WTG ID	Easting[1] [m]	Northing[1] [m]	WTG ID	Easting[1] [m]	Northing[1] [m]
T01	458853	5721594	T18	466207	5723430
T02	458685	5722082	T19	466293	5722824
T03	458756	5722567	T20	466711	5729705
T04	459518	5721714	T21	466771	5730287
T05	459584	5722157	T22	466804	5723380
T06	459637	5722587	T23	466912	5730979
T07	459708	5723054	T24	466630	5726724
T08	462198	5723499	T25	467223	5726089
T09	462340	5724695	T26	467278	5724773
T10	462791	5723439	T27	467403	5723331
T11	463408	5723282	T28	467323	5729252
T12	465069	5723430	T29	467662	5725331
T13	465102	5722990	T30	467551	5730153
T14	465248	5723919	T31	467683	5724225
T15	465606	5723479	T32	467964	5723825
T16	465616	5722934	T33	468258	5723514
T17	466758	5726258	T34	468632	5724068

[1] Coordinate system: UTM zone 55 South, WGS84 datum.

Table 3: Shadow flicker model settings for theoretical shadow flicker calculation

Model Parameter	Setting
Maximum shadow length	1405 m
Year of calculation	2029
Minimum angle to the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere
Sun modelled as	Disk
Offset between rotor and tower	Not required
Receptor height (single storey)	2 m
Receptor height (double storey)	6 m
Locations used for determining maximum shadow flicker within 50 m of each receptor	8 points evenly distributed on 50 m and 25 m radius circle centred on the sensitive receptor location (16 points total).

Table 4: Shadow flicker model settings for theoretical shadow flicker calculation - concluded

House ID[1]	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual: At dwelling [hr/yr]		Theoretical annual: Max within 50 m of dwelling [hr/yr]		Predicted actual annual[3]: At dwelling [hr/yr]		Predicted actual annual[3]: Max within 50 m of dwelling [hr/yr]	
				SF at 2 m	SF at 6 m	SF at 2 m	SF at 6 m	SF at 2 m	SF at 6 m	SF at 2m	SF at 6 m
D67	468582	5730329	T30	20.2	20.1	23.0	22.8	5.6	5.5	6.3	6.2
D68	468737	5730295	T30	14.3	14.1	15.9	15.7	3.9	3.8	4.3	4.2
D70	468913	5730054	T30	9.8	9.5	10.8	10.5	2.5	2.5	2.8	2.7
D73	469510	5724603	T34	0.0	0.0	12.6	12.7	0.0	0.0	2.9	3.0
D74	469711	5724415	T34	19.9	19.3	26.2	25.0	5.4	5.2	7.0	6.7
D75	469822	5724534	T34	19.8	18.8	28.9	28.2	5.3	5.0	8.0	7.8
D76	469938	5724573	T34	14.3	13.7	22.8	21.6	3.9	3.6	5.9	5.5
D81	467680	5726999	T24	22.0	21.6	26.8	26.3	6.0	5.9	7.2	7.1
D82	465354	5727002	T24	13.2	13.0	14.9	14.7	3.4	3.3	3.7	3.6
D83	465338	5726904	T24	12.1	11.7	13.3	13.0	3.1	3.0	3.4	3.4
			Annual duration limits	***30***		***30***		***10***		***10***	

Notes:

1. *Dwellings identified in Table 1 with no shadow flicker have been omitted from this table.*
2. *Coordinate system: UTM Zone 55 South, WGS 84 datum.*
3. *Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.*
4. *Dwelling to be unoccupied if project is constructed.*

Red *- exceeds the theoretical limit of 30 hrs/year*
Yellow *– exceeds the predicted actual limit of 10 hrs/year*

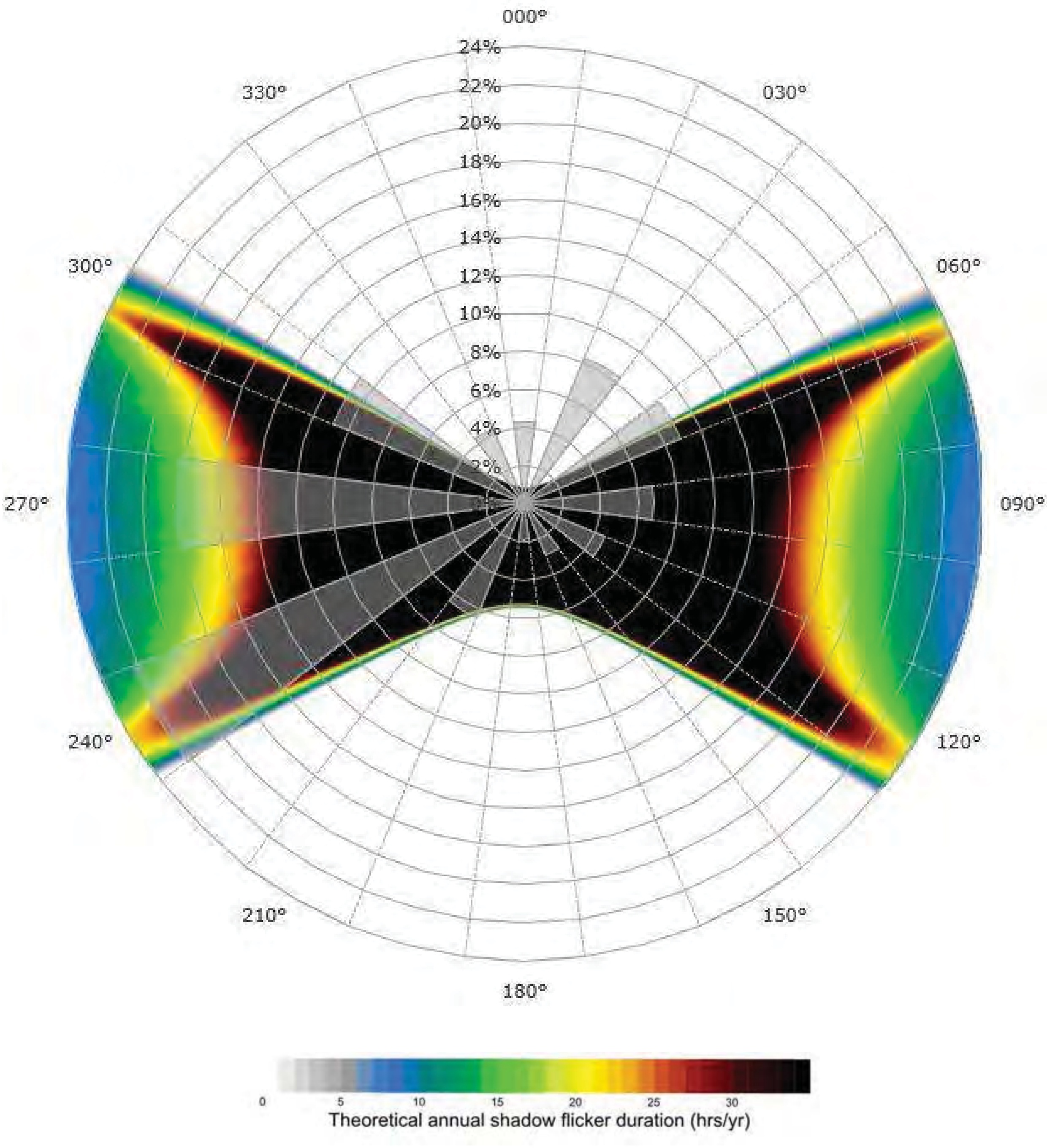

Figure 1: Indicative shadow flicker map and wind direction frequency distribution

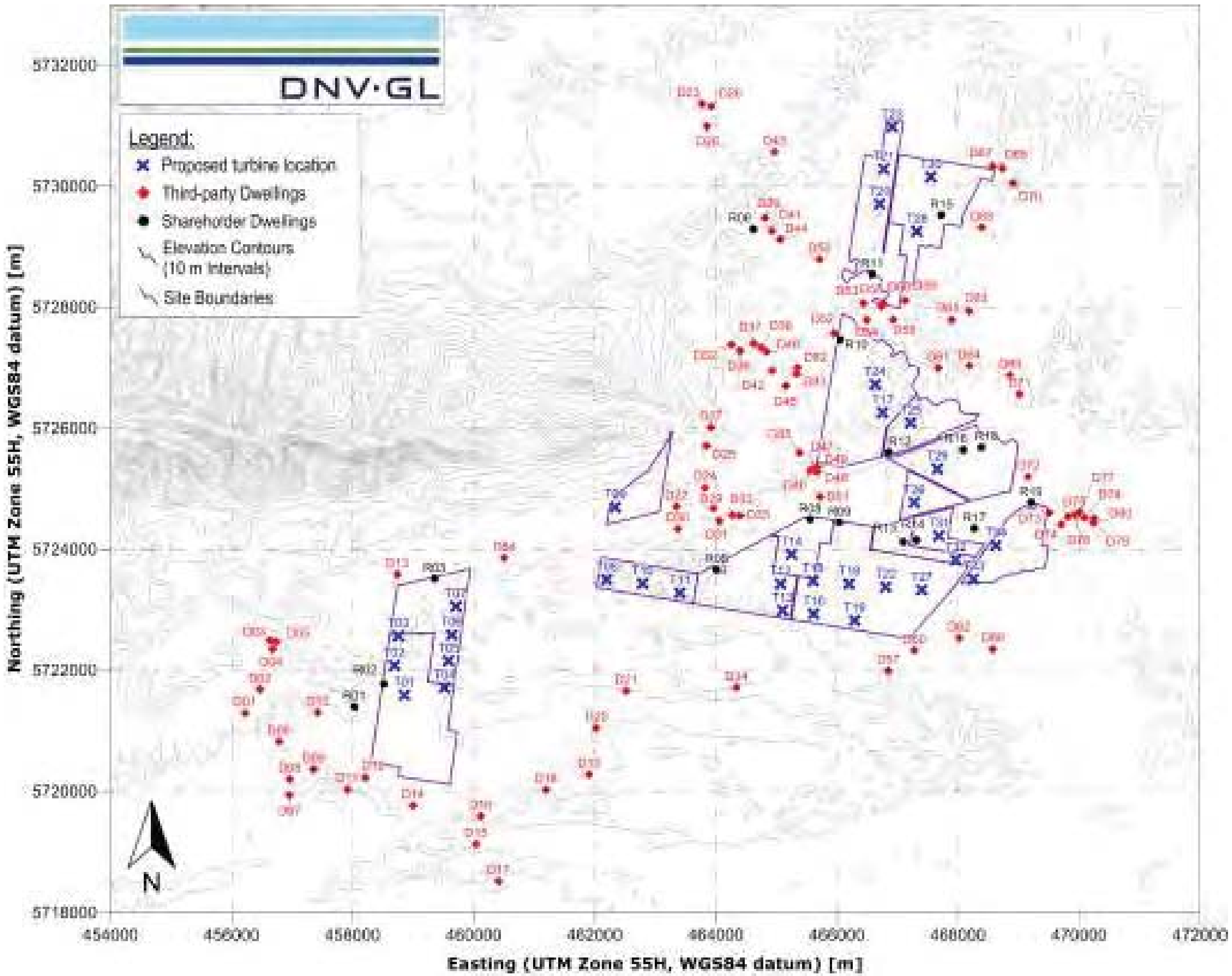

Figure 2: Map of the proposed Alberton Wind Farm with turbines, stakeholder and third-party dwelling locations

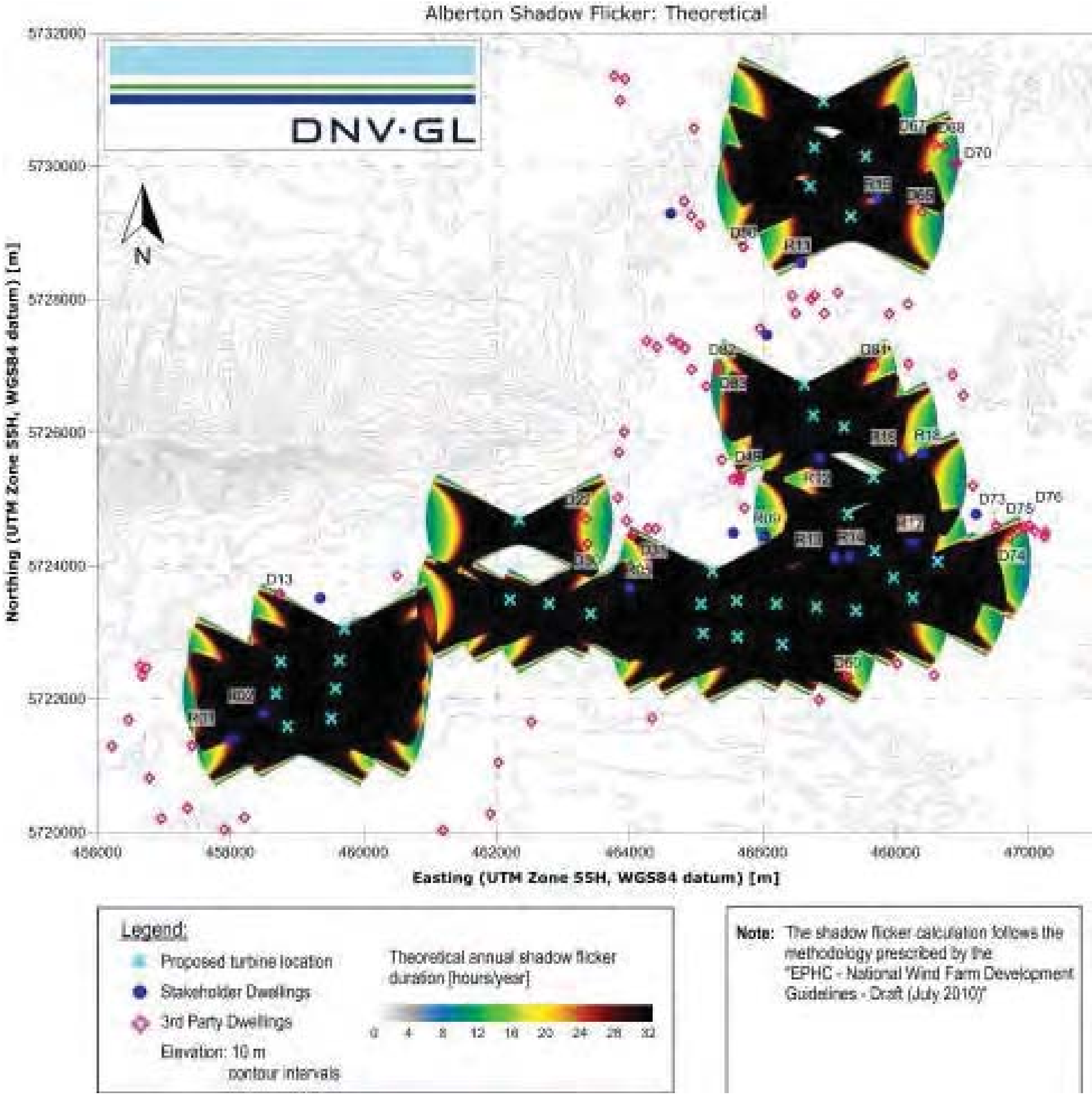

Figure 3: Map of the proposed Alberton Wind Farm with turbines, dwelling locations and maximum theoretical annual shadow flicker duration map between 2 m and 6m heights

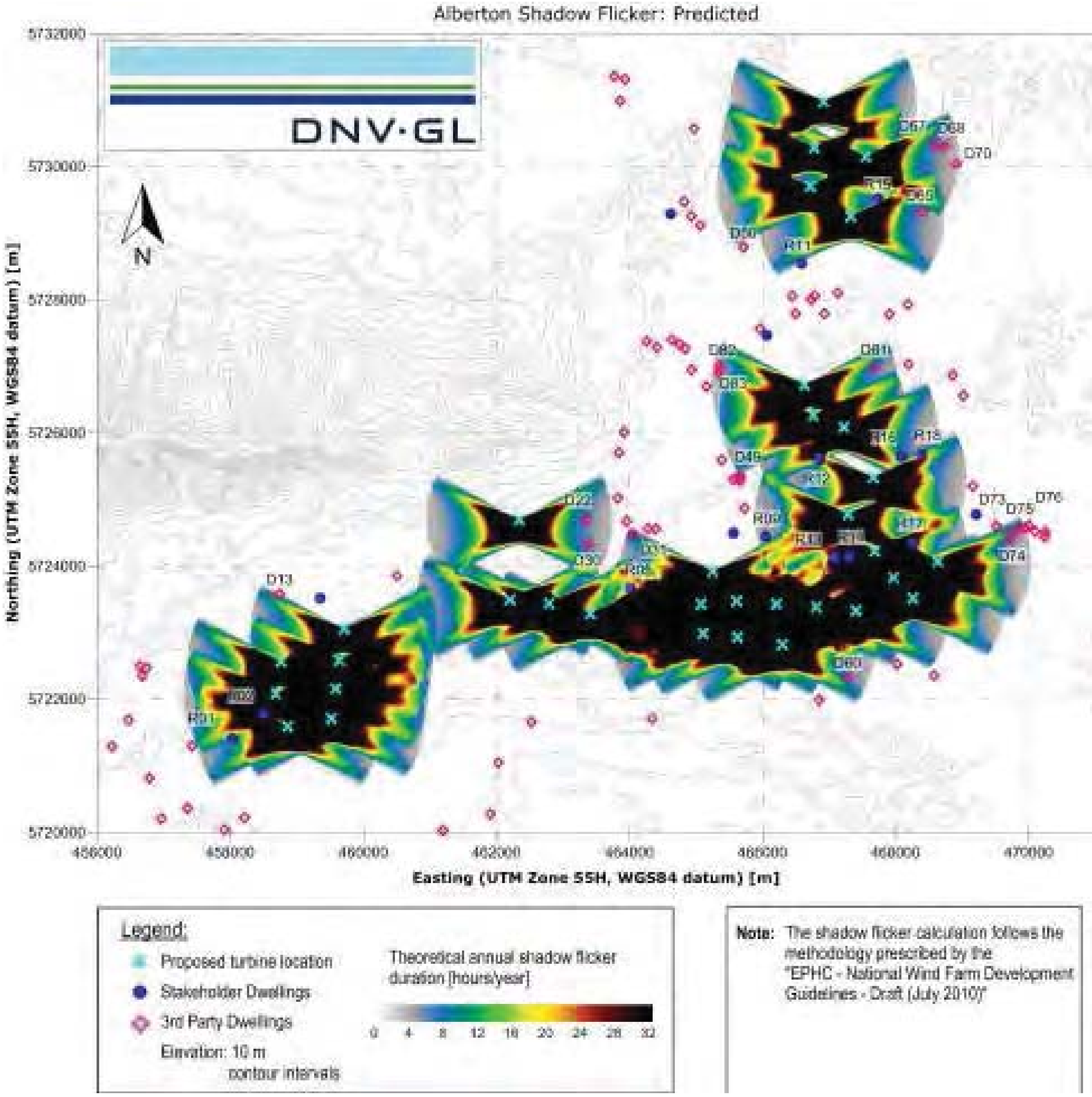

Figure 4: Map of the proposed Alberton Wind Farm with turbines, dwelling locations and maximum predicted annual shadow flicker duration map between 2 m and 6m heights

	Shadow flicker module cabinet with cabling
	Light sensor mounted to the tower of a wind turbine
	Light sensor mounted on top of the wind turbines nacelle

Figure 5: Shadow flicker protection system components

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