11.0 Shadow Flicker

11.1 Introduction

This chapter presents an investigation into potential shadow flicker impact at nearby buildings from the operation of the Keerglen Wind Farm. The assessment has been undertaken by ABO Energy Ireland Ltd.

11.1.1 Background to Shadow Flicker

The rotating blades of wind turbines cause shadows that are moving. The periodical change of light and shade at neighbouring buildings resulting from such moving shadows is called '*shadow flicker*' and may affect the quality of the natural light conditions. Increasing distances from the origin of the shadow reduces the perceptibility of the fluctuations of lightness, due to light scatter and atmospheric opacity.

11.1.2 Objectives

The objectives of this chapter are to describe:

- the relevant legislation and guidance;
- the methodology of the assessment;
- the existing environment;
- the potential impacts;
- the need for mitigation measures;
- any residual impacts.

11.2 Statement of Competence

Since 1996, ABO Energy Ireland Ltd. (formerly ABO Wind Ireland Ltd.) has developed and sold wind energy projects with an output of 2,750 megawatts, more than half of them as turnkey projects. From the early days, an in-house team of site appraisal experts have conducted technical studies which amongst other things include shadow flicker assessments for projects under development. This team has studied the shadow flicker impact of a very large number of planned wind farms across many countries, including projects in Ireland that have already been built or are at an advanced stage of development. Furthermore, the operational management team of ABO Wind has extensive experience of ensuring that planning conditions related to shadow flicker monitoring and mitigation are complied with. This includes monitoring of wind turbine sub-systems installed to reduce the durations of shadow flicker impact at sensitive locations nearby.

Maximilian Kilburg holds a Master of Science degree from the Department of Sustainability Sciences of Leuphana University, Lüneburg, Germany. Maximilian has been working in the wind energy industry since 2010 as a technical specialist in the fields of wind and site assessment and since 2014 with ABO. Maximilian has undertaken a large number of site assessments preparing numerous Shadow Flicker chapters.

11.3 Relevant legislation and guidance

The Wind Energy Development Guidelines (WEDGs)[1] published in 2006 states the following regarding shadow flicker.

> *"Careful site selection, design and planning, and good use of relevant software, can help avoid the possibility of shadow flicker in the first instance. It is recommended that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day.*
>
> *At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low. Where shadow flicker could be a problem, developers should provide calculations to quantify the effect and where appropriate take measures to prevent or ameliorate the potential effect, such as by turning off a particular turbine at certain times."*

Concerning appropriate planning conditions in relation to shadow flicker, the same WEDGs also state the following.

> *"Shadow flicker is not usually critical. However, in unusual circumstances, where the calculations indicate that occupied dwelling houses would be significantly affected, a condition requiring the non-operation of turbines at times when predicted shadow flicker might adversely impact on any inhabited dwelling within 500m of a turbine may be appropriate.*
>
> *Conditions may also address limits on the number of hours per year or minutes per day that the shadow flicker should affect an inhabited dwelling."*

In December 2019, the draft revised Wind Energy Development Guidelines (DWEDGs[2]) were published for public consultation by the Department of Housing, Planning and Local Government (DHPLG). One of the primary purposes of the review was to:

> *"strike a better balance between addressing the concerns of local communities in relation to wind farm proposals, whilst maintaining Ireland's ability to deliver on its binding energy policy obligations"*

In this context, the DWEDGs focus on addressing a number of key aspects associated with wind energy development, including the control and elimination of shadow flicker. The consultation on the DWEDGs concluded in February 2020. At the time of writing the adoption of the revised guidelines is pending. As such the 2006 guidelines remain in in place.

However, should the DWEDGs be adopted in advance of a planning decision being made on the Proposed Development, Keerglen Wind Farm will have the capability of complying with any revised requirements through for example the implementation of mitigation measures such as turbine control systems.

[1] Department of the Environment, Heritage and Local Government, *Wind Energy Development Guidelines*, 2006.
[2] Draft Revised Wind Energy Development Guidelines (2019). Available at https://www.housing.gov.ie/sites/default/files/public-consultation/files/draft_revised_wind_energy_development_guidelines_december_2019.pdf

The IWEA Best Practice Guidelines (2012)[3] support the WEDGs (2006) in the recommendation that a shadow flicker impact distance of at most ten rotor diameters is normally suitable for environmental impact assessments.

11.4 Methodology

In the absence of a technical standard that describes the requirements for a shadow flicker assessment in detail, international industry best-practice has been followed. The calculations have been undertaken using the industry standard WindPRO software, using settings that are in line with the guidelines described in Section 11.3.

The theoretical maximum durations of shadow flicker impact at nearby buildings, generally referred to as *'worst case'* calculations, can be modelled with high accuracy and precision from purely geometrical considerations (positions of the sun, each wind turbine rotor and each building). Such calculations make assumptions that generally result in very conservative predictions. It is common practice to supplement the worst-case calculations with estimations of shadow flicker durations that take into account typical site conditions, which are generally referred to as *'real case'* calculations. The methods of the worst case and real case calculations are described in the following sections.

11.4.1 Worst case calculations

The worst case calculations assume that the sun is shining at all astronomically possible times of the day and has a 100% solarisation intensity. Furthermore, it is assumed that the turbine rotors are moving at all times and are always oriented perpendicular to the sun, producing the highest possible shadow impacts.

The position of the sun is the basic methodical element of the shadow flicker calculation, which is dependent on the rotation of the Earth, the Earth's slope of the axis, as well as the elliptical orbit of the Earth around the sun. In addition, orographic, seasonal and daytime aspects have to be considered at each observation point.

For the whole year, the position of the sun has been calculated in one-minute intervals and the shadow of each wind turbine's rotor has been projected elliptically onto the surface of the Earth. Both the daily changing peak level of the sun and the actual maximal time of sunshine depend on the surrounding orography.

The sun is a non-punctual light source. An object that obstructs the sun relative to an observer produces an area of umbra (deep shadow) and an area of penumbra (partial shadow). In the area of the umbra, the light source is completely hidden behind the shadow casting object. In the penumbra an observer can always see a part of the light source. As the width of the rotor blades is relatively small, the umbra is only present a short distance behind the wind turbine and generally not important for shadow flicker. Therefore, the shadow flicker model calculations do not need to directly simulate the moving parts of the wind turbine. The

[3] Irish Wind Energy Association (IWEA), *Best Practice Guidelines for the Irish Wind Energy Industry*, 2012.

intensity of the penumbra decreases with the distance to the shadow casting object. At a distance of 500 m, it reduces to only approximately half of the intensity.

The calculation software assumes an idealised, perfectly clear view. In reality, aerosols mist the air, which decreases visibility and thus further reduces the intensity of the shadow flicker with increasing distance from the wind turbines.

All altitudes of the sun from 3° over the horizon, after sunrise and before sunset, are included in the calculations. At standard visibility, contrast shadows occur from 3° to 4°. Hence the value of 3° is conservative.

There is some ambiguity in the WEDGs (2006) as to whether the shadow flicker impact should be assessed within a distance of 500 m or within a distance of ten rotor diameters from all turbine locations (see Section 11.3). Since the IWEA Best Practice Guidelines (2012) supports the adoption of ten rotor diameters as the limit (see again Section 11.3), this more conservative distance has been used.

In the calculations, each shadow flicker receptor (residential building) is modelled as a vertical window of 1.0 m × 1.0 m dimensions at 1.0 m above ground level, always oriented in the direction of the sun. The assumption that all receptors always have a window in the direction of the sun, also known as *'greenhouse'* calculation mode, leads to conservative results. In some circumstances the shadow flicker effect may be smaller or removed completely if there is no window in the relevant direction.

11.4.2 Real case calculations

The worst-case shadow flicker calculations use the assumption that the weather is always perfectly clear, that the rotor is always oriented perpendicularly to the line between the sun and the observer and that the turbines are always rotating. The real case calculations aim to establish more realistic expectations for shadow flicker impact by accounting for these factors.

A correction for the expected proportion of time with sunshine can be made by using statistics from long-term observations at weather stations. Values for average daily sunshine hours in each calendar month at the Belmullet weather station, listed in Table 11.1, were used for this purpose. This data was available directly within the WindPRO modelling software used for the calculations.

Table 11.1: Sunshine probability data from the Belmullet weather station

Calendar month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average daily sunshine hours	1.36	2.16	2.65	4.82	5.79	4.41	4.42	4.07	3.73	2.48	1.71	0.89

The real case calculation also takes into account expected operational time of the wind turbine and the probability distribution of the rotor alignment. When the wind speed is too low for the turbine to produce energy, it will be at still-stand or idling (rotating so slowly that the flickering effect will not occur). This was accounted for by analysis of long term corrected wind speed data measured at an on-site meteorological LiDAR. Wind direction data from the same LiDAR was used to determine the distribution of rotor orientation.

The corrections do not include considerations of any joint probability distributions between wind and sunshine conditions, such as higher probability of low winds during clear high-pressure weather conditions. In this sense the method is likely conservative.

The real case calculations do not account for the weakening strength of the shadow with increasing distance due to the turbidity of the air (cloudiness due to aerosols). In that regard the calculations are therefore still conservative. Under many commonly occurring atmospheric conditions, the shadow flicker effect will have reduced to very faint well before ten rotor diameters, since the atmosphere is not perfectly clear.

It is furthermore noted that the real case calculations do not account for potential shading effects of trees or other objects that could act as obstacles between the wind turbine and the building in question. Where such trees or other objects are present, the actual shadow flicker durations to be expected may be lower than the estimates presented in this assessment, or the shadow flicker impact may disappear completely.

11.4.3 Parameters of Shadow Flicker Assessment

As outlined in Table 11.2 below (Section 11.5) the nearest residential buildings to the proposed turbines are located at a distance of 1.5km, 1.57km and 1.6km. The planning application associated with this EIAR seeks permission for a range of rotor diameters of between 133-150m. Only one residential dwelling (located 1500m away from the nearest turbine) is located within 10 rotor diameters of the largest rotor diameter within the range (the 150m Rotor Diameter). As no residential properties are located with 10 rotor diameters of the shorter rotor diameter options within the range, it was concluded that they would not form part of this assessment.

Accordingly, this shadow flicker assessment has been undertaken based on the scenario of an overall tip height of 180m, with a rotor diameter of 150m. Out of the different turbine model scenarios under consideration, this has the largest rotor diameter and therefore provides the most conservative results in terms of shadow flicker. For this rotor size, the limit of ten rotor diameters for shadow flicker impact corresponds to 1,500m. However, given there are a cluster of three residential dwellings in close proximity to each other, all three dwellings have been included in this assessment, even though two of them are located outside of 10 rotor diameters from the nearest turbine.

11.5 Description of the Environment

Shadow flicker mainly impacts residential buildings, where the flickering occurs through windows. For this reason, and also because such buildings are the significant locations of risk for extended exposure, shadow flicker assessments generally focus exclusively on residential dwellings.

There are only three residential buildings located within such a distance from the proposed Keerglen wind turbines that shadow flicker may have an impact. The locations of these buildings are listed as coordinates in Table 11.2 and shown on a site map in Figure 11.1. The location data was obtained from the Eircode database and by aerial image verification.

There are no buildings located within a distance of 500 m of the turbines. Hence the strongest shadow flicker impact is avoided in accordance with the WEDGs (2006).

Table 11.2: Residential Building Locations
Irish ITM-IRENET95 (IE), geocentric, GRS80

Label	ITM X	ITM Y	Distance to nearest turbine
H001	508775	833147	1.6km
H002	508407	833440	1.5km
H003	508489	833494	1.57km

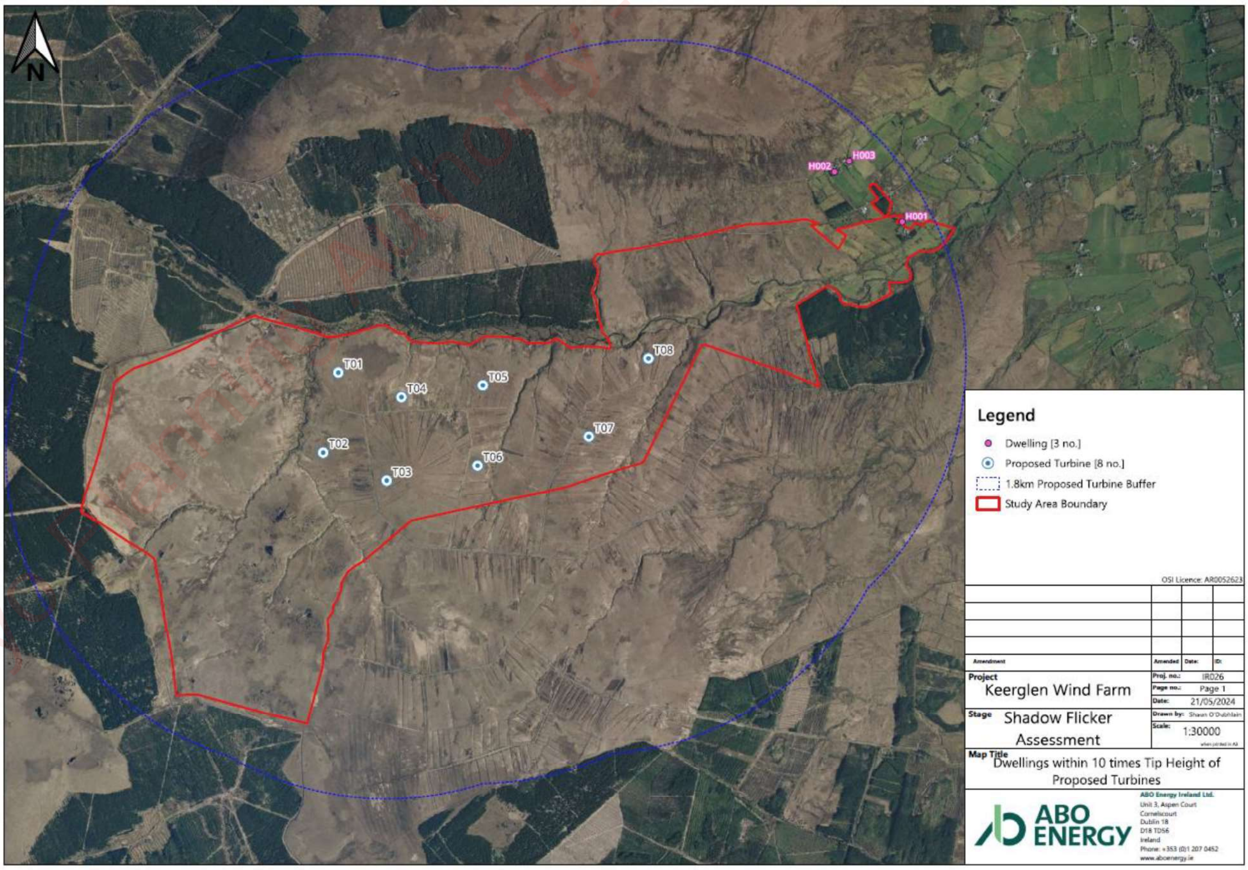

Figure 11.1: Residential Building Locations

The representation of each of the buildings within the modelling software was undertaken as described in Section 11.4.

11.6 Statement of Potential Impacts

A summary of modelled shadow flicker durations at the nearby residential buildings described in Section 11.5 is provided in Table 11.3. The values have been calculated as outlined in Section 11.4, and accordingly can be considered extremely conservative. Only those residential buildings which could potentially be affected by shadow flicker are considered. Buildings not included in Table 11.3 are expected to experience negligible impact.

Detailed results of the calculations are presented in Appendix 11.1.

Table 11.3: Calculated durations of shadow flicker impact

Label	Worst Case			Real Case
	Hours per year	Days per year	Maximum hours per day	Hours per year
H001	0	0	0	0
H002	11:30	50	0:24	1:18
H003	0	0	0	0

Note:
Highlighted cells mark values exceeding 30 hours per year or 30 minutes per day. No cells are highlighted as exceedances do not occur.

The WEDGs (2006) recommend that shadow flicker at neighbouring dwellings within 500m should not exceed 30 hours per year or 30 minutes per day. As has been demonstrated on Site Layout drawings included with this EIAR, there are no houses within 500m of the nearest turbine set out in the proposed Keerglen Wind Farm. As a result, at each of the residential buildings outlined in the Table 11.3, the results of the worst-case calculations show no exceedances of the limits of 30 hours per year and/or 30 minutes per day recommended by the WEDGs (2006). The real case calculations show that, after accounting for sunshine probabilities and wind conditions at the site, the annual shadow flicker durations for one residential building are minimal and well below the prescribed limits per year.

11.7 Cumulative Impacts

Where existing wind turbines are in operation nearby or further wind turbines are planned in the vicinity, it is important to consider the cumulative shadow flicker impacts of all wind turbines upon each residential dwelling. However, since shadow flicker only occurs at relatively short distances (see Section 11.3 and Section 11.4), it is only necessary to account for neighbouring wind turbines that are located close by. There are no other operational or known planned wind turbines within a 10 times rotor diameter distance of the nearest residential dwellings (H001, H002, H003) assessed as part of this Shadow Flicker assessment.

Glenora Wind Farm DAC have submitted a Strategic Infrastructure Development planning application to An Bord Pleanála (ABP Reg. Ref. 318701) seeking permission for the construction of 22 no. wind turbines and all associated works. The Glenora Wind Farm planning application has a determination date target of 16th September 2024. The turbine parameters sought as part of that planning application are:

- A total tip height of 180m;
- Hub height of 99m; and
- Rotor diameter of 162m

Following a review of the co-ordinates of the residential dwellings (H001, H002, H003) assessed as part of this Shadow Flicker assessment, and the closest wind turbines on the Glenora Wind Farm scheme layout, the two closest turbines in the proposed Glenora Wind Farm layout are turbines 16 and 22. Residential dwelling H002 is the closest residential dwelling to both of these Glenora turbines. Glenora turbine 16 is located c.2.2km and Glenora turbine 22 located c.1.95km away from H002. Therefore, it is clear that both Glenora turbines 16 and 22 are located more than 10 times the distance of their proposed rotor diameter (162m) from the residential dwellings assessed as part of this Shadow Flicker assessment. Accordingly, no cumulative shadow flicker impacts are expected as a result of the proposed Keerglen Wind Farm development in combination with the neighbouring proposed Glenora Wind Farm project.

11.8 Mitigation and Monitoring Measures

The results presented in Section 11.6 suggest that shadow flicker may be experienced at only one of the residential buildings (H002) in the surrounding area. The remaining residential buildings are expected to experience no impact in either a worst case or real case scenario.

The annual duration of shadow flicker should not exceed 30 hours per year or 30 minutes per day at nearby residential dwellings. The results in Section 11.6 indicate that **no exceedances of the prescribed limits will be experienced at H002**.

The new DWEDGs (2019) recommend eliminating shadow flicker impact at residential buildings, whereas the WEDGs (2006) recommend reducing the impact to below 30 hours per year and 30 minutes per day.

To eliminate shadow flicker, a shadow flicker control system can be deployed if necessary. A shadow flicker control system is an optional wind turbine sub-system, integrated with the control system of the turbine, which stops the turbine at appropriate times in order to avoid shadow flicker at sensitive receptors (buildings). Such technology has been available for a number of years and is now mature, proven and widely available.

The shadow flicker control system of each turbine is programmed with a schedule during which it is not permitted to cast shadows. Typically, the system also includes light sensors that measure shadow flicker potential. Then, during times when the sensors indicate that the light conditions make shadow flicker possible, the turbine will be stopped at all times that fall within the pre-defined schedule.

The schedule is generally defined based on the results of the worst case shadow flicker calculations, with a focus on the days of the year with the longest durations. It is also possible to tailor the times to specific preferences, in case for example nuisance is considered more likely during certain times of the day than others.

The current common practice, which follows the WEDGs (2006), is to reduce shadow flicker to below 30 hours per year and 30 minutes per day. However, it would be technically possible to implement a shadow flicker control system that reduces the impact at all surrounding residential buildings to zero, to comply with the recommendations of the DWEDGs (2019). Such a strategy has the drawback of increasing the associated energy production losses.

11.9 Residual Effects

As explained in Section 11.4, shadow flicker impact reduces with distance. At the distances between the wind turbines and residential buildings in question, strong flickering effects will not occur.

As described in Section 11.8, shadow flicker can be either completely eliminated or mitigated to the degree considered necessary by equipping the wind turbines with a shadow flicker control system. Accordingly, the operation of the installed shadow flicker control measures will ensure that there will be no impact from shadow flicker. The operation and performance of the shadow flicker control measures will be monitored on an ongoing basis. As such, there will be no residual impacts as a result of the proposed development.

11.10 Conclusions

The potential for shadow flicker impact at the residential buildings surrounding the Keerglen Wind Farm has been assessed with reference to relevant legislation and guidance. Industry-standard methods and tools have been used for the calculations. Shadow flicker impact was modelled at sensitive receptor locations in the area surrounding the Keerglen turbines, including the cumulative effect of the proposed Glenora Wind Farm. All residential buildings are located at a distance of either 1.5km or more from the proposed turbines, and therefore the strong shadow flicker impacts, which may occur at short distances, are avoided.

The calculations suggest that Keerglen wind farm does not cause any shadow significant flicker impact at nearby receptors. Keerglen turbines cause some shadow flicker impact at one residential property (H002), however as described in Section 11.6, the duration is well below the limits per year and hours per day. Accordingly, there are no exceedances of the limits at any sensitive receptor locations (residential properties), whether in the worst case nor in the real case/expected scenario.

Moreover, shadow flicker impacts can readily be eliminated by equipping the wind turbines with a shadow flicker control system, which stops them at appropriate times. Accordingly, even if there were any impacts beyond the prescribed limits, the operation of shadow flicker control measures would ensure that there will be no impact from shadow flicker on residential buildings.