ST PATRICKS PLAINS WIND FARM

Shadow Flicker Assessment

Epuron Projects Pty Ltd

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Wind Farm Shadow Flicker and Blade Glint Assessment

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EXECUTIVE SUMMARY

DNV has been commissioned by Epuron Projects Pty Ltd ("the Proponent") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed St Patricks Plains Wind Farm ("the Project") in Tasmania. The results of the shadow flicker assessment are described in this document.

Background and methodology

DNV has assessed the expected annual shadow flicker durations for the Project with methodology informed by the Draft National Wind Farm Development Guidelines [1] (Draft National Guidelines), the Guidelines for Development of Wind Energy Facilities in Victoria [2] (Victorian Planning Guidelines), and standard industry practices. The Draft National Guidelines and the Victorian Planning Guidelines have been suggested by EPA Tasmania to aid preparation of the Environmental Impact Statement for the St Patricks Plains Wind Farm [3].

The Draft National Guidelines [1] recommend limits of 30 hours per year on the theoretical shadow flicker duration, and 10 hours per year on the actual shadow flicker duration. In addition, the Victorian Planning Guidelines recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling.

A Project layout consisting of 47 wind turbines with a proposed rotor diameter of 162 m and hub height of 150 m has been considered. Seventeen dwellings in the area surrounding the Project have been considered for this assessment. Five of these dwellings are participating dwellings belonging to wind farm host landowners or landowners who have entered into a formal agreement with the Proponent. The remaining 12 dwellings are neighbour dwellings.

The theoretical shadow flicker durations at dwellings in the vicinity of the Project 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 turbine orientation and cloud cover.

Assessment results

The results of the shadow flicker assessment are summarised in Table 4.

Based on this assessment, a number of dwellings are expected to experience some shadow flicker above a moderate level of intensity, which may occur up to a distance of around 10 rotor diameters from the wind farm.

A total of seven dwellings are predicted to experience some shadow flicker above a moderate level of intensity, of which five are participating dwellings and two are neighbour dwellings.

Out of the five participating dwellings predicted to experience some shadow flicker above a moderate level of intensity, four are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. When considering the likely reduction in duration due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of two participating dwellings remain slightly above the recommended limit of 10 hours per year.

Out of the two neighbour dwellings predicted to experience some shadow flicker above a moderate level of intensity, one is predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. When considering the likely reduction in duration due to cloud cover and rotor orientation, the predicted actual shadow flicker duration within 50 m of the one neighbour dwelling remains slightly above the recommended limit of 10 hours per year.

The calculation of the predicted actual shadow flicker duration does not take into account other potential reductions due to low wind speed, vegetation, or other shielding effects around each house in calculating the number of shadow flicker hours.

The Proponent has advised DNV [4] that they have an intention to reduce or manage the actual shadow flicker duration at the O7-1 neighbour dwelling where the predicted actual shadow flicker duration is in excess of the 10 hours per year limit recommended by the Draft National Guidelines [1]. The Proponent has proposed that these measures may include the planting of trees and vegetation; installation of additional screening structures, industrial strength curtains or blinds; or curtailment of the turbines contributing most significantly to shadow flicker at the dwelling. The turbines contributing most significantly to shadow flicker in the 50 m area surrounding the neighbour dwelling has been identified from the modelled theoretical shadow flicker durations, and this can be useful to guide a curtailment strategy aiming to reduce the occurrence of shadow flicker at this neighbour dwelling.

The effects of blade glint have not been quantified in this study as the Victorian Planning Guidelines [2] and the National Wind Farm Development Guidelines – Draft [1] do not provide any quantification methodology. The guidelines, however, recommend that the Proponent ensures that the turbine blades used have a surface finish with a low reflectivity to avoid occurrences of blade glints.

1 INTRODUCTION

Epuron Projects Pty Ltd ("the Proponent") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed St Patricks Plains Wind Farm ("the Project") in central Tasmania. The results of this work are reported here. This document has been prepared in accordance with DNV proposal L2C-226991-AUMEL-P-01 Issue A, dated 18 January 2022 (note proposal is incorrectly dated 2021), and is subject to the terms and conditions in that agreement.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed turbine layout [5] and configuration using a methodology informed by the Draft National Wind Farm Development Guidelines (Draft National Guidelines) prepared by the Environment Protection and Heritage Council (EPHC) in July 2010 [1], the Policy and Planning Guidelines for Development of Wind Energy Facilities in Victoria (Victorian Planning Guidelines) prepared by the Victorian Department of Environment, Land, Water and Planning in July 2021 [2], and standard industry practices [6, 7, 8]. The Draft National Guidelines and Victorian Planning Guidelines have been suggested by EPA Tasmania to aid preparation of the Environmental Impact Statement for the St Patricks Plains Wind Farm [3].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The proposed St Patricks Plains Wind Farm ("the Project") is located approximately 70 km south-west of Launceston, and lies on a central plateau surrounded by the Great Lake, Arthurs Lake, the Lagoon of Islands, and Lake Echo. An overview of the Project location is presented in Figure 2.

The site is located on the central highlands surrounded by several ridges or peaks, with elevations ranging approximately 750 m to 1000 m above mean sea level (ASL). A digital elevation model (DEM) extending approximately 20 km from the site was acquired from publicly available SRTM1 data [9].

2.2 The project

2.2.1 Proposed wind farm layout

The Project is composed of 47 wind turbines [5]. A map of the site with the proposed turbine layout is shown in Figure 3, and the coordinates of the proposed turbine locations are given in Table 1.

DNV has modelled the shadow flicker based on a turbine model with a rotor diameter of 162 m and a hub height of 150 m [5]. The maximum blade chord length for the turbine, defined as the dimension through the thickest part of the blade, is 4.32 m [5].

2.2.2 Shadow receptor locations

A list of 60 dwellings within 5 km of the proposed St Patricks Plains wind farm was provided to DNV by the Proponent [5]. Seventeen dwellings have been identified as having the potential to experience shadow flicker, and have been considered in this assessment. The coordinates of these 17 dwellings are presented in Table 2.

Out of the 17 dwellings identified:

- five are participating dwellings belonging to wind farm host landowners or landowners who have entered into a formal agreement with the Proponent, and
- twelve are neighbour dwellings.

The remaining 43 dwellings are at locations that are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1.

It should be noted that the scope of the current work did not include a comprehensive survey of sensitive land uses and building locations in the area, and so DNV is relying on information provided by the Proponent.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

EPA Tasmania has issued project specific guidelines for the preparation of an Environmental Impact Statement (EIS) of the St Patricks Plains Wind Farm to Epuron Pty Ltd [3]. In relation to shadow flicker, the document states that:

> *"Shadow flicker should be modelled to assess the likelihood of disturbance to any residents in the immediate vicinity. The results of the modelling should be provided in the EIS with a discussion of how this will be managed or minimised."*

Methodology for the quantification of shadow flicker impacts and a regulation of acceptable limits were not provided by the project specific guidelines [3]. Instead, the project specific guidelines suggest that the Draft National Guidelines [1] and the Victorian Planning Guidelines [2] may be of use to prepare the EIS.

In relation to shadow flicker, the Victorian Planning Guidelines [2] 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."*

The Victorian Planning Guidelines also include the following example permit condition:

> *"Shadow flicker from the wind energy facility must not exceed 30 hours per annum at any pre-existing dwelling (insert date), unless an agreement has been entered into with the relevant landowner waiving this requirement. The agreement must be in a form that applies to the land comprising a pre-existing dwelling for the life of the wind energy facility, to the satisfaction of the responsible authority, and must be provided to the responsible authority upon request."*

Although the Victorian Planning Guidelines state that *"[t]he seasonal duration of [shadow flicker] can be calculated from the geometry of the machine and the latitude of the site [and] modelled in advance"*, they do not provide detailed methodologies for these calculations.

The Draft National Guidelines [1], however, include recommendations for shadow flicker limits relevant to wind farms in Australia and advice and methodologies for assessing shadow flicker durations.

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 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 assumes that the evaluation of the maximum shadow flicker duration within 50 m of a dwelling (as required by the Draft National Guidelines) is similar to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be adequate, however it is acknowledged that, in rural areas, the 'garden fenced area' may extend beyond 50 m from a dwelling.

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

The Draft National Guidelines also 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 [7, 8] or approximately 1200 m to 1900 m for modern wind turbines (which typically have rotor diameters of 120 m to 190 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 times the maximum blade chord as an appropriate limit, which corresponds to approximately 1000 m to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 m to 6 m).

For the purposes of this assessment, DNV has considered the guidance and recommendations given in the Draft National Guidelines, the Victorian Planning Guidelines, and standard industry practices in relation to shadow flicker.

3.2 Blade glint

Blade glint involves the regular reflection of the 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. Blade glint is not generally a problem for modern wind turbines [2, 1].

Methodology for the quantification of blade glint impacts as well as a regulatory limit were not provided by any of the project specific guidelines [3], the Victorian Planning Guidelines [2], and the Draft National Guidelines [1]. A common resolution from the Victorian Planning Guidelines and the Draft National Guidelines suggest that the Proponent ensures the blades of the wind turbines have a finish with low reflectivity. Specific text extracts from these documents are provided below.

In relation to blade glint, the project specific guidelines from EPA Tasmania [3] states that:

> *"A blade glint assessment should be included in the EIS to determine the likelihood of disturbance to any residents in the immediate vicinity."*

In relation to blade glint, guidance from the Victorian Planning Guidelines [2] states that:

> *"Blades should be finished with a surface treatment of low reflectivity to ensure that glint is minimised."*

In relation to blade glint, guidance from the Draft National Guidelines [1] states that:

> *"Blade glint can be produced when the sun's light is reflected from the surface of wind turbine blades. Blade glint has potential to annoy people.*
>
> *All major wind turbine blade 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.*
>
> *Proponents should ensure that blades from their supplier are of low reflectivity."*

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 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:

- the direction of the property relative to the turbine
- the distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be)
- 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)
- the turbine 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).

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

Figure 1 Examples of wind turbine 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 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 that the rotors of the turbines are disks that 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, 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 surveyed house locations and has determined the highest shadow flicker duration within 50 m of each of the provided 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 at the receptor may be facing a particular direction less affected by shadows cast from the turbines. 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 wind turbine that is likely to cause annoyance due to shadow flicker (the zone of influence of shadows). The UK wind industry and planning guidelines in the UK suggest that a distance of 10 rotor diameters (10D) may be appropriate [7, 8], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord (265C) as an appropriate distance.

The determination of the distance of 265C for the zone of influence of shadows suggested by the Draft National Guidelines is provided in Appendix E.7 of [1], and explains that the distance of 10D for the zone of influence of shadows was actually the basis for the derivation of the distance of 265C at the time of publication of the Draft National Guidelines.

DNV notes that the recommendation of a distance of 265C can only be found in the Draft National Guidelines and the Queensland State Government planning guidance State Code 23 [10], and that standard practice in the European wind industry is to still consider a distance of 10D for the zone of influence of shadows [6, 11]. In at least one instance, DNV has also observed evidence of shadow flicker at or beyond 10D from wind turbines. Although the level of annoyance caused by shadow flicker can be subjective, this demonstrates the potential for its effects to extend to at least a distance of 10D, regardless of the durations of these shadow flicker occurrences. This is supported by the following reports [8, 11]. As such, DNV typically considers the greater of the 10D and 265C distances for shadow flicker assessments.

For the current assessment, DNV has applied a maximum shadow length of 10D, which corresponds to a distance limit of 1620 m. Beyond this 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 may therefore be affected by shadow flicker intensities below the moderate level of intensity assumed by this distance limit. To account for this possibility, and although not suggested by the Draft National Guidelines [1], DNV has also assessed the shadow flicker for an increased distance limit of 15 times the rotor diameter (15D), or 2430 m, to include the potential for shadow flicker that is below a moderate level of intensity.

In this report shadow flicker of a moderate level of intensity or above is assumed to occur up to a distance of approximately 10D from the wind farm. Conversely, shadow flicker below a moderate level of intensity is assumed to occur beyond a distance of 10D and up to a distance of approximately 15D from the wind farm.

The model also makes the following assumptions and simplifications:

- there are clear skies every day of the year
- the plane of rotation of the blades of the turbines is always perpendicular to the direction of the line of sight from the location of interest to the Sun
- the turbine blades are always rotating, inherently assuming continuous wind flow across the site.

The first two of these items are addressed in the calculation of the predicted actual shadow flicker duration as described in Section 4.1.4. The third item is not considered but is unlikely to have a significant impact on the results. 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 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 turbine 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 turbine increases, increasing the area around the turbine 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 wind turbine will not always be oriented such that its rotor is in the worst-case position (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 overestimation of the 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.

4.1.4 Predicted actual duration

As discussed 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:

- Shannon Hec (096021), located approximately 8 km from the centre of the site [12],
- Liawenee (096033), located approximately 25 km from the centre of the site [13],
- Tarraleah Village (095018), located approximately 40 km from the centre of the site [14],
- Melton Mowbray (North Stockman) (094201), located approximately 55 km from the centre of the site [15],
- Ross (The Boulevards) (093053), located approximately 55 km from the centre of the site [16].

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 58% and 70%, and the average annual cloud cover is approximately 65%. This means that on an average day, 65% 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 duration 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. Wind direction frequency distributions derived from wind measurements at the site were provided by the Proponent [17] 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 turbine 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 turbine orientation, be included. However, DNV considers that the 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. 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.

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.

4.2 Blade glint

As discussed in Section 3.2, a methodology for the quantification of blade glint impacts were not provided by any of the project specific guidelines [3], the Victorian Planning Guidelines [2], and the Draft National Guidelines [1].

5 ASSESSMENT RESULTS

5.1 Shadow flicker

Shadow flicker assessments were carried out at all provided dwelling locations, or ‘receptors’, as outlined in Table 2.

The theoretical and predicted actual shadow flicker durations at all dwellings identified to be affected by shadow flicker based on modelling parameters discussed in Section 4.1 are presented in Table 4. The maximum predicted shadow flicker durations within 50 m of these receptors are also presented in this table. 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.

In addition to the assessment based on standard DNV methodology, the Proponent has also requested calculation of the theoretical and predicted actual shadow flicker durations at dwellings using a distance of 265C for the zone of influence of shadows [18]. The results from this calculation are presented in Table 5, but these results have *not* been used as the basis for evaluating compliance in this assessment.

Based on DNV’s modelling, a number of dwellings are predicted to experience some shadow flicker of at least a moderate level of intensity, which is expected to occur up to a distance of around 10 rotor diameters from the wind farm. A total of seven dwellings are predicted to experience some shadow flicker above a moderate level of intensity, five of which are participating dwellings and two of which are neighbour dwellings.

Out of the five participating dwellings, four are predicted to experience theoretical shadow flicker durations within 50 m of the dwelling that exceed the limit recommended by the current guidelines. When considering the likely reduction due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of two participating dwellings remain slightly above the recommended limit of 10 hours per year.

Out of the two neighbour dwellings, one is predicted to experience theoretical shadow flicker durations within 50 m of the dwelling that exceed the limit recommended by the current guidelines, and this is neighbour dwelling O7-1. When considering the likely reduction due to cloud cover and rotor orientation, the predicted actual shadow flicker duration within 50 m of the one neighbour dwelling remains slightly above the recommended limit of 10 hours per year.

It is likely that some form of mitigation, including turbine curtailment, may be required to limit shadow flicker durations so that the Project adheres to limits suggested in the relevant guidelines [2, 1]. Mitigation options are briefly discussed in Section 5.1.1. It should be noted that if implementing turbine curtailment as a component of the shadow flicker mitigation strategy, this will likely result in a reduction in the energy output of the wind farm.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a moderate level of intensity and thus unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker below a moderate level of intensity that may occur beyond this distance limit. To account for this possibility, and although not part of the methodology outlined in the Draft National Guidelines, DNV has also assessed the shadow flicker impacts for the Project using an extended distance for the zone of influence of shadows intended to capture the occurrence shadow flicker that is below a moderate level of intensity. For the purpose of this assessment, to account for shadow flicker that is below a moderate level of intensity, the distance limit has been increased by 50% (to 15D), and the results of this additional assessment are illustrated in the map presented in Figure 5. These results indicate the possibility for five additional dwellings to experience some shadow flicker that is below a moderate level of intensity. These dwellings are noted in Table 4.

5.1.1 Mitigation options

The effects of shadow flicker may be reduced through a number of mitigation options such as the removal or relocation of turbines, the use of smaller turbines, installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies (or shadow flicker protection systems) which shut down turbines when shadow flicker is likely to occur.

The Proponent has advised DNV [4] that they have an intention to reduce or manage the actual shadow flicker duration at the one neighbour dwelling where the predicted actual shadow flicker duration is in excess of the 10 hours per year limit recommended by the Draft National Guidelines [1]. This neighbour dwelling is O7-1 as shown in Table 4. The Proponent has proposed that measures may include the planting of trees and vegetation; installation of additional screening structures, industrial strength curtains or blinds; or curtailment of the turbines contributing most significantly to shadow flicker at these dwellings. Specifically regarding curtailment strategies, the Proponent has informed DNV that they have contacted wind turbine manufacturer Vestas for the potential to include a shadow flicker detection system [19] into turbines which contribute most significantly to shadow flicker at neighbour dwellings [20].

The turbines contributing most significantly to shadow flicker at the affected neighbour dwelling can be identified through their individual contributions to the theoretical shadow flicker duration within 50 m of the receptor where the theoretical shadow flicker duration exceeds 30 hours per year [1]. This can be useful to guide a curtailment strategy aiming to reduce the occurrence of shadow flicker at neighbour dwelling.

For neighbour dwelling O7-1, the maximum theoretical shadow flicker duration within 50 m of the receptor point occurs to the southwest of the dwelling, and at 2 m height above ground level representative of the elevation of a window at the ground level of a dwelling. Turbines contributing to the theoretical shadow flicker durations here are turbines T01, T02, and T68. The modelled time of occurrences of the theoretical shadow flicker from these turbines over a modelled year is shown in the hourglass plot in Figure 7. The figure shows that turbine T02 contributes most to the theoretical shadow flicker duration, and is predicted to be most prevalent in the evening over the Australian summer months of November to January of the modelled year.

5.2 Blade glint

As discussed in Section 3.2, blade glint is not expected to be an issue for the project provided a non-reflective finish is applied to the wind turbine blades.

6 CONCLUSIONS

A shadow flicker assessment was carried out at all dwelling locations in the vicinity of the Project. For the purpose of this assessment, DNV has considered a layout consisting of 47 turbines with a rotor diameter of 162 m and a hub height of 150 m. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 4.

Based on the modelling conducted by DNV, seven dwellings are predicted to experience some shadow flicker above a moderate level of intensity, five of which are participating dwellings and two of which are neighbour dwellings.

Out of the five participating dwellings, four are predicted to experience theoretical shadow flicker durations within 50 m of the dwelling that exceed the limit recommended by the current guidelines. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker duration within 50 m of two participating dwellings are expected to remain slightly above the limit recommended in the guidelines.

Out of the two neighbour dwellings predicted to experience some shadow flicker above a moderate level of intensity, one is predicted to experience a theoretical shadow flicker duration within 50 m of the dwelling that exceeds the limit recommended by the current guidelines. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of the one neighbour dwelling is expected to remain slightly above the limit recommended in the guidelines.

The Proponent has advised DNV [4] that they have an intention to reduce or manage the actual shadow flicker durations at the one neighbour dwelling where the predicted actual shadow flicker duration is in excess of the 10 hours per year limit recommended by the Draft National Guidelines [1]. The Proponent has proposed that these measures may include the planting of trees and vegetation; installation of additional screening structures, industrial strength curtains or blinds; or curtailment of the turbines contributing most significantly to shadow flicker at these dwellings. The turbines contributing most significantly to theoretical shadow flicker duration at the neighbour dwelling has been identified, and this can be useful to guide a curtailment strategy aiming to reduce the occurrence of shadow flicker at the neighbour dwelling.

It is recommended that the Proponent ensures the turbine blades are coated with a non-reflective paint in order to avoid the occurrence of blade glint from the wind farm.

7 REFERENCES

[1] Environment Protection and Heritage Council (EPHC), "National Wind Farm Development Guidelines - Draft," July 2010.

[2] Department of Environment, Land, Water and Planning, "Development of Wind Energy Facilities in Victoria, Policy and Planning Guidelines," July 2021.

[3] "Project Specific Guidelines for Preparing an Environmental Impact Statement for Epuron Projects Pty Ltd St Patricks Plains Wind Farm," Environment Protection Authority Tasmania, Tasmania, 2019.

[4] Information within email from C Bao (Epuron Projects Pty Ltd) to Z Ng (DNV), 27 April 2022.

[5] Information within email from R. Riggs (Epuron Projects Pty Ltd) to T. Gilbert (DNV), 25 March 2022.

[6] "National Policy Statement for Renewable Energy Infrastructure (EN-3)," Department of Energy & Climate Change, UK, 2011.

[7] "Planning for Renewable Energy - A Companion Guide to PPS22," Office of the Deputy Prime Minister, UK, 2004.

[8] "Update of UK Shadow Flicker Evidence Base," Parsons Brinckerhoff, UK, 2011.

[9] N. Wilson, P. K. Tickle, J. Gallant, T. Dowling and A. Read, "1 second SRTM Derived Hydrological Digital Elevation Model (DEM-H) version 1.0. Record 1.0.4.," Geoscience Australia, Canberra, 2011.

[10] Department of State Development, Infrastructure, Local Government and Planning, "Planning guidance, State code 23: Wind farm development," State of Queenslands, Brisbane, February 2022.

[11] "Review of Light and Shadow Effects from Wind Turbines in Scotland," LUC in association with Pager Power, Scotland, 2017.

[12] Bureau of Meteorology, "Climate statistics for Australian locations - Shannon Hec," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_096021_All.shtml. [Accessed 24 March 2022].

[13] Bureau of Meteorology, "Climate statistics for Australian locations - Liawenee," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_096033_All.shtml. [Accessed 24 March 2022].

[14] Bureau of Meterorology, "Climate statistics for Australian locations - Tarraleah Village," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_095018_All.shtml. [Accessed 24 March 2022].

[15] Bureau of Meterology, "Climate statistics for Australian locations - Melton Mowbray (North Stockman)," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_094201_All.shtml. [Accessed 24 March 2022].

[16] Bureau of Meteorology, "Climate statistics for Australian locations - Ross (The Boulevards)," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_093053_All.shtml. [Accessed 24 March 2022].

[17] Information within email from R. Riggs (Epuron Projects Pty Ltd) to Z. Ng (DNV), 25 March 2022.

[18] Information within email from C Bao (Epuron Projects Pty Ltd) to T Gilbert (DNV), 6 April 2022.

[19] Spica Technology ApS, "Shadow Detection System, Vestas, Denmark," Spica Technology ApS, 25 October 2020. [Online]. Available: https://www.spicatech.dk/reference/shadow-dectection-system-vestas-denmark/. [Accessed 03 May 2022].

[20] Information within email from C Bao (Epuron Projects Pty Ltd) to Z Ng (DNV), 3 May 2022.

Table 1 Proposed turbine layout for the Project site [5]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
T01	487523	5346922	975
T02	487672	5346435	926
T03	487875	5345968	953
T04	488037	5345412	904
T06	489373	5343489	941
T07	489608	5342943	902
T08	489610	5342440	885
T09	484652	5346126	905
T11	485781	5343864	901
T12	486630	5343776	892
T13	484115	5345642	903
T14	483902	5344904	900
T15	484640	5344067	900
T16	484374	5343208	893
T17	485143	5342917	900
T18	485852	5342557	894
T19	486150	5341967	891
T20	486410	5341453	887
T25	485365	5341819	887
T29	483327	5345140	909
T30	483267	5344700	904
T31	482908	5343774	897
T32	483189	5344262	901
T33	483423	5343658	901
T39	487573	5341586	874
T42	488041	5339481	865
T43	488098	5338755	868
T44	488462	5337982	884
T45	487556	5337348	897
T46	487512	5336845	878
T47	488014	5335860	883
T48	488240	5337428	910
T49	488325	5336902	924
T50	489242	5337801	923
T51	489025	5337283	936
T52	488850	5336501	916
T53	488753	5335985	886
T54	488526	5335267	850
T55	490000	5337390	884
T56	489789	5336214	861
T57	489966	5336876	886
T58	490505	5336505	842
T59	490648	5335912	848
T68	487553	5347444	955
T69	488093	5336443	934
T70	489354	5336821	883
T71	490624	5337253	844

1. *Coordinate system: MGA zone 55, GDA1994 datum* [5].

Table 2 Location of receptors assessed for potential shadow flicker in this report [5]

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m] (and nearest turbine ID)	
H8-1	Participating	483610	5346615	1096	T13
L19-1	Participating	486619	5337381	938	T45
M10-1	Participating	487138	5344780	1099	T04
M12-1	Participating	487116	5342683	1188	T39
Q13-1	Participating	490773	5342494	1164	T08
J5-2	Neighbour	485250	5348395	2346	T09
M4-1	Neighbour	487701	5349714	2275	T68
M5-1	Neighbour	487060	5348620	1275	T68
O5-1	Neighbour	488990	5348498	1782	T68
O6-1	Neighbour	489248	5348171	1844	T68
O6-2	Neighbour	489094	5347569	1546	T68
O7-1	Neighbour	489136	5347117	1615	T02
O7-2	Neighbour	489320	5346879	1707	T02
P7-1	Neighbour	489612	5346811	1931	T03
P8-1	Neighbour	490082	5346697	2324	T03
P8-2	Neighbour	489493	5346541	1716	T03
P8-3	Neighbour	489964	5346505	2157	T03

1. *Coordinate system: MGA zone 55, GDA94 datum* [5].

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1620 m
Year of calculation	2034
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (disk for turbine orientation reduction calculation)
Sun modelled as	Disk
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 house location

Table 4 Theoretical and predicted actual annual shadow flicker duration (distance of 10D for the zone of influence of shadows)

House ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual[3] At dwelling [hr/yr] 2 m	Theoretical annual[3] At dwelling [hr/yr] 6 m	Theoretical annual[3] Max within 50 m [hr/yr] 2 m	Theoretical annual[3] Max within 50 m [hr/yr] 6 m	Predicted actual annual[3,4] At dwelling [hr/yr] 2 m	Predicted actual annual[3,4] At dwelling [hr/yr] 6 m	Predicted actual annual[3,4] Max within 50 m [hr/yr] 2 m	Predicted actual annual[3,4] Max within 50 m [hr/yr] 6 m
H8-1	Participating	483610	5346615	T09	**36.4**	**36.8**	**44.7**	**44.6**	10.0	**10.1**	**12.4**	**12.4**
L19-1	Participating	486619	5337381	T45 T46	**30.3**	**30.4**	**45.8**	**47.3**	7.1	7.1	**10.3**	**10.8**
M10-1	Participating	487138	5344780	T04	**39.7**	**40.8**	**51.6**	**51.8**	7.2	7.4	9.6	9.8
M12-1	Participating	487116	5342683	T18	17.4	17.1	18.7	18.6	4.0	4.0	4.4	4.3
Q13-1	Participating	490773	5342494	T07 T08	**38.4**	**39.0**	**41.9**	**42.4**	8.9	9.0	9.7	9.8
O6-1[5]	Neighbour	489248	5348171	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O6-2	Neighbour	489094	5347569	T68	11.9	11.8	12.8	12.7	2.8	2.7	3.0	2.9
O7-1	Neighbour	489136	5347117	T01 T02 T68	**37.0**	**37.0**	**51.2**	**51.0**	8.9	8.8	**12.1**	**12.1**
O7-2[5]	Neighbour	489320	5346879	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P7-1[5]	Neighbour	489612	5346811	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8-1[5]	Neighbour	490082	5346697	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8-2[5]	Neighbour	489493	5346541	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8-3[5]	Neighbour	489964	5346505	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recommended duration limits					***30 hr/yr***				***10 hr/yr***			

1. *Dwellings identified in Table 2 for which there is no theoretical shadow flicker occurrence up to a distance limit of 15 times the rotor diameter have been omitted from this table.*
2. *Coordinate system: MGA zone 55, GDA94 datum* [5].
3. *Zone of influence of shadows assumed to extend to a distance of 10 times the rotor diameter following standard wind industry practice* [7, 8, 6].
4. *Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.*
5. *Dwelling is not predicted to experience any shadow flicker above a moderate level of intensity, but may experience some shadow flicker below a moderate level of intensity.*

Table 5 Theoretical and predicted actual annual shadow flicker duration (distance of 265C for the zone of influence of shadows)

House ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual[3]				Predicted actual annual[3,4]			
					At dwelling [hr/yr]		Max within 50 m [hr/yr]		At dwelling [hr/yr]		Max within 50 m [hr/yr]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
H8-1	Participating	483610	5346615	T09	0.0	0.0	**44.7**	**44.6**	0.0	0.0	**12.4**	**12.4**
L19-1	Participating	486619	5337381	T45 T46	**30.3**	**30.4**	**45.8**	**47.3**	7.1	7.1	**10.3**	**10.7**
M10-1	Participating	487138	5344780	T04	**39.7**	**40.8**	**51.6**	**51.8**	7.2	7.4	9.6	9.8
M12-1[5]	Participating	487116	5342683	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q13-1	Participating	490773	5342494	T08	0.0	0.0	21.6	21.6	0.0	0.0	5.0	5.0
O6-1[5]	Neighbour	489248	5348171	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O6-2[5]	Neighbour	489094	5347569	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O7-1[5]	Neighbour	489136	5347117	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O7-2[5]	Neighbour	489320	5346879	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P7-1[5]	Neighbour	489612	5346811	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8-1[5]	Neighbour	490082	5346697	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8-2[5]	Neighbour	489493	5346541	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P8-3[5]	Neighbour	489964	5346505	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recommended duration limits					***30 hr/yr***				***10 hr/yr***			

1. *Dwellings identified in Table 2 for which there is no theoretical shadow flicker occurrence up to a distance limit of 15 times the rotor diameter have been omitted from this table.*
2. *Coordinate system: MGA zone 55, GDA94 datum* [17].
3. *Zone of influence of shadows assumed to extend to a distance of 265 times the maximum blade chord length as suggested by the Draft National Guidelines* [1].
4. *Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.*
5. *Dwelling may experience some degree of shadow flicker.*

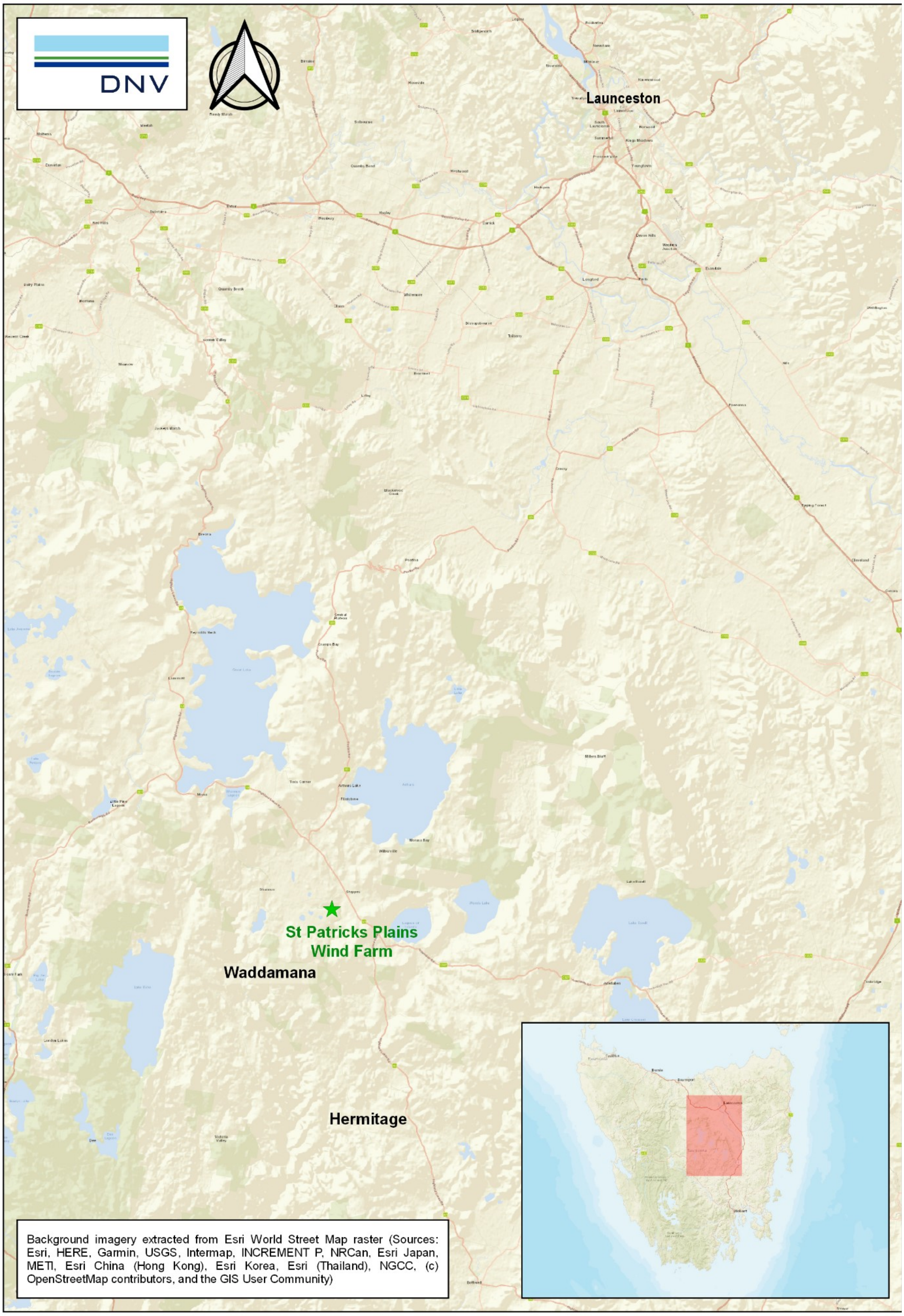

Figure 2 Location of the Project

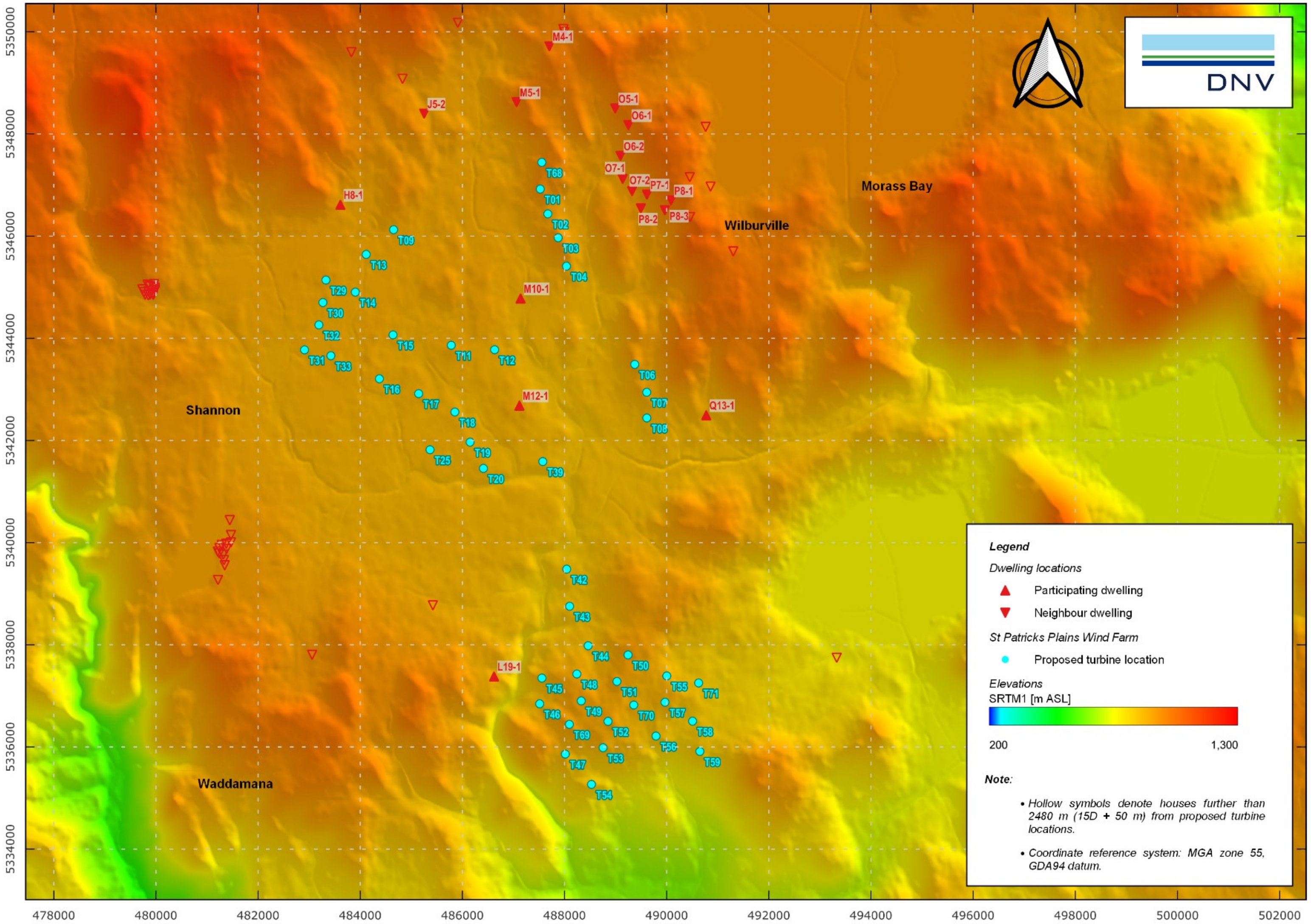

Figure 3 Elevation map of the Project

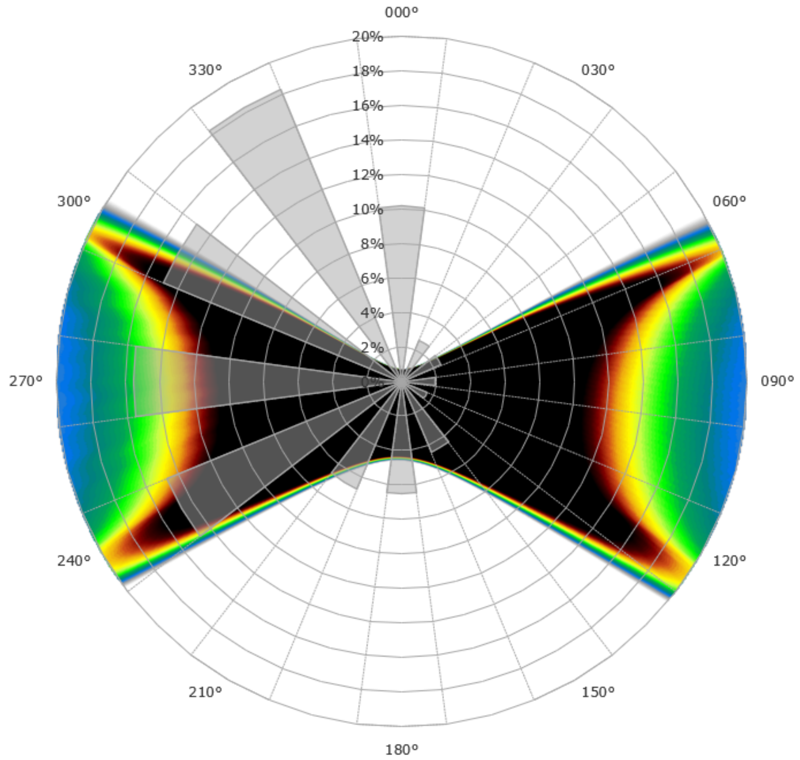

Figure 4 Indicative shadow flicker map and wind direction frequency distribution

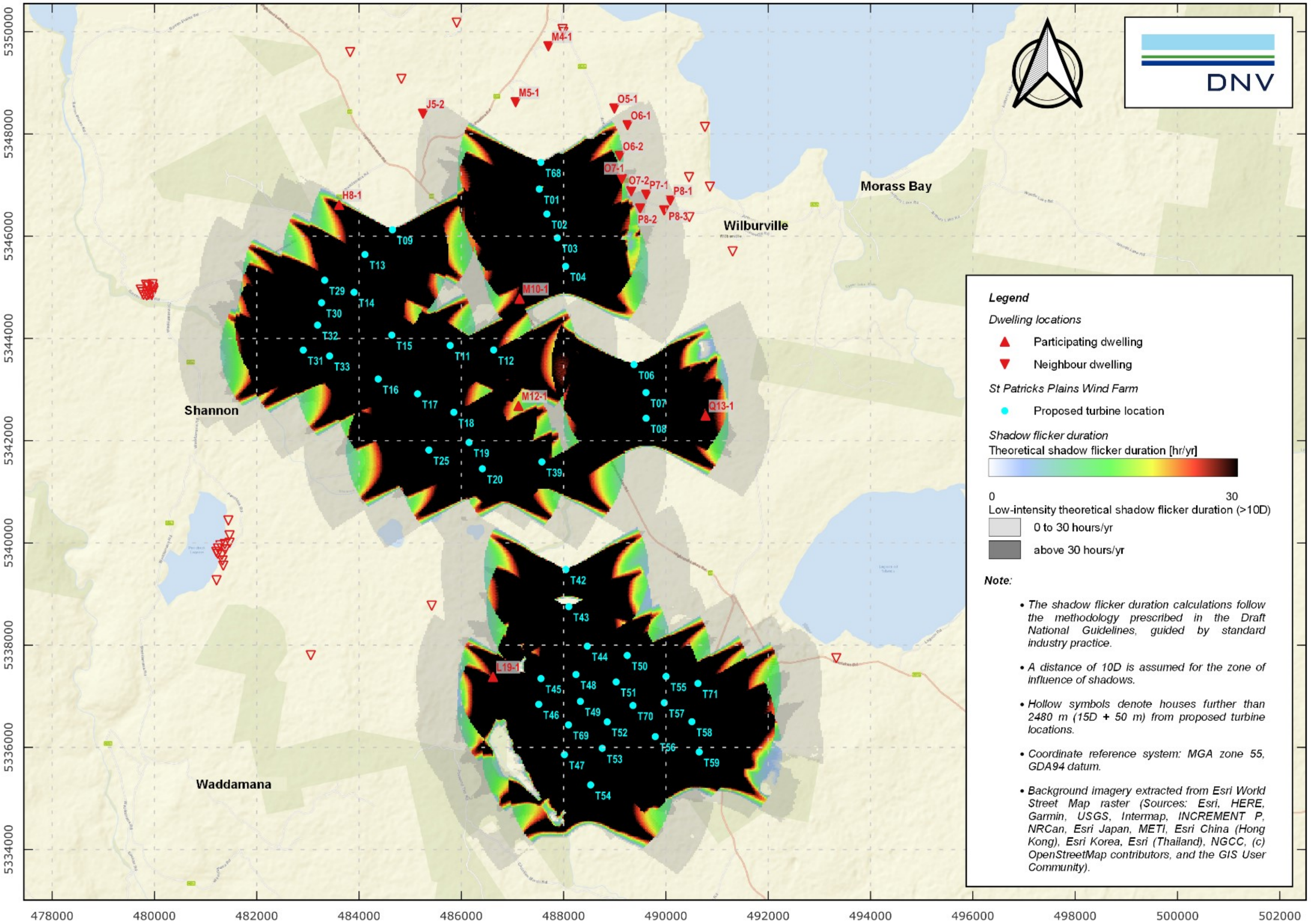

Figure 5 Theoretical annual shadow flicker duration map

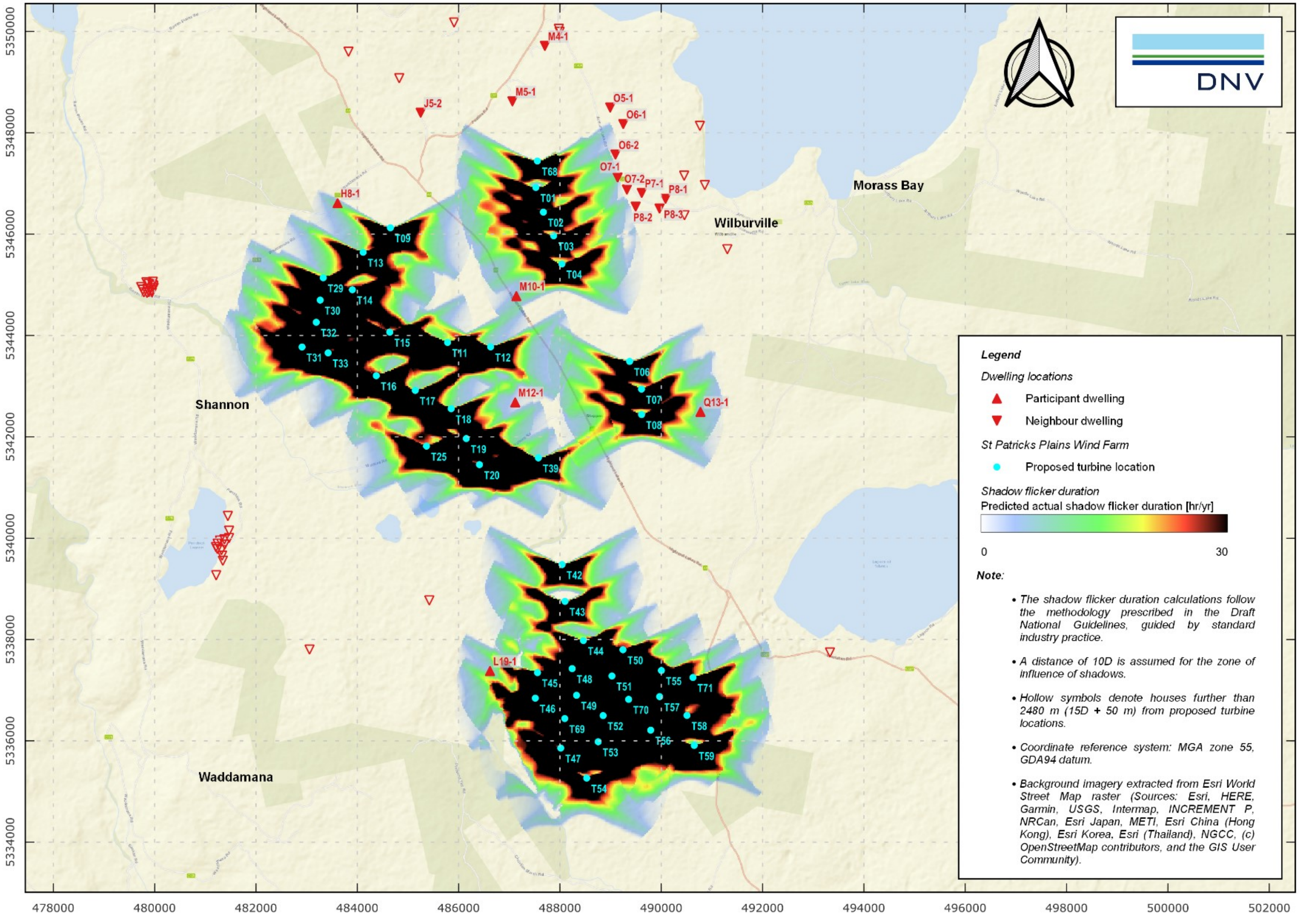

Figure 6 Predicted actual annual shadow flicker duration map

Dwelling ID: O7-1
Window height: 2 m above ground level
Worst case direction: Southwest of receptor

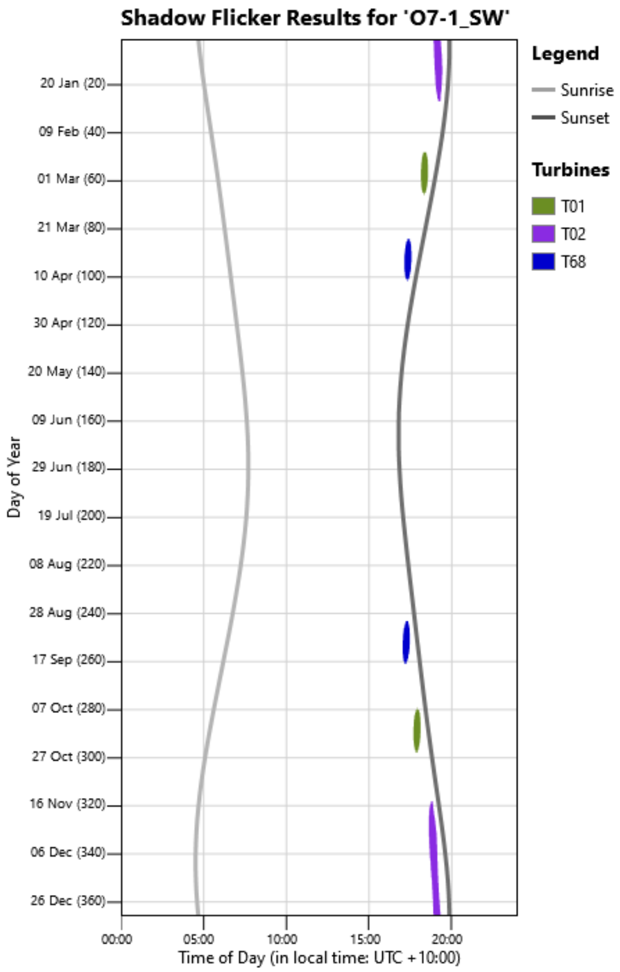

Figure 7 Predicted time of occurrences of theoretical shadow flicker in the worst-case direction and window height within 50 m of the neighbour dwelling.

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, optimising 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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