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APPENDIX 10.4

Shadow Flicker Assessment

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ENVIRONMENTAL IMPACT ASSESSMENT REPORT (EIAR) FOR THE PROPOSED BARNADIVANE WIND FARM & SUBSTATION, CO. CORK

VOLUME 2 – MAIN EIAR
CHAPTER 10 – SHADOW FLICKER

Prepared for: Barnadivane Wind Farm Ltd & Arran Windfarm Ltd.

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10. SHADOW FLICKER

10.1 Introduction

This chapter considers the potential shadow flicker effects at nearby residential buildings associated with the operation of the proposed Barnadivane Wind Farm. The specific objectives of the chapter are to:

- describe the assessment methodology and relevant guidance;
- describe the potential impacts;
- describe the need for any mitigation measures, if required; and
- assess the residual impacts remaining, following the implementation of any mitigation measures.

The assessment has been undertaken by Colum Breslin and reviewed by Jim Singleton, both of TNEI Group.

Colum Breslin has experience of shadow flicker modelling in Ireland and the UK and has worked on both pre-construction (feasibility and planning applications) and complaints investigations. He is skilled in shadow flicker prediction and the specification of appropriate mitigation measures.

Jim Singleton is the Team Manager of TNEI's Environment and Engineering Team. He has 15 years environmental consultancy experience and has worked on wind turbine developments ranging from single turbines to over 300 MW developments, including feasibility studies, authoring of ES chapters, compliance surveys, due diligence and appeals.

A detailed description of the project to be assessed in this EIAR Chapter is provided in Chapter 2.

10.1.1 Scope of Assessment

10.1.1.1 Conditions required for Shadow Flicker

Under certain combinations of geographical position, wind direction, weather conditions and times of day and year, the sun may pass behind the rotors of a wind turbine and cast a shadow over the windows of nearby buildings. When the blades rotate and the shadow passes across a window, to a person within that room the shadow appears to 'flick' on and off; this effect is known as 'shadow flicker'. The phenomenon occurs only within buildings where shadows are cast across a window aperture, and the effects are typically considered up to a maximum distance of 10 times the rotor diameter from each wind turbine.

The 10 times rotor diameter criterion, which effectively sets the size of the study area, is detailed in several international publications including the German '*Guideline for Identification and Evaluation of the Optical Emissions of Wind Turbines*' (2002), the UK's '*Update of UK Shadow Flicker Evidence Base*' (Parsons Brinkerhoff for DECC, 2011) and Ireland's own '*Wind Energy Development Guidelines'* (WEDG 2006).

Specifically, the WEDG 2006 states *"At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low".*

10.1.1.2 Study Area

The proposed development consists of 6 turbines, each with a maximum rotor diameter of 117 m. Accordingly, a study area of 1,170 m from each of the turbines was selected for this assessment i.e. ten times the maximum rotor diameter.

The assessment considers all potential shadow flicker sensitive receptors identified within the study area, which includes habitable residential buildings and buildings that are mixed residential and commercial. The identified receptor locations are detailed on Figure 10.5 and presented in tabulated format in Appendix 10.1.

The suns path in the sky starts in the morning from the eastern horizon, continues to increase in elevation until it is at its highest in the sky in the afternoon, and then decreases in elevation and sets in the western horizon in the evening. This path differs depending on the time of the year, and the suns angle (or azimuth) and elevation are higher during the summer months and lower in the winter months. The general path of the sun across the sky will not change, however, and due to the latitude of the proposed development, the suns azimuth relative to the turbines and receptors is such that shadow flicker in some of the southern areas of the study area will never have the potential to occur. As such, whilst all residential receptors within the study area have been included in the assessment, this does not necessarily mean that all identified receptors will have shadow flicker predicted to occur. The ‘Maximum Extent of Shadow Coverage’, where there is the *potential* for shadow flicker to occur, is detailed in Figure 10.6.

10.1.1.3 Effects to be Assessed

This chapter presents the results and findings of the potential shadow flicker effects at all the identified receptors and quantifies the theoretical maximum number of hours per annum where shadow flicker may occur at a building.

10.2 Methodology

It is possible to predict the total theoretical number of hours per year that shadow flicker may occur in a building from the relative position of the turbines to the building, the geometry of the wind turbines, the latitude of the wind turbine site and the size & orientation of the windows potentially affected. The predictions can be used to identify the times when curtailment may be required in order to mitigate the effects of shadow flicker. The predictions assume that during daylight hours the sun is shining all day, every day.

The potential for shadow flicker to occur and the intensity and duration of any effects depend upon the following factors:

1. the location and orientation of the window relative to the turbines;
2. whether the window has a direct, unobstructed line of sight to the turbine rotor;
3. the distance of the building from the turbines;
4. the turbine geometry;
5. the time of year (which impacts the trajectory of the sun’s path across the sky);
6. the frequency of cloudless skies (particularly at low elevations above the horizon); and,
7. the wind direction (which impacts on turbine orientation).

Several specialist software packages are available that can take account of variables 1-5 listed above to determine the maximum theoretical number of shadow flicker hours that could occur at each window under worst-case conditions. Weather conditions, however, (as detailed in items 6-7), cannot be accounted for accurately. Therefore, the software model assumes cloudless skies 100% of the time and that all turbines are face on to all receptors. In reality this cannot happen so the output from the model will be inherently conservative, although estimates of typical weather conditions can be factored into the assessment at a later stage to provide a more realistic estimate of the likely occurrence of shadow flicker.

Where obstructions are present between a window and turbine due to terrain, this is accounted for within the software model, however, the model does not consider other obstructions that may be present, such as walls, buildings, trees etc.

For this assessment, predictions of shadow flicker have been undertaken using the industry standard software package ReSoft WindFarm, based on the proposed turbine locations and turbine dimensions.

10.2.1 Relevant Guidance

'International Legislation and Regulations for Wind Turbine Shadow Flicker Impact ' (Koppen, 2017) presents an overview of the assessment methodologies most commonly used in countries that have their own specific legislation or guidance with regards to shadow flicker effects. The paper states that nearly all countries base their guidance on the German guidelines '*Guideline for Identification and Evaluation of the Optical Emissions of Wind Turbines*'(2002).

The limit values within the German guidelines are 30 minutes per day and 30 days per year. These limits are, however, based on worst case conditions i.e. the total theoretical number of hours per year that shadow flicker may occur, assuming that the sun is always shining during daylight hours. If it is found that mitigation measures are required, then a further limit value of 8 hours per year is set based on the real case shadow flicker i.e. what is actually occurring and not the theoretical maximum that may occur.

Many countries have adopted the German guideline limits, either directly or with some small adjustments. Australia, Belgium (Walloon region), Brazil, Canada, India, Sweden, and USA all have a worst-case limit of 30 hours a year or 30 minutes a day. The UK has no set limit but also typically adopts these guideline levels for assessment purposes.

Belgium (Flanders region) sets a real case limit of 8 hours a year or 30 mins a day, Denmark a real case limit of 10 hours a year and Netherlands a real case limit of 17 days a year where shadow flicker occurs for more than 20 minutes a day.

There is no standard for the assessment of shadow flicker in Ireland, although a maximum of 30 hours per year and 30 mins per day within 500 m of a wind turbine is recommended, as detailed in Wind Energy Development Guidelines (2006).

10.2.1.1 Cork County Development Plan 2022

The Cork County Development Plan (Cork County Council, 2022) states the following in relation to shadow flicker:

"Consider proposals where it can be shown that significant impacts on the following can be avoided:

- *Residential amenity particularly in respect of noise, shadow flicker and visual impact;"*

The Plan does not, however, provide any detail on how to undertake an assessment of shadow flicker.

10.2.1.2 Wind Energy Development Guidelines (2006)

There is no standard for the assessment of shadow flicker in Ireland, however, The Wind Energy Development Guidelines 2006 (WEDG 2006) provided by the Department of the Environment, Heritage and Local Government (DoEHLG) states;

> *"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."*

10.2.1.3 Draft Revised Wind Energy Development Guidelines (2019)

The DoEHLG published the Draft Revised Wind Energy Development Guidelines in December 2019. The draft revised guidelines set out a zero shadow flicker policy, encouraging the use of technology for shadow flicker control, to prevent it occurring at sensitive receptors. It should be noted, however, that it is not possible to reduce shadow flicker effects to zero. This is due to both the reaction time of any light sensors fitted to the turbines (the sun needs to be sensed for a specific time period before the control module reacts) and the time taken for the blades to slow down to a stop once potential shadow flicker effects are identified. Accordingly, it is possible to mitigate shadow flicker effects but not possible to eliminate them.

The 2019 revised guidelines are currently at draft stage and were subject to consultation and liable to change before the final version is issued. As such, until the revised guidelines are published, the currently adopted WEDG 2006 guidelines will continue to be considered for the assessment of shadow flicker at the proposed development.

10.2.1.4 IWEA Best Practice Guidelines

In March 2012, the Irish Wind Energy Association (IWEA) issued a document detailing best practice guidance for wind farms (IWEA, 2012).

The document provides a preferred methodology to predict the worst-case shadow flicker conditions to provide the most robust results from the assessment. With regards to shadow flicker, the IWEA guidelines support those given in the WEDG, stating:

> *"The assessment of potentially sensitive locations or receptors within a distance of ten rotor diameters from proposed turbine locations will normally be suitable for EIA purposes"*

10.2.2 Field Assessment

Building location data was supplied by Fehily Timoney & Company, derived from a combination of site surveys and supplementary GIS data. The supplied dataset covered an area 10 rotor diameters from the turbines. The dataset was refined through the use of aerial imagery to identify any additional buildings omitted from the dataset, as well as identifying building condition (habitable, derelict etc.), and building dimensions; the building centre-point co-ordinates were also refined where required. Any building that was clearly identified as uninhabitable (such as a farm outbuilding) or derelict was removed, however where this was not possible to confirm, the building was considered as part of the assessment.

Two receptors (receptors 34 and 36) have been identified within the WEDG 500 m assessment area, and in total 38 receptors have been identified within the 1,170 m shadow flicker study area, as shown on Figure 10.5.

Appendix 10.1 contains the model input data for all of the receptors and their windows.

10.2.3 Extent of Shadow Flicker Assessment

The shadow flicker model calculates the total theoretical occurrence of shadow flicker at all receptors per year based on a theoretical worst-case scenario that assumes the sky is always clear, the turbines are always aligned face-on to each window and that there is a clear and undisturbed line of sight between the windows and all of the turbines (except where this is prevented due to topography). In reality, the turbines will not always be orientated as described, clouds will obscure the sun and line of sight may be obscured (for example, from leaves on trees). Accordingly, the theoretical worst-case scenario details the predictions of all possible shadow flicker occurrences, however the actual shadow flicker effects that will occur, will only be possible for some of this time.

To provide a more realistic prediction of potential shadow flicker effects, historical weather data can be used to apply a correction factor, which considers the frequency of clear skies when shadows may be cast. Data compiled by Met Éireann from the nearest long-term weather station to Barnadivane Wind Farm (Cork) has been used to determine the average sunshine hours; this data is presented in Table 10-1.

Table 10-1: Average Monthly Sunshine Hours at Cork Airport Weather Station (1978-2007)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sunshine Hours: Mean Daily Duration[i] (Hr:Min)	01:48	02:24	03:18	04:18	05:12	05:48	05:24	05:12	04:18	03:00	02:18	01:42	**03:54**
Mean Daylight Hours[ii] (Hr:Min)	08:48	09:54	11:54	13:54	15:36	16:36	16:6	14:30	12:36	10:36	08:48	07:48	**12:12**
% Sunshine	23%	24%	28%	38%	40%	35%	34%	36%	34%	28%	26%	22%	**32%**

i Based on meteorological data from Cork 1981-2010 (https://www.met.ie/climate-ireland/1981-2010/cork.html)

ii Based on sunrise and sunset times for Cork 2022 (https://www.sunrise-and-sunset.com/en/sun/ireland/cork/2021)

The annual average percentage of sunshine hours is 32%, therefore a correction factor of 32% can be applied to the theoretical annual predicted levels of shadow flicker to account for the time when the correct meteorological conditions are present for shadows to be cast. It is worth noting that this correction does not account for any additional reductions that would occur as a result of variations in wind speed, wind direction, or by determining whether there is line of sight between a turbine and receiver. These 'likely' levels of shadow flicker are, therefore, still considered to be a conservative estimate.

10.2.4 Modelling Parameters

The shadow flicker model is based on a 'greenhouse' modelling approach, where the entire length of each façade of a building is assumed to be a window (and is therefore sensitive to shadow flicker). Each modelled window is assumed to have a height of 2 m. This approach presents a worst case estimate of shadow flicker in the absence of any detailed window location and dimension data and modelling the full façade will result in higher predicted levels than will actually occur.

The parameters that have been used in the shadow flicker assessment are detailed in Table 10-2.

Table 10-2: Turbine Dimensions

Hub Height (m)	Rotor Diameter	Tip Height (m)
72.5	**117**	**131**

10.3 Existing Environment

Some properties to the north, east and west of the proposed development could be experiencing shadow flicker effects from the existing Garranereagh Wind Farm. This is considered in 10.4.3 in a cumulative assessment. Figure 10.7 presents the shadow throw area, where shadow flicker effects may occur, based on a 10 rotor diameter study area for the Garranereagh Wind Farm.

10.4 Potential Impacts

There is the potential for shadow flicker to occur at 28 of the 38 receptors considered within the study area. At the remaining 10 receptors there is no potential for shadow flicker effects to occur because the suns angle relative to the turbines and receptors never reaches the required position.

A full listing of the worst-case total theoretical instances of shadow flicker by receptor can be found in Appendix 10.2. The calculated area over which shadows from the turbines may be cast (resulting in the potential for shadow flicker to occur) is shown on Figure 10.6.

10.4.1 Annual Impacts

The shadow flicker model for annual impacts sets out the total theoretical hours per year that each receptor can potentially receive shadow flicker. To consider a more realistic 'likely' scenario, the annual average sunshine hours for the region have also been taken into account. The predicted 'likely' levels of shadow flicker have been checked against the WEDG criteria of 30 hours per year, as detailed in Table 10-3.

10.4.2 Daily Impacts

It is not appropriate to apply the annual average sunshine hours correction to the predicted daily totals as the data is based upon monthly averages, which cannot be applied to daily levels with sufficient accuracy. Furthermore, the infrequency of clear skies is more likely to reduce the overall number of instances of shadow flicker over the year, rather than reduce the length of each individual instance. As such, the assessment of daily impacts considers the maximum theoretical amount of shadow flicker only and is inherently conservative.

The predicted maximum theoretical hours per day of shadow flicker is detailed in Table 10-3. Further details, including the duration of individual shadow flicker events occurring at each receptor, are included in Appendix 10-2.

Table 10-3: Shadow Flicker Predicted Levels by Receptor

Receptor ID	Easting (IRENET 95)	Northing (IRENET 95)	Total Theoretical Days Per Year	Maximum Theoretical Minutes Per Day	Total Theoretical Hours Per Year (Hours:Mins)	'Likely' Hours Per Year (Hours:Mins)
1	535011	563958	148	56	82:30	26:24
16	533407	561851	0	0	0:00	0:00
17	532991	562143	78	43	42:00	13:26
18	533015	562460	149	47	97:24	31:10
20	532903	562399	138	39	74:54	23:58
21	532974	562529	169	44	82:18	26:20
22	532555	562698	26	29	9:42	3:06
23	532593	563305	0	0	0:00	0:00
29	534309	561942	49	35	23:12	7:25
30	534581	562066	79	33	28:18	9:03
31	534579	562689	131	37	64:42	20:42
32	534590	562767	113	35	47:30	15:12
34	534739	563622	129	61	87:06	27:52
36	533935	562817	210	109	249:48	79:56
39	533191	563542	168	47	83:12	26:37
41	534733	562755	92	32	35:48	11:27
43	535249	564283	37	37	15:36	4:59
47	532835	562868	99	38	44:30	14:14
48	533205	562565	172	62	142:06	45:28
49	534832	562850	99	31	32:30	10:24
51	532892	562596	173	39	84:12	26:56
55	533276	563444	224	57	125:48	40:15
56	535470	564076	35	31	14:24	4:36
59	533580	561627	0	0	0:00	0:00
60	533538	561596	0	0	0:00	0:00
61	534563	562040	62	34	27:30	8:48
63	533624	561705	0	0	0:00	0:00
64	533729	561670	0	0	0:00	0:00
65	533770	561645	0	0	0:00	0:00
66	534547	561945	92	35	41:30	13:16
67	534566	561987	74	35	31:54	10:12
71	534700	562325	88	33	35:18	11:17
74	533453	564592	20	16	4:30	1:26
75	534150	564943	0	0	0:00	0:00
76	534208	564976	0	0	0:00	0:00
77	533562	564624	0	0	0:00	0:00
158	532965	562089	88	41	44:18	14:10
162	535494	564122	34	31	13:18	4:15
TOTALS				**Number of Receptors which May Experience:**		
				> 30 Minutes/Day	**> 30 Hours/Year**	
				25	20	4

There are two receptors located within the WEDG 500 m assessment area and both of these exceed the daily 30 minutes and the annual 30 hours per year when considering the worst case predictions. Taking into account the 'likely' sunshine hours per day, one receptor (receptor 36) remains above the 30 hours per year limit. Accordingly, mitigation measures will be required reduce shadow flicker impacts for this location.

When considering the wider 1170 m study area, the number of receptors that exceed 30 minutes in a day is 25. 20 receptors exceed the annual limit of 30 hours per year, however, taking into account the 'likely' sunshine hours this is reduced to just 3 receptors.

10.4.3 Potential Cumulative Impacts

The IWEA Guidelines recommend that all existing and/or permitted wind farm developments within 2 km of a proposed development should be considered in a cumulative shadow flicker assessment. There is one wind farm located within 2 km of the proposed development, Garranereagh Wind Farm, which is located immediately to the east. Garranereagh Wind Farm consists of 4 no. of Enercon E-82 turbines with a rotor diameter of 82 m and a tip height of 119.3 m.

Due to the close proximity of Garranereagh Wind Farm to the proposed development, there is an overlap of shadow throw areas where shadow flicker from both developments has the potential to occur. This can be seen on Figure 10-7.

Shadow flicker modelling of both turbine developments has been undertaken, with a 10 rotor diameter study area applied to all turbines. Shadow flicker effects from both the Proposed Wind Farm and Garranereagh Wind Farm are predicted to occur at six receptors. These receptors are located to the east of the Proposed Wind Farm and to the west of Garranereagh. It should be noted that shadow flicker from both developments would not occur at the same time, or upon the same facades/windows, however, the total number and duration of shadow flicker occurrences at the property would increase due to the cumulative operation of both developments.

The predicted maximum theoretical minutes per day and hours per year of shadow flicker from the combined operation of both developments is detailed below:

Receptor ID	Easting (IRENET95)	Northing (IRENET95)	Total Theoretical Days Per Year	Maximum Theoretical Minutes Per Day	Total Theoretical Hours Per Year	'Likely' Hours Per Year
1	535011	563958	178	56	91:24	29:14
31	534579	562689	152	58	82:36	26:25
32	534590	562767	130	55	62:54	20:07
34	534739	563622	209	86	168:12	53:49
36	534733	562755	127	49	62:42	20:03
49	534832	562850	99	31	32:30	10:24
TOTALS				**Number of Receptors that may experience:**		
				> 30 Minutes/Day	**> 30 Hours/Year**	
				6	6	1

The Cumulative Assessment, therefore, concludes as follows:

- Of the six receptors within 10 rotor diameters of both the Proposed Wind Farm and Garraneragh Wind Farm, five receptors are predicted to receive cumulative shadow flicker effects from the operation of both turbine developments. Calculated shadow flicker levels at the sixth receptor (49) are identical to those detailed in Table 10-11, therefore the potential shadow flicker effects at this receptor are from the Proposed Wind Farm only.
- The maximum theoretical minutes per day of existing shadow flicker at these receptors are above WEDG daily limits. Accordingly, mitigation measures are required.
- The theoretical maximum number of hours per year of shadow flicker at all receptors exceed the WEDG limits, however, when considering likely sunshine hours, only one receptor is above the WEDG limits.

10.5 Mitigation Measures

Shadow flicker control modules, consisting of light sensors and specialised software, will be installed on the turbines to prevent operation during periods when shadow flicker is predicted to exceed the thresholds set out in WEDG 2006 at all sensitive receptors located within 10 rotor diameters of the proposed development. This is beyond the requirements of WEDG 2006, which recommends the limits apply only to properties located within 500 m of a development.

The calculated shadow flicker periods, which are detailed in Appendix 10-3, can be input into the turbine control software and when the correct conditions are met i.e. the light intensity is sufficient, the turbine is operational and orientated towards the receptor, the event is within a calculated potential period of shadow flicker, and the thresholds identified in the WEDG 2006 have been exceeded (30 minutes per day or 30 hours per year of shadow flicker), individual turbines will cease operation (allowing for a short period for the control software to react and for the turbine blades to gradually slow down) until the conditions for shadow flicker are no longer present.

10.6 Residual Impacts

The proposed method of mitigation can be used to mitigate shadow flicker effects to all properties within the 10 rotor diameter study area to stay below the WEDG 2006 guidelines levels.

10.7 Do-Nothing Scenario

In the ‘Do-Nothing’ Scenario, Barnadivane Wind Farm would not be constructed and the potential impacts from shadow flicker on local receptors would not occur, except for receptors effected by Garranereagh Wind Farm, where if the conditions are met some shadow flicker effects can occur. No mitigation measures would be required.

10.8 Conclusion

A shadow flicker assessment has been undertaken on 38 receptors within 10 rotor diameters of the proposed Barnadivane Wind Farm, with a cumulative assessment caried out to include the neighbouring Garranereagh Wind Farm.

Based on the Wind Energy Development Guidelines 2006 (WEDG 2006) thresholds, the predicted 'Maximum Theoretical Minutes Per Day' of shadow flicker exceeds 30 minutes at 25 receptors.

When considering the 'Total Theoretical Hours Per Year', 20 receptors are predicted to exceed the WEDG 2006 threshold of more than 30 hours per year. However, when accounting for a more 'likely' scenario, where the average annual sunshine hours are considered, there are only 4 receptors that are predicted to exceed more than 30 hours per year.

Of the 38 receptors within 10 rotor diameters of the Proposed Wind Farm, six receptors are also within 10 rotor diameters of Garranereagh Wind Farm; of these, five receptors may experience cumulative shadow flicker effects. The cumulative assessment has identified that in addition to the conclusions stated in the paragraphs above, one additional receptor has the potential to exceed the threshold of 30 hours per year when considering a 'likely' scenario, resulting in a total of five receptors above this threshold.

A scheme of mitigation would be implemented into the turbine control software to cease turbine operation during periods when the WEDG 2006 thresholds are being exceeded. Turbine shutdowns would be applied automatically during periods of sunshine and after accounting for accumulated shadow flicker exposure, wind speed and wind direction, allowing for the reaction time of the shadow flicker control modules and also allowing for a short period of time for the turbine blades to slow down to a stop.

With the implementation of the proposed mitigation measures, no cumulative impacts with other proposed or operational wind farms in the area are predicted to occur on any receptors in the study area.

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