6.0 Shadow Flicker

6.1 Introduction

This chapter presents excerpts of the shadow flicker assessment, prepared by DNV GL – Energy Renewables Advisory (DNV GL) for the Project. The full shadow flicker assessment (DNV GL, 2016) is included in Appendix K, Volume 3 of this EIS.

6.1.1 Overview of shadow flicker

Shadow flicker may occur under certain combinations of geographical position and time of day, when the sun passes behind 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 on 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).

6.1.2 Parameters and data

The shadow flicker assessment is based on the proposed wind turbine layout provided in Figure 2.1 (Volume 2) which has informed the delineation of the Project Site. Other parameters incorporated into this assessment reflect the Project specifications that are detailed in Chapter 2 Project Description.

A list of the coordinates of dwellings in the vicinity of the Project was used for this assessment; only houses within 1.5 km of the Project have been considered in the analysis. This distance has been selected to meet the requirements of the Queensland Wind Farm Planning Guidelines (DILGP, 2016), which state that the first step in performing a shadow flicker assessment is to determine the extent of shadows from turbines and suggest a distance equivalent to 265 maximum blade chords (the thickest part of the blade) as an appropriate limit. This limit corresponds to around 800 m to 1,325 m for modern wind turbines, which typically have maximum blade chord lengths of three to five metres. For the assessment undertaken by DNV GL (2016) this distance has been applied conservatively, with the minimum required distance buffered by 100 m (therefore equating to 1,500 m). Figure 2.2 (Volume 2) shows a map of the Project Site with the proposed turbine layout and sensitive receptor locations.

6.2 Scope of assessment

The duration of shadow experienced at a specific location has been determined using a geometrical 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 Project, in accordance with the assessment requirements described in the Queensland Wind Farm State Code and Planning Guideline (DILGP, 2016).

As this analysis method is moderate to very conservative and generally results in over-estimation of the number of hours of shadow flicker experienced at a dwelling, an attempt has been made to quantify the likely reduction in shadow flicker duration due to cloud cover, and produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

6.3 Legislative requirements and policy

The Queensland Wind Farm State Code states that a proposed wind farm must avoid shadow flicker impacts on existing adjoining sensitive land use(s) by ensuring that:

> *'The modelled blade shadow flicker impact on any existing adjoining sensitive land use(s) does not exceed 30 hours per annum and 30 minutes per day… [and] wind turbine blades have a low reflectivity finish'.*

The associated Queensland Wind Farm Planning Guidelines provide background information, a proposed methodology, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm in order to demonstrate compliance with the Queensland Wind Farm State Code.

In addition to the requirement that the modelled theoretical shadow flicker at an existing sensitive land use should not exceed 30 hours per year or 30 minutes per day, the Queensland Wind Farm Planning Guidelines recommend that the actual shadow flicker duration, determined by taking into account reductions due to cloud cover and the use of turbine control strategies, should not exceed 10 hours per year. The guidelines also recommend that the shadow flicker duration should be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a sensitive land use.

A sensitive land use is defined under the State Planning Policy 2016 as caretakers accommodation, child care centre, community care centre, community residence, detention facility, dual occupancy, dwelling house, dwelling unit, educational establishment, health care services, hospital, hotel, multiple dwelling, non-resident workforce accommodation, relocatable home park, residential care facility, resort complex, retirement facility, rooming accommodation, rural workers' accommodation, short-term accommodation, or tourist park.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine or around 800 m to 1,400 m for modern wind turbines (which typically have rotor diameters of 80 m to 140 m). Beyond this distance, the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This is acknowledged in the Queensland Wind Farm Planning Guidelines, which state that the first step in performing a shadow flicker assessment is to determine the extent of shadows from turbines and suggest a distance equivalent to 265 maximum blade chords (the thickest part of the blade) as an appropriate limit. This limit corresponds to around 800 m to 1,325 m for modern wind turbines, which typically have maximum blade chord lengths of 3 m to 5 m.

The Queensland State Code and Planning Guidelines do not provide any specific guidance on blade glint, except to note that wind turbine blades should have a low reflectivity finish.

6.4 Shadow flicker duration

6.4.1 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 the wind turbine details such as the 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 that the model calculates the maximum duration for which there is potential for shadow flicker to occur.

In line with the methodology proposed in the Queensland Wind Farm Planning Guidelines, the potential for shadow flicker at sensitive receptors has been undertaken and has determined the highest shadow flicker duration within 50 m of the centre of each sensitive receptor location. The assessment has assumed that the shadow flicker duration within 50 m of each sensitive receptor is representative of the shadow flicker that would be experienced with 50 m of the centre of the sensitive land use on which the receptor is located.

Shadow flicker has been calculated at sensitive receptors at heights of two metres, to represent ground floor windows, and six metres, to represent second floor windows. The sensitive 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 sensitive receptor locations have been carried out with a temporal resolution of one minute; if shadow flicker occurs in any one minute period, the model records this as one minute of shadow flicker. The shadow flicker map was generated using a temporal resolution of five minutes to reduce computational requirements to acceptable levels.

An assumption has been made regarding the maximum length of a shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker. Using the wind farm specifications listed in Chapter 2 Project Description, the most conservative value corresponds to 10 rotor diameters, or 1,400 m. There are 14 sensitive receptors within 1,400 m of the wind turbines. Under the Queensland Wind Farm Planning Guidelines, this will be conservative for any turbine with a maximum blade chord of less than 5.3 m.

The model makes the following assumptions and simplifications:

- There are clear skies for 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 specified location 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 are contained within the full Shadow Flicker Assessment (DNV GL, 2016), in Appendix K, Volume 3 of this EIS.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a relatively flat area is shown in Figure 2 of the DNV GL report in Appendix K, Volume 3. 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 the morning sun while the lobes to the east result from the 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.

6.4.2 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, including:

- 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
- 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
- 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
- The modelling of the wind turbine rotor as a disc, rather than individual blades results in an overestimate of shadow flicker duration
- 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
- 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
- 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 shadow flicker duration.

6.4.3 Predicted actual shadow flicker duration

As outlined in Section 6.4.2 there are a number of effects which may reduce the incidence of shadow flicker that are not taken into account in the calculation of the theoretical shadow flicker duration. Exclusion of these effects 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 sensitive receptor.

Cloud cover is typically measured in oktas or eighths of the sky covered with cloud. DNV GL (2016) obtained data from five Bureau of Meteorology (BoM) stations located in proximity to the site, namely:

- 041522 – Dalby Airport (around 55 km from the Project Site)
- 040158 – Nanango Wills Street (around 55 km from the Project Site)
- 041359 – Oakey Aero (around 85 km from the Project Site)
- 040922 – Kingaroy Prince Street (around 51 km from the Project Site)
- 041023 – Dalby Post Office (around 40 km from the Project Site).

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 33% and 58%, and average annual cloud cover is around 45%. This means that on an average day, 45% of the sky in the vicinity of the Project 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 monthly reductions of between 40% and 51% are expected.

Due to limitations in the availability of cloud cover data, the methodology used in this assessment deviates from the method recommended by the Queensland Wind Farm Planning Guidelines for assessing the reduction in shadow flicker due to cloud cover. The guidelines recommend using the “number of cloudy days” parameter provided by BoM, while the shadow flicker assessment has calculated cloud cover based on oktas (eighths of the sky covered with cloud) averaged between 9am and 3pm. However, the approach undertaken is deemed to provide a suitable estimate of the likely impact of cloud cover on the shadow flicker duration.

No attempt has been made to account for rotor orientation, vegetation or other shielding effects around each sensitive 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 in this assessment can still be regarded as a conservative estimate.

6.4.4 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. Blade glint is not generally a problem for modern wind turbines, provided the blades are coated with a non-reflective pant, and it is therefore not considered further in this assessment.

6.5 Potential impacts

There are 14 sensitive receptors within 1,400 m of the wind turbines. However, only seven of these sensitive receptors are likely to experience shadow flicker. The theoretical maximum predicted shadow flicker durations are presented in Table 6.1. Shadow flicker durations above the limits proposed in the Queensland Wind Farm State Code and Planning Guideline are highlighted in bold.

Table 6.1 Theoretical and predicted actual shadow flicker durations (DNV GL, 2016)

				Theoretical Daily Shadow Flicker				Theoretical Annual Shadow Flicker				Predicted Actual Annual Shadow Flicker[4]			
Sensitive Receptor ID[1]	Easting[2] [m]	Northing[2] [m]	Contributing Turbines	At Receptor[3] [min/day]		Max Within 50 m[3] [min/day]		At Receptor[3] [hr/yr]		Max Within 50 m[3] [hr/yr]		At Receptor[3] [hr/yr]		Max Within 50 m[3] [hr/yr]	
				2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m	2m	6 m
A	340084	7046384	65, 72, 73	**45**	**51**	**60**	**59**	**53.5**	**56.0**	**61.2**	**60.6**	**29.6**	**31.2**	**34.3**	**34.1**
C	336840	7049667	78, 81	**38**	**38**	**42**	**42**	27.5	28.3	**36.6**	**37.4**	**13.1**	**13.5**	**17.5**	**17.9**
D	336677	7050047	80	28	29	30	30	**31.6**	**31.2**	**34.0**	**33.8**	**18.9**	**18.7**	**20.4**	**20.2**
E	341659	7047168	66	30	30	**32**	**31**	14.1	14.2	15.4	15.4	8.0	8.1	8.8	8.8
F	341691	7047075	66	29	29	30	30	13.3	13.3	14.5	14.3	7.7	7.8	8.4	8.3
G	346234	7042890	22, 26, 30	**40**	**39**	**42**	**42**	**48.0**	**48.3**	**64.5**	**64.9**	**27.2**	**27.5**	**36.7**	**37.0**
H	346168	7042875	26, 30	**36**	**37**	**39**	**39**	**41.7**	**41.9**	**47.0**	**47.4**	**24.0**	**24.1**	**26.9**	**27.2**
Limits				30		30		30		30		10		10	

[1] All sensitive receptors affected by shadow flicker belong to participating landowners.

[2] Coordinate system: MGA zone 56, GDA94 datum.

[3] Sensitive receptors predicted to experience zero hours of shadow flicker within 50 m of the receptor have been omitted from this table.

[4] Considering likely reductions in shadow flicker duration due to cloud cover only

A shadow flicker assessment has been carried out at all sensitive receptors located within 1.5 km of the Project Site and the results are presented in Table 6.1. The maximum predicted theoretical shadow flicker durations within 50 m of sensitive receptors are also presented in Table 6.1. The results are presented in shadow flicker maps at two metres and six metres above ground in Appendix K, Volume 3. Additionally, the results are presented in the form of shadow flicker duration contours are also provided in Appendix K, Volume 3.

The results indicate that seven sensitive receptors in the vicinity of the Project are predicted to experience some shadow flicker based on the methodology recommended in the Queensland Wind Farm Planning Guidelines. Of these, six are predicted to be affected by theoretical shadow flicker durations of greater than the recommended 30 hours per year or 30 minutes per day within 50 m of the receptor locations. All of these sensitive receptors are located on land belonging to landowners hosting wind turbines on their property.

An assessment of the level of conservatism associated with the worst-case results has been conducted by calculating the possible reduction in shadow flicker duration due to cloud cover. These adjusted results are presented as predicted actual shadow flicker in Table 6.1. Consideration of these factors reduces the predicted shadow flicker duration by 40 per cent to 52 per cent at the receptors accepted by shadow flicker.

After reductions due to cloud cover, five of the sensitive receptors that are expected to exceed the 30 hour limit are predicted to be subject to an actual shadow flicker duration above the limit of 10 hours within 50 m of the receptor location, as recommended in the Queensland Wind farm Planning Guidelines. All sensitive receptors which would experience exceedances of the limit are participating landowners.

The method prescribed by the Queensland Wind Farm Planning Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover and/or turbine operation scheduling be included. As a result, no other potential sources of reduction, such as turbine orientation, were considered. Additionally, shadow flicker durations have been calculated within 50 m of sensitive receptors, rather than within 50 m of the centre of sensitive land use(s). Finally, there are some deviations between the method used to calculate the reduction in shadow flicker duration due to cloud cover, due to limitations in the availability of suitable cloud cover data.

6.6 Mitigation measures

If shadow flicker presents a problem, its effects can be reduced through a number of measures. These could include (in hierarchical order):

- Installation of screening structures and/ or planting of trees to block shadows cast by the turbines
- Use of turbine control strategies which shut down turbines when shadow flicker is likely to occur.

Shadow flicker provisions will be included in the Deed of Release with landowners hosting wind farms on their properties where the assessment indicates that shadow flicker impacts could be experienced at a sensitive receptor. In addition, AGL will consult with participating landowners who may experience shadow flicker impacts to identify feasible and reasonable management and mitigation measures, should they be required.

The results presented in the DNV GL (2016) shadow flicker assessment and summarised in this chapter of the EIS are derived from a hypothetical turbine model with a 110 m hub height and a 140 m blade diameter configuration. 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.

6.7 Residual impacts

Residual impacts, i.e. those impacts which could be experienced by sensitive receptors after the application of management and mitigation measures, are not expected at sensitive receptors.

A site visit could be undertaken during detailed design of the wind farm to complement the results of this analysis. This would allow a better understanding of the vegetation coverage in the area, and the potential for shadow flicker shielding at dwellings expected to experience shadow flicker.

6.8 Summary and conclusion

An assessment to determine annual duration of shadow flicker at sensitive receptors in the vicinity of the Project has been undertaken in accordance with the Queensland Wind Farm Planning Guidelines.

The assessment of theoretical shadow flicker durations shows that seven of the sensitive receptors are predicted to experience some of level of theoretical shadow flicker within 50 m of the receptor location. Six sensitive receptors are predicted to be affected by theoretical shadow flicker durations of greater than the Queensland Wind Farm State Code and Planning Guidelines recommended limits of 30 hours per year or 30 minutes per day within 50 m of the receptor location.

All sensitive receptors for which the theoretical modelling of annual shadow flicker indicates exceedances of the limit are landowners hosting wind turbines on their properties.

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 cloud cover. The results of this analysis shows that five of the seven sensitive receptors are predicted to experience actual annual shadow flicker durations within 50 m of the sensitive receptor location that are in excess of the limit of 10 hours recommended in the Queensland Wind Farm Planning Guidelines.

All sensitive receptors for which the modelling of predicted actual annual shadow flicker indicates exceedances of the limit are participating landowners.

The calculations of the predicted actual shadow flicker duration does not take into account any reduction due to turbine orientation, low wind speed, vegetation or other shielding effects around each house, and 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 sensitive receptor could include (in hierarchical order):

- Installation of screening structures and/ or planting of trees to block shadows cast by the turbines
- Use of turbine control strategies which shut down turbines when shadow flicker is likely to occur.

Shadow flicker provisions will be included in the Deed of Release with landowners hosting wind turbines on their properties where the assessment indicates that shadow flicker impacts could be experienced at a sensitive receptor. In addition, AGL will consult with landowners hosting wind turbines on their properties who may experience shadow flicker impacts to identify feasible and reasonable management and mitigation measures.

6.9 References

DILGP, 2016. Queensland Wind Farm State Code and Planning Guideline

DNV GL – Energy Renewables Advisory, 2016, *Coopers Gap Wind Farm Shadow Flicker and Blade Glint Assessment*, April 2016.