BIALA WIND FARM

Shadow Flicker and Blade Glint Assessment

Environmental Resources Management Australia Pty Ltd

Report No.: 170223-AUME-R-02, Rev. E
Date: 10 July 2015
Status: Final

IMPORTANT NOTICE AND DISCLAIMER

1. This document is intended for the sole use of the Client as detailed on the front page of this document to whom the document is addressed and who has entered into a written agreement with the DNV GL entity issuing this document ("DNV GL"). To the extent permitted by law, neither DNV GL nor any group company (the "Group") assumes any responsibility whether in contract, tort including without limitation negligence, or otherwise howsoever, to third parties (being persons other than the Client), and no company in the Group other than DNV GL shall be liable for any loss or damage whatsoever suffered by virtue of any act, omission or default (whether arising by negligence or otherwise) by DNV GL, the Group or any of its or their servants, subcontractors or agents. This document must be read in its entirety and is subject to any assumptions and qualifications expressed therein as well as in any other relevant communications in connection with it. This document may contain detailed technical data which is intended for use only by persons possessing requisite expertise in its subject matter.

2. This document is protected by copyright and may only be reproduced and circulated in accordance with the Document Classification and associated conditions stipulated or referred to in this document and/or in DNV GL's written agreement with the Client. No part of this document may be disclosed in any public offering memorandum, prospectus or stock exchange listing, circular or announcement without the express and prior written consent of DNV GL. A Document Classification permitting the Client to redistribute this document shall not thereby imply that DNV GL has any liability to any recipient other than the Client.

3. This document has been produced from information relating to dates and periods referred to in this document. This document does not imply that any information is not subject to change. Except and to the extent that checking or verification of information or data is expressly agreed within the written scope of its services, DNV GL shall not be responsible in any way in connection with erroneous information or data provided to it by the Client or any third party, or for the effects of any such erroneous information or data whether or not contained or referred to in this document.

4. Any wind or energy forecasts estimates or predictions are subject to factors not all of which are within the scope of the probability and uncertainties contained or referred to in this document and nothing in this document guarantees any particular wind speed or energy output.

KEY TO DOCUMENT CLASSIFICATION

Strictly Confidential	:	For disclosure only to named individuals within the Client's organisation.
Private and Confidential	:	For disclosure only to individuals directly concerned with the subject matter of the document within the Client's organisation.
Commercial in Confidence	:	Not to be disclosed outside the Client's organisation.
DNV GL only	:	Not to be disclosed to non-DNV GL staff
Client's Discretion	:	Distribution for information only at the discretion of the Client (subject to the above Important Notice and Disclaimer and the terms of DNV GL's written agreement with the Client).
Published	:	Available for information only to the general public (subject to the above Important Notice and Disclaimer).

Project name:	Biala Wind Farm	
Report title:	Shadow Flicker and Blade Glint Assessment	
Customer:	Environmental Resources Management Australia Pty Ltd, Lumley House, Level 15, 309 Kent St, NSW 2000	
Contact person:	Erin Dethridge	
Date of issue:	10 July 2015	
Project No.:	170223	
Report No.:	170223-AUME-R-02, Rev. E	
Document No.:	170223-AUME-R-02-C	

DNV GL - Energy
Renewables Advisory
Suite 25, Level 8
401 Docklands Dr
Docklands, VIC, 3008
Australia
Tel: +61-3-9600-1993

Task and objective:
Biala Wind Farm Shadow Flicker and Blade Glint Assessment

Prepared by:	Verified by:	Approved by:
J McMahon Engineer	T Gilbert Senior Engineer	G Slack Area Manager, Pacific

☐ Strictly Confidential
☐ Private and Confidential
☐ Commercial in Confidence
☐ DNV GL only
☒ Client’s Discretion
☐ Published

Keywords:
Biala wind farm shadow flicker assessment

Reference to part of this report which may lead to misinterpretation is not permissible.

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2014-02-13	First issue – PRELIMINARY DRAFT	J McMahon	T Gilbert	G Slack
B	2014-02-25	Finalised SF results - DRAFT	J McMahon	T Gilbert	G Slack
C	2015-06-05	Updated report with client feedback and reference to SEARs	J McMahon	T Gilbert	G Slack
D	2015-06-24	Revision based on client comments	J McMahon	T Gilbert	G Slack
E	2015-07-10	Minor revision	J McMahon	T Gilbert	G Slack

Table of contents

1 EXECUTIVE SUMMARY

DNV GL has been commissioned by Environmental Resources Management Australia Pty Ltd ("the Client" or "ERM") to independently assess the expected annual shadow flicker duration in the vicinity of the proposed Biala Wind Farm, on behalf of Newtricity who is developing the wind farm. The results of the work are reported here. This document has been prepared pursuant to DNV GL proposal 170223/PP/01 Issue A, dated 22 August 2013, and is subject to the terms and conditions therein.

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 Biala 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.

ERM has commissioned DNV GL to assess the shadow flicker based upon a layout provided for the Biala Wind Farm consisting of 31 wind turbines. A hypothetical turbine model with a hub height of 110 m and a blade diameter of 150 m has been considered, as requested by Newtricity [2]. Newtricity has also previously provided the locations of 17 dwellings in the vicinity of the wind farm [3] and elevation contours for the site area [5, 6]. These have been used to determine the theoretical duration of shadow flicker caused by the Biala Wind Farm at each dwelling.

The Draft NSW Planning Guidelines [8] recommend a shadow flicker limit of 30 hours per year. However, the Draft NSW Guidelines do not contain or recommend a methodology for assessing shadow flicker durations. Planning guidelines in a number of other jurisdictions [9, 10] refer to the EPHC Draft National Wind Farm Development Guidelines [11] 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 indicate that, of the dwellings identified by Newtricity for study, there are locations within 50 m of 5 dwellings that are predicted to experience some shadow flicker. Four of these locations are predicted to experience a theoretical shadow flicker duration in excess of the recommended limit of 30 hours per year, however these are all stakeholder dwellings. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to turbine orientation and cloud cover, the same 4 stakeholder dwellings are expected to experience shadow flicker durations in excess of the recommended limit of 10 hours per year within 50 m of the house location.

It is understood that Newtricity has approached the landholders of the 4 dwellings where the shadow flicker limits are predicted to be exceeded, and have obtained agreement from the landholders that the predicted shadow flicker durations are acceptable.

The prediction of the actual shadow flicker duration does not take into account any reduction due to low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours. Therefore, the values presented may still be regarded as conservative. The effects of shadow flicker can also 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 the relocation of turbines.

It should be noted that the results presented here have been generated based on a hypothetical turbine configuration with a 110 m hub height and 150 m blade diameter, as discussed in Section 2.2. 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

ERM has been commissioned by Newtricity to prepare the Environmental Impact Statement for the proposed Biala Wind Farm, to be developed approximately 8.5 km northeast of the town of Biala and 14.5 km southwest of the town of Crookwell, New South Wales. The terrain at the proposed Biala wind farm can be described as undulating, with elevations varying between approximately 750 m and 930 m above sea level. The site and surrounds can generally be described as open farmland interspersed with areas of denser vegetation and tall trees, particularly in the northeast section of the site.

Detailed elevation data for the site area up to 2 km from the wind farm boundary was obtained by Fugro Spatial Solutions on behalf of Newtricity [5]. This data was provided to DNV GL. Elevation data for areas further than 2 km from the wind farm boundary were obtained by DNV GL from the NSW Department of Land and Property Information [6]. The contours for the Biala Wind Farm are displayed in Figure 3.

2.2 Proposed Wind Farm Layout

The proposed turbine layout for the Biala Wind Farm is comprised of 31 wind turbine generators. The turbines are proposed to be located on top of low lying hills present across the site with base elevations ranging from approximately 813 m to 903 m above sea level.

DNV GL has modelled the shadow flicker using a hypothetical turbine with a 110 m hub height and 150 m blade diameter configuration, as requested by Newtricity [2]. These turbine dimensions are intended to encapsulate the turbine configurations under consideration for the site. The results generated based on these dimensions will be conservative for turbine configurations with dimensions that remain inside the turbine envelope by satisfying all of the following criteria:

- A rotor diameter of 150 m or less;
- A maximum blade chord of 5.7 m;
- An upper blade tip height of 185 m or less;
- A lower tip height of 35 m or greater.

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

2.3 House Locations

A list of houses neighbouring the wind farm was supplied to DNV GL by Newtricity [3]. Two houses, which were identified by DNV GL during a site visit on 6 April 2014, are also included in the list of houses assessed in this report.

The supplied list of houses also includes unbuilt house locations for which development approval has been granted. An unbuilt house location with development approval lying within the wind farm boundary (designated 'DA16' in this assessment) has been included in the assessment. A second stakeholder location has been identified but has not been included in the assessments at the request of Newtricity. This involved landholder has an agreement with Newtricity confirming that they will not act on this DA if the Project is approved [4].

The coordinates of dwellings in the vicinity of the wind farm are presented in Table 1. DNV GL has assumed that all listed houses 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 the Client.

3 PLANNING GUIDELINES

The Secretary's Environmental Assessment Requirements for the Biala Wind Farm (SEARs) [7] state the following with regard to shadow flicker:

> *"The EIS must address the following specific matters for both the wind farm and associated infrastructure: … the EIS must … assess the impact of shadow "flicker" [and] "blade glint" … from the wind farm."*

In addition, the Draft NSW Planning Guidelines for Wind Farms (Draft NSW Guidelines) [8] currently state:

> *"The impact of 'shadow flicker' from wind turbines on neighbours' houses within 2 km of a proposed wind turbine should be assessed. The shadow flicker experienced at any dwelling should not exceed 30 hours per year as a result of the operation of the wind farm. Specialist modelling software should be used to model shadow flicker impacts prior to the finalisation of the turbine layout."*

Although the Draft NSW Guidelines specify a shadow flicker limit (30 hours per year), neither the SEARs or the Draft NSW Guidelines specify a methodology for assessing shadow flicker impacts. Guidelines for wind farm development in other jurisdictions (including Victoria [9] and Queensland [10]) refer to the EPHC Draft National Wind Farm Development Guidelines (Draft National Guidelines) [11] with regard to the methodology for assessing shadow flicker. DNV GL has utilised this methodology to conduct shadow flicker assessments across Australia and has utilised it to assess the shadow flicker impact for the Biala Wind Farm.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration at a dwelling 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.

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the SEARs, Draft NSW 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 approximately 10 rotor diameters from a turbine [12] or approximately 800 to 1300 m for modern wind turbines (which typically have rotor diameters of 80 to 130 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 800 to 1325 m for modern wind turbines (which typically have maximum blade chord lengths of 3 to 5 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."*

The Draft National Guidelines also provide commentary on the negligible risk of distraction of vehicle drivers, and state the following:

> *"There is a negligible risk associated with distraction of vehicle drivers who experience shadow flicker, for the following reasons:*
>
> - *Shadow flicker is little different for a vehicle in motion than the effect of shadows from trees on the side of the road or high passing vehicles, neither of which represent a significant risk in terms of road transport.*
> - *In spite of extensive searches, no references to motor vehicle accidents caused by this phenomenon have been found.*
>
> *It is noted, however, that until wind farms become widespread in Australia they will represent a novelty that could cause distraction for drivers (regardless of shadow flicker). Consideration should be given to development of viewing areas for wind farms close to high volume roads."*

[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; 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 SEARs and Draft NSW Guidelines do not provide any guidance on this parameter. 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. Newtricity has nominated a turbine rotor diameter of 150 m for this study. DNV GL has assumed a maximum shadow length equivalent to the more conservative of the two approaches described above, and in this case, a length of 10 rotor diameters or 1500 m has been used. Under the Draft National Guidelines, this will be conservative for any turbine with a maximum blade chord of less than 5.7 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 2. 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 three Bureau of Meteorology (BoM) stations, located a distance of approximately 38 to 78 km from the site [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 two closest stations, Goulburn and Taralga, are both approximately 4.5 oktas. This means that on an average day, 4.5/8 or approximately 56% 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. An assessment of the likely reduction in shadow flicker duration due to cloud cover was conducted on a monthly basis, which indicated that a reduction of 52% to 61% is expected at the affected dwellings.

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 masts 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 2. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis, which indicated that a reduction of 17% to 29% 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 adjusted 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 assessment was carried out at all dwelling locations, or "receptors", located within 3 km of the proposed Biala 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. The maximum predicted theoretical shadow flicker durations within 50 m of these receptors are also presented in this table. The results are presented in the form of shadow flicker maps at 2 m and 6 m above ground in Figure 4 and Figure 5 respectively. Additionally, the results are presented in the form of shadow flicker duration contours in Figure 6 and Figure 7.

These results indicate that 4 of the existing stakeholder dwellings and one unbuilt dwelling with development approval are predicted to experience some shadow flicker based on the methodology recommended in the Draft National Guidelines. The same four stakeholder dwellings are also predicted to be affected by theoretical shadow flicker durations of greater than the NSW Guidelines recommended limit of 30 hours per year within 50 m of the house locations.

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. These adjusted results are presented as predicted actual shadow flicker durations in Table 4. Consideration of turbine orientation and cloud cover reduces the predicted shadow flicker duration by 61% to 70% at the dwellings affected by shadow flicker.

After reductions due to turbine orientation and cloud cover are taken into account, the same 4 stakeholder dwellings are predicted to be subject to an actual shadow flicker duration above the limit of 10 hours within 50 m of the house location, as recommended in the Draft National Guidelines.

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 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

If shadow flicker presents a problem, its effects can be reduced through a number of measures. These include 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.

It should be noted that the results presented here have been generated based on a hypothetical turbine model with a 110 m hub height and 150 m blade diameter configuration, as discussed in Section 2.2. If the turbine eventually selected for the site has dimensions smaller than those considered here, but still within the hypothetical turbine envelope, then shadow flicker durations in the vicinity of the site are likely to be lower than those predicted here.

6 CONCLUSION

An analysis has been conducted to determine the annual duration of shadow flicker experienced at dwellings in the vicinity of the proposed Biala 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 4 to Figure 7. The shadow flicker results for each house location predicted to be affected by shadow flicker are also listed in Table 4.

The assessment of theoretical shadow flicker duration shows that 5 of the dwellings identified by Newtricity are predicted to experience some level of theoretical shadow flicker within 50 m of the house location. Four of these dwellings are also predicted to be affected by theoretical shadow flicker durations of greater than the NSW Guidelines recommended limit of 30 hours per year within 50 m of the house locations, however these are all stakeholder dwellings.

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 the same 4 stakeholder dwellings are predicted to experience actual annual shadow flicker durations within 50 m of the house location that are in excess of the limit of 10 hours recommended in the Draft National Guidelines.

It is understood that Newtricity has approached the landholders of the four dwellings where the shadow flicker limits are predicted to be exceeded, and have obtained agreement from the landholders that the predicted shadow flicker durations are acceptable.

The calculation of the predicted actual shadow flicker duration does not take into account any reduction due to low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours. Therefore, the values presented may still be regarded as a conservative assessment.

If shadow flicker presents a problem, mitigation strategies to reduce the duration of shadow flicker experienced at a dwelling can include: 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.

7 REFERENCES

1. "Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines", Freund H-D, Kiel F.H., DEWI Magazine No. 20, Feb 2002, pp43-51.
2. Email from A. Lavery of Newtricity to T. Gilbert of DNV GL, 14 December 2014.
3. Emails from A. Lavery of Newtricity to D. Price of DNV GL, 3, 4, 7, 18 March, 5 April 2014.
4. Email from E. Dethridge of ERM to T. Gilbert of DNV GL, 25 February 2015.
5. Data files received from Fugro Spatial Solutions on 22 May 2014.
6. Data files received from NSW Department of Land and Property Information on 14 April 2014.
7. "Secretary's Environmental Assessment Requirements (SSD 13_6039), NSW Planning and Infrastructure, 19 May 2015.
8. "Draft NSW Planning Guidelines Wind Farms", NSW Planning and Infrastructure, December 2011.
9. "Policy and planning guidelines for development of wind energy facilities in Victoria", Sustainable Energy Authority Victoria, July 2012.
10. "Wind farm state code, Planning guideline – draft for consultation", Queensland Department of State Development, Infrastructure and Planning, April 2014.
11. "National Wind Farm Development Guidelines – Public Consultation Draft", Environmental Protection and Heritage Council (EPHC), Jul 2010.
12. "Planning for Renewable Energy – A Companion Guide to PPS22", Office of the Deputy Prime Minister, UK, 2004
13. "Climate statistics for Australian locations – Gurnang State Forest", Bureau of Meteorology, viewed 15 January 2015, http://www.bom.gov.au/climate/averages/tables/cw_063033.shtml
14. "Climate statistics for Australian locations – Taralga Post Office", Bureau of Meteorology, viewed 15 January 2015, http://www.bom.gov.au/climate/averages/tables/cw_070080.shtml
15. "Climate statistics for Australian locations – Goulburn TAFE", Bureau of Meteorology, viewed 15 January 2015, http://www.bom.gov.au/climate/averages/tables/cw_070263.shtml

List of Tables

List of Figures

House ID	Easting[1] (m)	Northing[1] (m)	Type	Status	Distance to nearest turbine (m)
HS01[2]	716458	6172607	House	Stakeholder	911
HS02[2]	716378	6172571	House	Stakeholder	912
HN03	714805	6174684	House	Non-Stakeholder	2409
HN04	713279	6174207	House	Non-Stakeholder	2598
HN05	716899	6174610	House	Non-Stakeholder	2243
HN06	718838	6173981	House	Non-Stakeholder	2004
HN07	719217	6173652	House	Non-Stakeholder	2062
HS08[2]	718825	6171869	House	Stakeholder	962
HN09	717729	6169285	House	Non-Stakeholder	2005
HS10[2]	713039	6171444	House	Stakeholder	1002
HN11	717228	6168754	House	Non-Stakeholder	2001
HN12	716395	6167298	House	Non-Stakeholder	2035
HN13	711857	6166539	House	Non-Stakeholder	2377
HN14	711969	6166279	House	Non-Stakeholder	2382
HN15	711963	6169014	House	Non-Stakeholder	2442
DA16[2, 3]	717303	6170119	DA house	Stakeholder	1093
HN17	718838	6169071	House	Non-Stakeholder	2920

Notes:
1. Coordinate system is WGS84 Zone 55H
2. Project stakeholders are highlighted in the above table.
3. Location with development approval for a house.

Table 1: Dwelling locations within 3 km of turbines at the proposed Biala Wind Farm

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]
T01	717864	6171824	897
T02	717535	6172459	874
T03	717211	6172095	893
T04	716535	6170896	902
T05	716389	6171280	902
T06	716235	6171670	898
T07	716003	6170542	903
T08	715899	6170905	882
T09	715503	6171219	867
T10	715337	6171583	858
T11	715269	6171908	845
T12	715149	6172300	836
T13	715415	6170615	871
T14	715165	6170992	900
T15	714719	6171266	864
T16	714332	6171832	827
T17	714042	6171415	823
T18	715593	6169908	893
T19	715322	6170274	890
T20	714763	6170375	870
T21	714201	6170556	862
T22	713921	6170969	823
T23	714064	6170175	862
T24	715042	6169630	876
T25	714491	6169769	856
T26	715169	6169139	859
T27	714673	6168987	864
T28	714425	6169376	836
T29	714657	6168605	850
T30	714409	6167741	832
T31	714079	6167384	813

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

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

Model Setting	Value
Maximum shadow length	1500 m
Year of calculation	2027
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (Disc for turbine 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[1]	25 m grid centred on house location

[1] In addition to the 25 m resolution grid points, points were added every 45° on a 50 m radius circle centred on the house location.

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

House ID	Easting[1] [m]	Northing[1] [m]	Dwelling status	Contributing Turbines	Theoretical Annual: At Dwelling[2] [hr/yr]		Theoretical Annual: Max Within 50 m of Dwelling[2] [hr/yr]		Predicted Actual Annual[3]: At Dwelling[2] [hr/yr]		Predicted Actual Annual[3]: Max Within 50 m of Dwelling[2] [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
HS01	716458	6172607	Stakeholder	T02, T12	27.8	29.6	32.2	31.8	9.6	10.2	11.0	10.9
HS02	716378	6172571	Stakeholder	T02, T03, T12	29.0	29.8	51.8	51.7	9.5	9.3	18.5	18.6
HS08	718825	6171869	Stakeholder	T01, T02	31.4	30.3	35.0	33.6	11.0	10.6	12.1	11.6
HS10	713039	6171444	Stakeholder	T16, T17, T22	51.8	52.7	70.4	70.8	17.4	17.8	25.7	26.0
DA16	717303	6170119	Development Approval	T07	9.4	9.0	10.4	10.0	3.6	3.5	4.0	3.8
Limits				**n/a**	**30**		**30**		**10**		**10**	

[1] UTM Zone 55 (WGS84 datum)
[2] Dwellings with zero hours shadow flicker have been omitted from this table, and values above the recommended limits are highlighted in red
[3] Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation

Table 4: Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker.

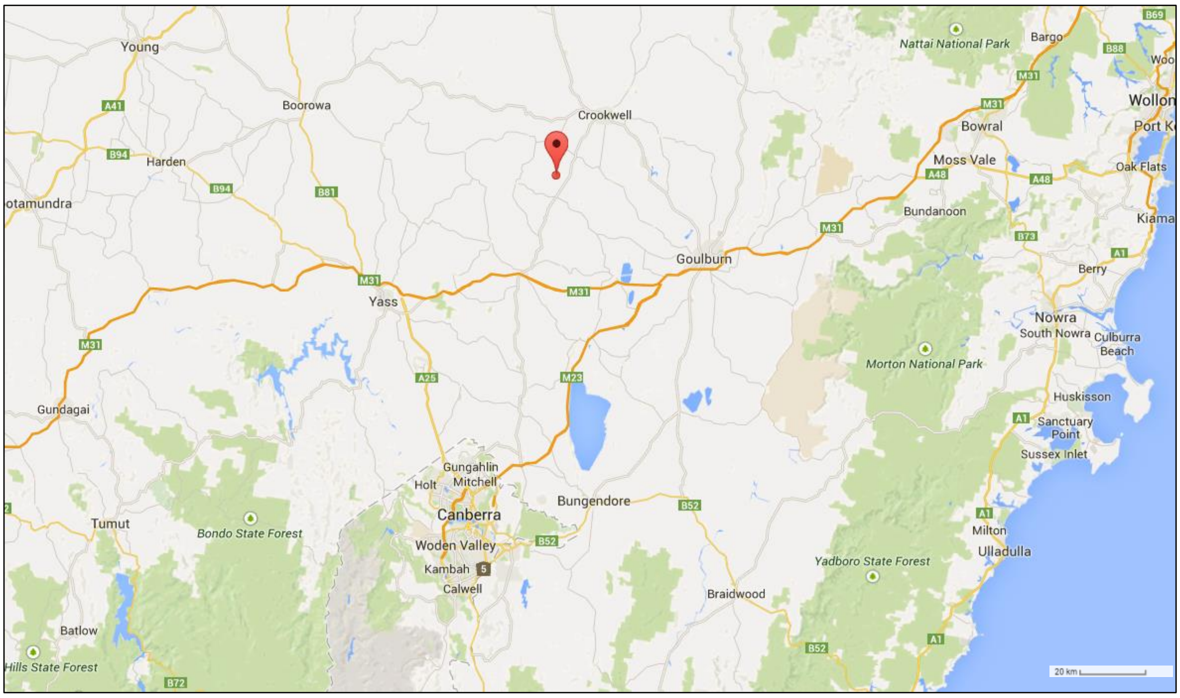

Figure 1: Location of the proposed Biala Wind Farm

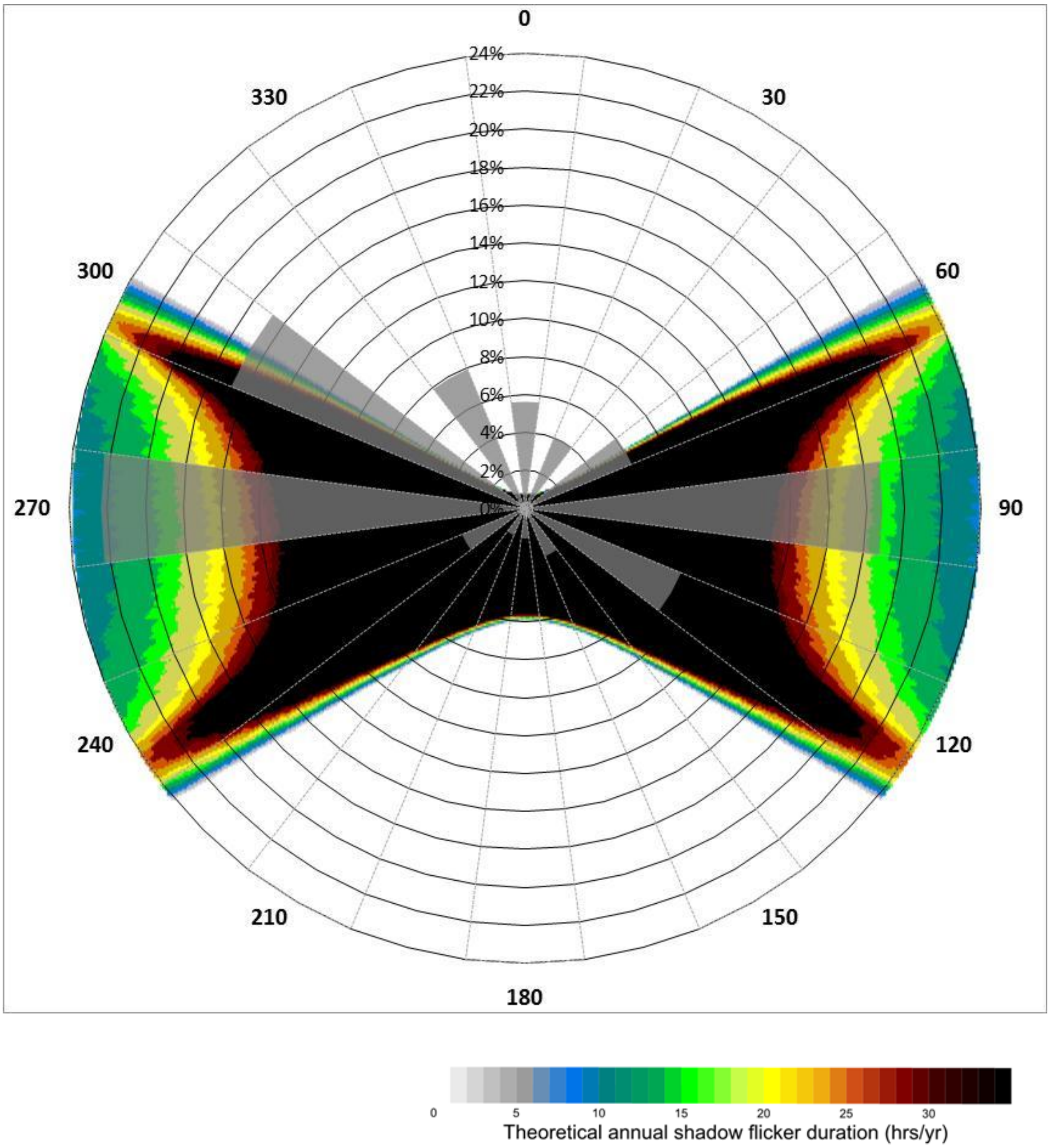

Figure 2: Indicative shadow flicker map and wind direction frequency distribution

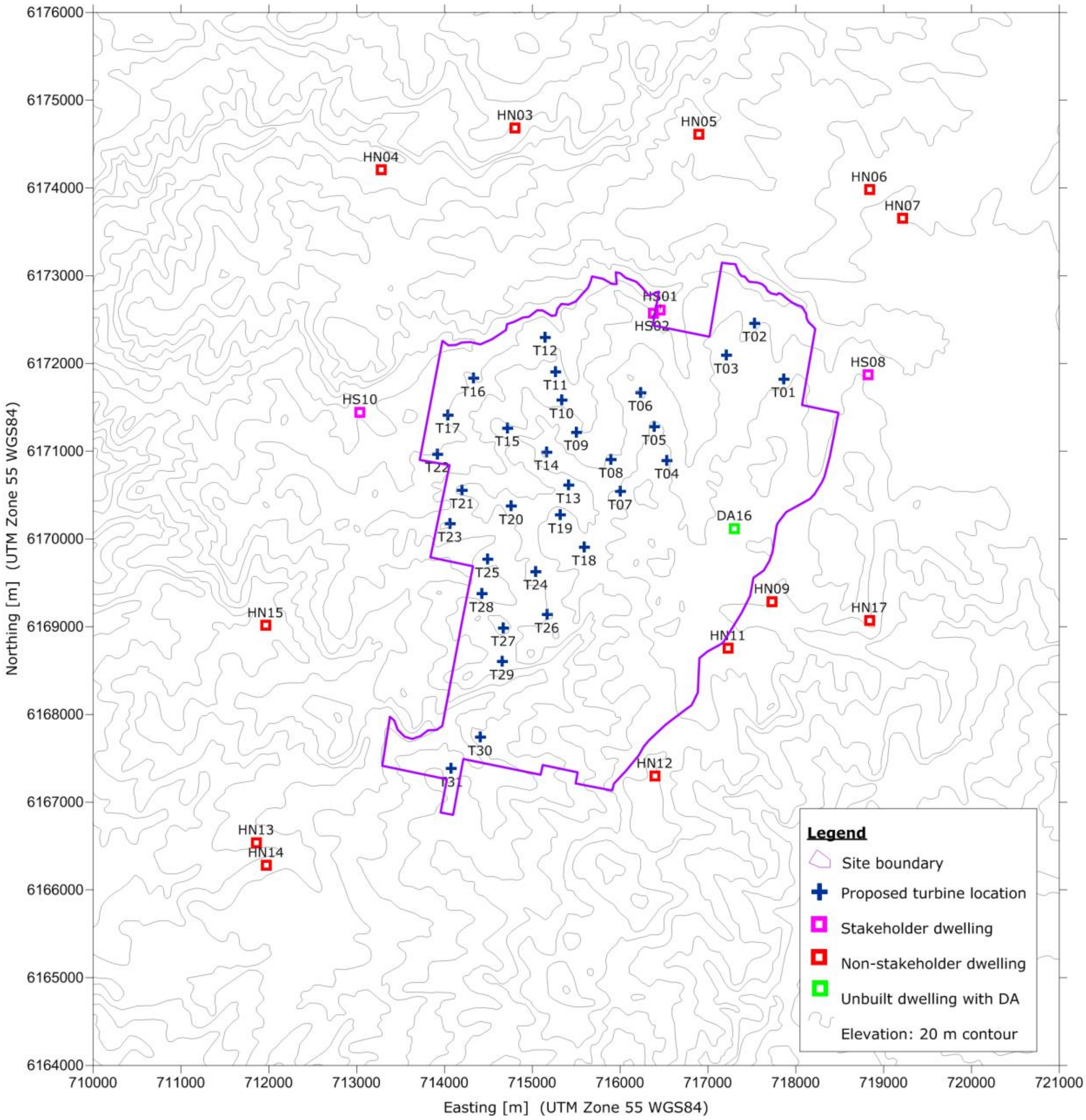

Figure 3: Map of the proposed Biala Wind Farm with turbines, stakeholder dwelling, non-stakeholder and development approval dwelling locations.

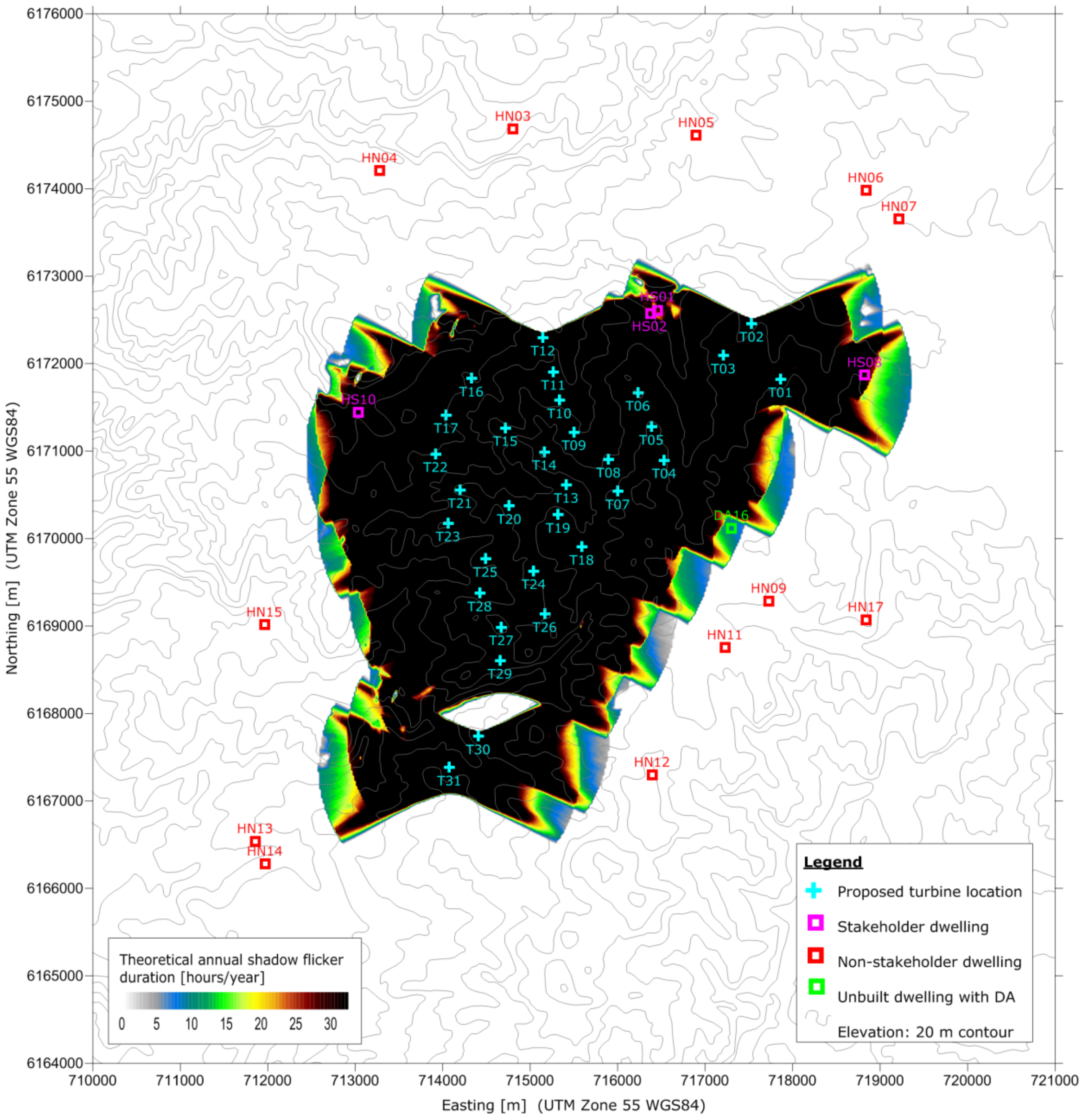

Figure 4: Map of the proposed Biala Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level

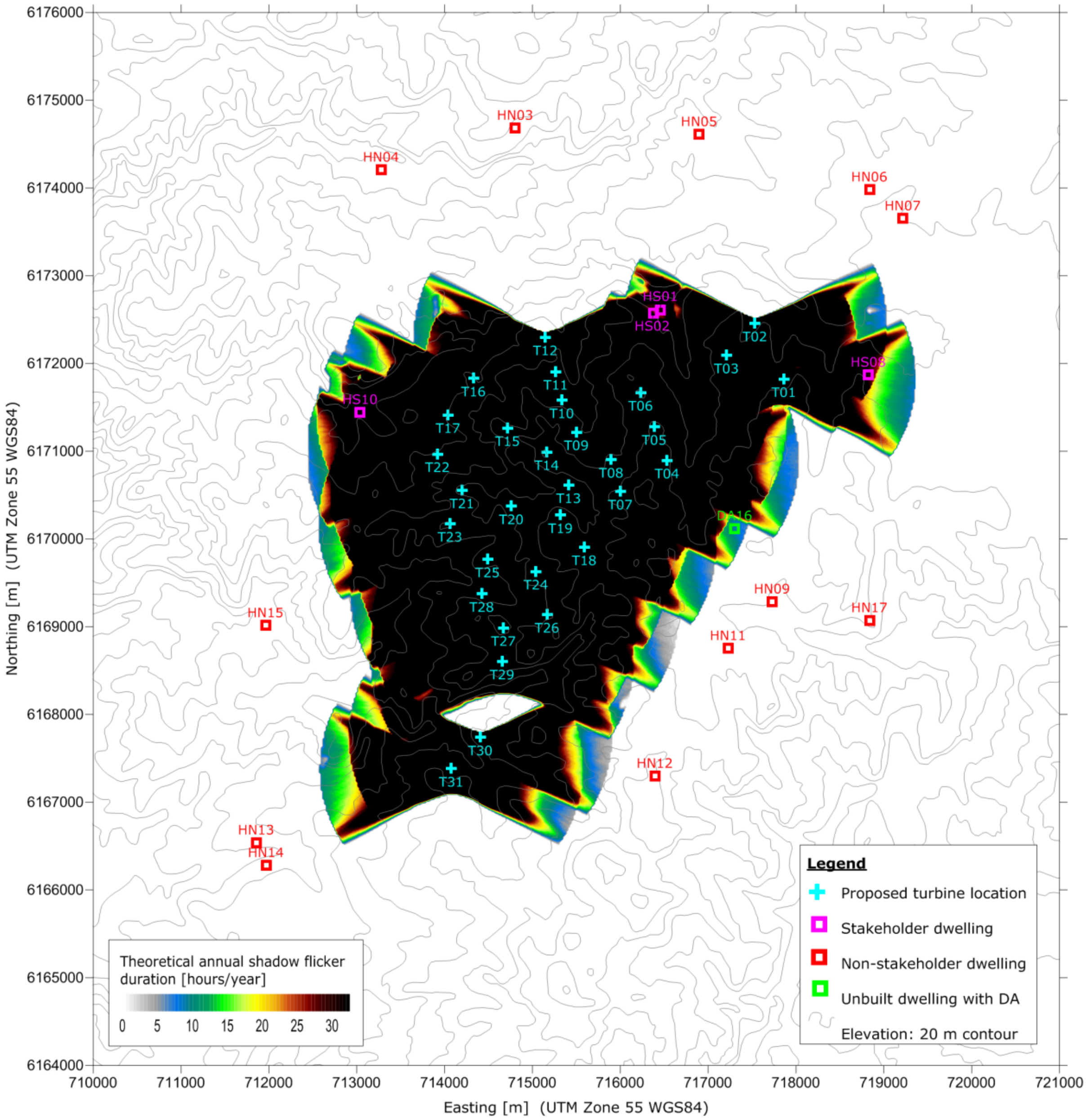

Figure 5: Map of the proposed Biala Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level

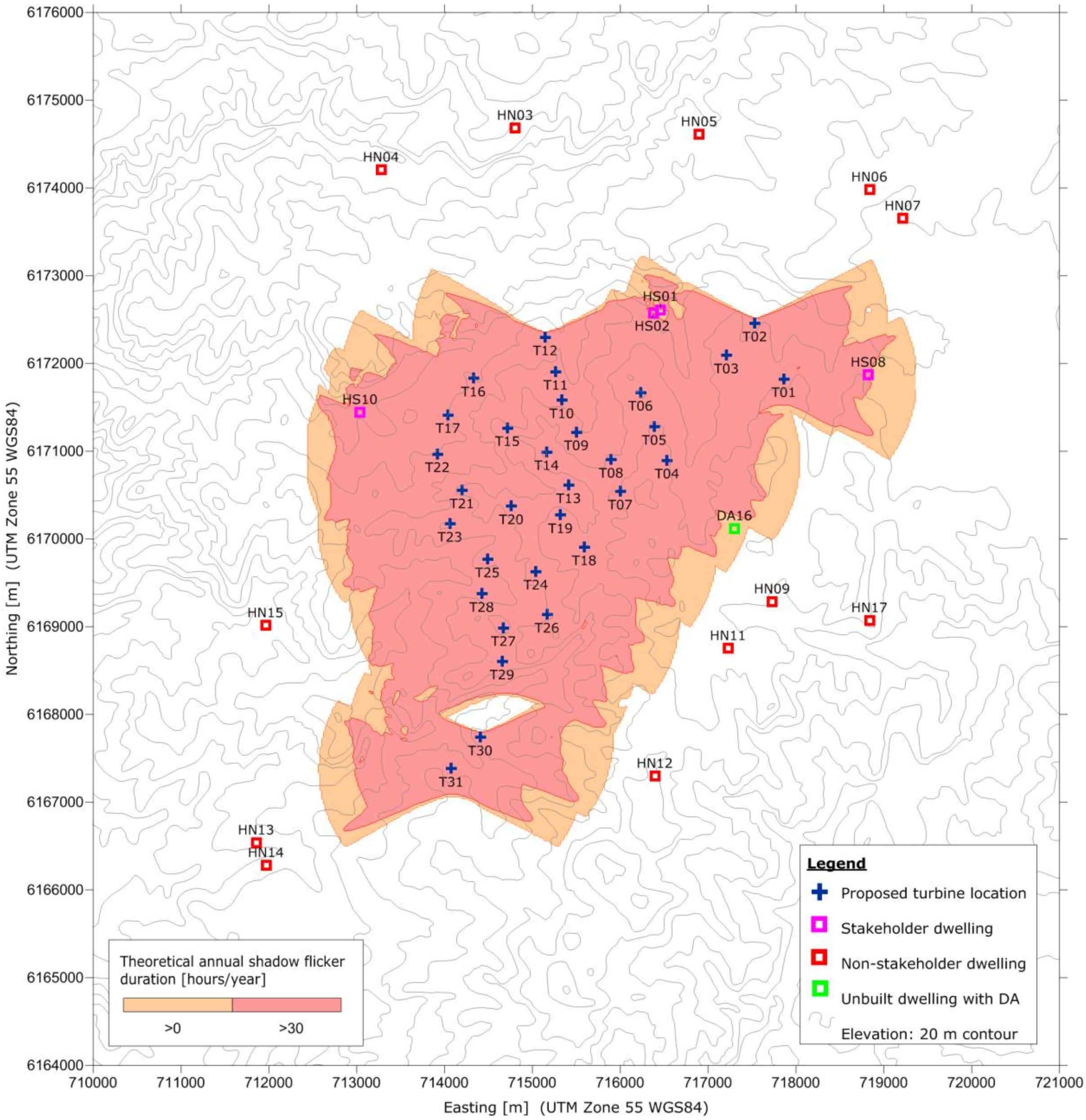

Figure 6: Map of the proposed Biala Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level

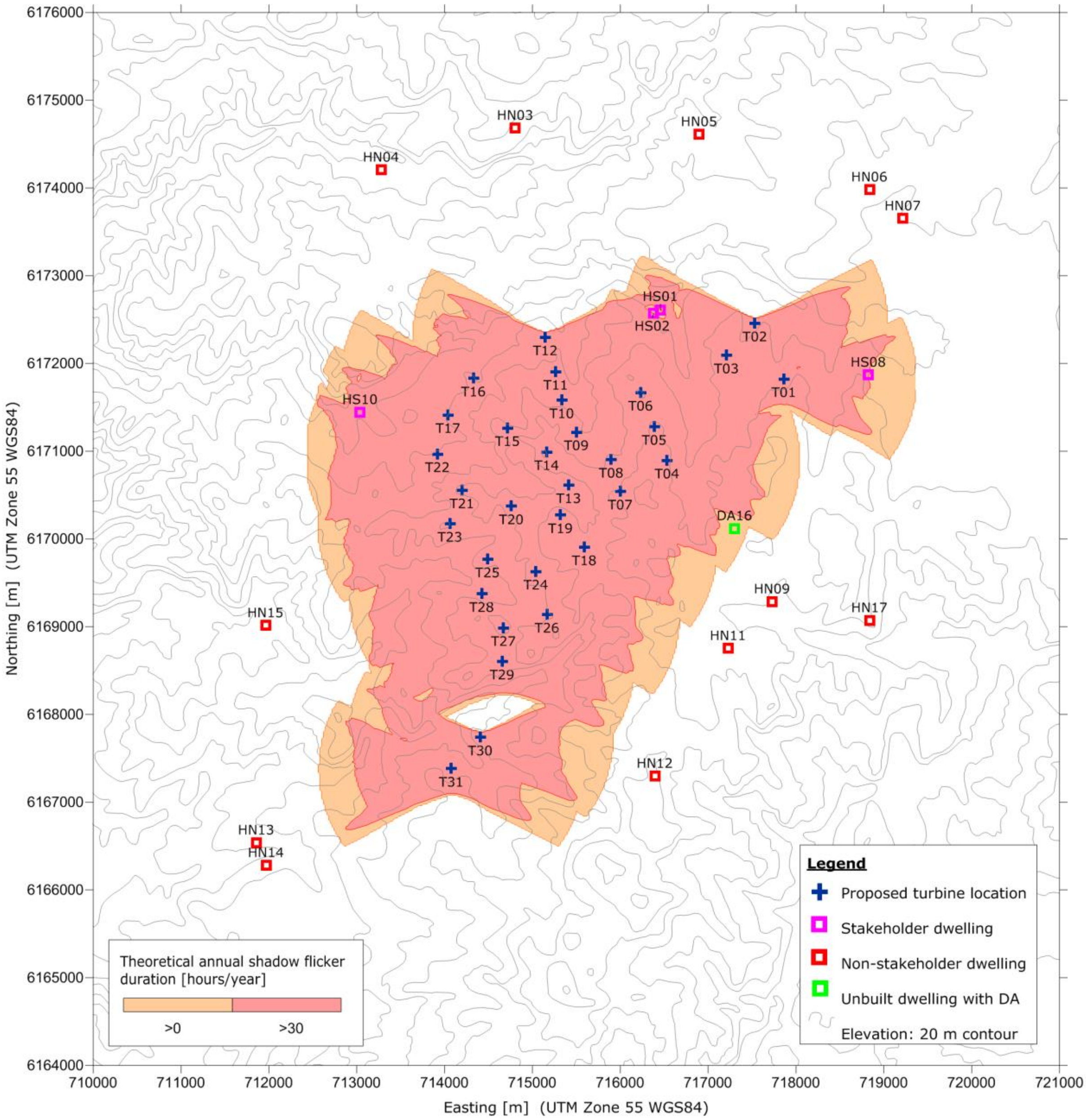

Figure 7: Map of the proposed Biala Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.