Drumlins Park Wind Farm

Chapter 12: Shadow Flicker

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12.1 Introduction

This chapter addresses the likely effects of shadow flicker on nearby properties within the vicinity of the proposed development. The candidate turbine selected for assessment in this chapter is the General Electric GE 5.5-158 (Option TU1 - see **Chapter 3** for further details) as it has a largest rotor diameter of the selected candidate turbines and therefore has the greatest likelihood to result in the occurrence of shadow flicker. As with all tall structures, wind turbines can cast long shadows on neighbouring areas when the sun is low in the sky. During sunny conditions and under certain combinations of geographical position, weather conditions and the time of day, the sun may pass behind the moving wind turbine blades and cause a shadow to flicker on and off of neighbouring properties. This is phenomenon known as shadow flicker.

Dwellings and buildings may be affected by shadow flicker (i.e. when a turbine blade shadow passes an open door or window within a flicker zone) as the sunlight comes from one source. Shadow flicker is not as obvious outside as sunlight comes from all directions.

Shadow flicker generally lasts only for a short period and happens only in certain specific combinations of weather and geographic conditions such, as follows:

- The sun is shining and is at a low angle in the sky (after dawn and before sunset);
- The turbine is located directly between the sun and the affected property;
- The wind speed is high enough to move the turbine blades, and
- The turbine blades are orientated such that they are horizontal to the sun.

Given the very low likelihood of such conditions occurring simultaneously, the likelihood of shadow flicker at any receptor is low.

12.2 Statement of Authority

This chapter has been prepared by members of the GES Planning Team, with specialist technical input provided by Cormac McPhillips, Project Technician at GES. Cormac has significant experience of preparing shadow flicker prediction models for a number of existing and permitted wind energy developments, including for a number of operational phase shadow flicker monitoring programmes, and has carried out visual inspections to confirm the efficacy of the prediction models and mitigation measures.

12.3 Assessment Methodology

12.3.1 Wind Energy Development Guidelines for Planning Authorities

The assessment has been carried out in accordance with all statutory guidelines and uses techniques which are recognised as best practice by the relevant environmental health organisations. The Wind Energy Development Guidelines for Planning Authorities 2006 state:-

> *"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"

Given that the Guidelines state that the likelihood for shadow flicker at distances greater than 10 no. rotor diameters from a turbine is low, the assessment of likely shadow flicker effects at all dwellings within 10-times overall tip height is considered to be an extremely conservative approach. Other elements of the overall project, including the grid connection options and construction phase haul routes, have no potential to generate shadow flicker effects and thus have been screened out from further assessment.

12.3.2 Passing Frequency

A periodic change in the light produced by the sun occurs at a particular location because of the rotating wind turbine rotor. This is referred to as a pulsating light level. Research has shown that the consequences of the pulsating light level are dependent on the frequency. The frequency is determined by the speed of the rotor and the number of rotor blades in the case of wind turbines.

From this research, including research done into the lighting of traffic tunnels, most people tested who experienced frequencies between 5 and 10 Hz (Hertz) were subject to virtually no nuisance. The candidate turbine (see above) has a typical rotational speed of 10rpm (revolutions per minute) and three rotor blades. The maximum passing frequency is, therefore 0.5Hz (30 times per minute), which is well below nuisance level. The effects of passing frequencies have, therefore, not been considered in this assessment.

12.3.3 Candidate Turbine Model & Layout

As outlined in **Chapter 3**, a specific wind turbine model has not yet been selected and will only be confirmed following a pre-construction tendering process. The primary dimension of the wind turbines to be installed will be 180m (up to) and this will not be altered by the turbine model ultimately erected and as such, it is considered that either candidate turbine outlined at **Chapter 3** could be used in this assessment. However, due to the longer blades of 79m (moving parts) of the General Electric GE 5.5-158 wind turbine (Option TU1), it has been selected as the basis for this chapter. It should also be noted that the erection of any wind turbine model within the overall tip height envelope of 180m will not affect the substantive conclusions of this assessment.

As it is not possible at this point to confirm the precise rotor diameter of the turbines which will be installed, and consequently the number of dwellings within the 10-times rotor diameter criterion, all dwellings and potential shadow flicker sensitive locations within 1,800m (10-times overall tip height) are assessed within this chapter.

12.3.4 Receptor Survey

The location of all properties near the proposed development was recorded using Ordnance Survey Ireland (OSI) data, a detailed planning registry search and a physical survey of the area. A total of 123 no. receptors within 1,800m radius (10-times overall tip height) of the candidate turbine were identified. The topography of the local area, the proposed development site and the elevation of nearby receptors was also modelled using OSI data.

12.3.5 Impact Prediction Model

WindPro software, a detailed computer model which can estimate the likely occurrence of shadow flicker, was used to predict the likely impact of the proposed development. The prediction model assesses the likelihood for shadow flicker to occur at receptor locations relative to the wind turbine locations and with long term average sunshine hours.

12.3.6 Model Assumptions

Sunshine Hours & Angle

Shadow flicker cannot occur if the sun is not shining, therefore the probability of sunshine must be considered as part of this assessment. Historical metrological data from 1982 to 1993 from Clones Meteorological Station was used to assess the number of sunshine hours (c. 5km from the proposed development site) (see **Table 12.1**).

Mean Daily Duration (hours/day)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.45	1.93	2.72	4.31	5.45	4.41	4.74	3.96	3.48	2.54	1.71	1.01

Table 12.1: Average Daily Sunshine Hours (Clones 1982-1993)

A simple calculation using the above recorded data shows that the probability of sunshine is approximately 3.14 hours per day when averaged over a 12 month period. The absence of a high mean daily duration of sunshine will result in a significant decrease in the potential for shadow flicker effects when the 'worst case' scenario is adjusted.

There is a great difference in light levels between a shadow at a short distance and a shadow at a long distance. The potential impact is greatest at a short distance from the wind turbine since the rotor blade screens the whole of the sun at a short distance. Shadows at a greater distance from the wind turbine have a low intensity since the blades no longer cover the sun completely and, therefore, the light contrast is strongly reduced. If an observer experiences shadow from the sun when it is lower than three degrees above the horizon, the distance to the wind turbine will be of such a length that it is likely that the consequences of the intensity of the shadow can be ignored. Sunshine is, moreover, generally tempered by mist, cloud cover, vegetation growth or buildings in the surrounding area when the position of the sun is lower than three degrees. To account for this, the sun's minimum angle has been set at three degrees in the shadow flicker model.

Greenhouse Mode

Each receptor is modelled in 'greenhouse' mode. This effectively assumes a conservative 'worst case' impact where each receptor is constructed entirely of glass (windows on all elevations) and that no intervening screening is afforded by walls, vegetation or other opaque objects between the receptor and the wind turbine

Turbine Rotation

The candidate wind turbine, a General Electric GE 5.5-158, has a cut-in wind speed of 3m/s and cut out of 25m/s. According to the wind atlas and data obtained from the on-site meteorological mast, the average adjusted wind speed over the proposed development site is approximately 7.5m/s at 101m. Typically in Ireland, wind speed is between 3m/s and 25m/s for 85% of the time (based on an average of 7.5m/s). Therefore the turbines are likely to be operational for 85% of the year.

The shadow flicker model, however, assumes that the turbine rotor is rotating 100% of the time. Therefore, the model is highly conservative, precautionary and does not account for the being non-operational for a variety of reasons including grid unavailability, turbine maintenance and turbine breakdown. The turbine is likely to be non-operational for 15% of the time due to the above factors.

Wind Direction & Rotor Orientation

Wind direction plays a crucial role in determining the likelihood of shadow flicker. A wind turbine directs the rotor at right angles to the wind direction (turns the rotors to 'attack' the wind in order to generate power) when there is sufficient wind. The wind direction is, therefore, the critical determining factor for the orientation of the rotor and also for the position of the rotor in relation to the sun.

Given weather variability, it is not possible that that sunshine will always coincide with wind turbines facing parallel the sun such that the blades are orientated in a horizontal position (directly or indirectly) to cause shadow flicker at any receptor. However, it is assumed for the purposes of the model that, when the sun is shining, wind direction is such that shadow flicker can be caused at all receptors simultaneously.

Summary of Assumptions

In summary, the 'worst case' shadow flicker model calculation is based on a number of conservative and highly precautionary assumptions, as follows:

- When the sun is always shining, there is constant adequate wind speed such that each turbine is always rotating and that the turbine rotor tracks the sun by orientating the turbine exactly as the sun moves, such that shadow flicker is caused at receptors;
- Ordnance Survey Ireland digital data is used as the only topographical reference. Simulations are run on a 'lunar landscape' without allowing for the obscuring effect of any vegetation or other structures between the location of receptors and the position of the sun in the sky;
- Each receptor is constructed entirely of glass (windows on all elevations), all the rooms are occupied and that the curtains or blinds, if present, are always open; and
- There will be no downtime for any of the turbines as a result of a mechanical fault, grid availability or routine maintenance.

12.3.7 Assumed v. Expected Shadow Flicker

It is important to note that over the course of a year, it can be assumed in the model that it will be sunny for a percentage of the year and to adjust the 'worst case' predictions accordingly to find the 'expected' shadow flicker hours. However, over the course of a day, it cannot be assumed that it will only be sunny for a percentage of the day (it may be sunny all day or not at all). Therefore, it is not possible to adjust the 'worst case' predictions to find the 'expected' shadow flicker hours over the course of a day. Therefore, as is best practice, the values presented in this chapter are conservative 'worst case' hours per day (in accordance with a precautionary approach) and 'expected' hours per year.

The 'worst case' calculations (hours per day) necessarily significantly overestimate the number of hours of shadow flicker per day experienced at any receptor. On the other hand, the 'expected' values (hours per year) consider the probability of sunshine and predominant wind direction at the proposed development site and therefore is more representative of the actual levels of shadow flicker which may be experienced. However, the model is based on the highly precautionary assumptions described above and represents an over-estimation of the actual impact.

12.4 Description of the Existing Environment

The receiving baseline environment is a rural drumlin landscape, typical of County Monaghan and characterised by one-off dwellings, often accompanied by agricultural buildings, and fields bounded by mature hedgerows.

A total of 123 no. receptors have been identified within 1,800m of a proposed wind turbine (10-times overall tip height) as illustrated at **Annex 12.1**).

12.5 Description of Likely Effects

12.5.1 Construction Phase

As the proposed turbines will not be operational during the construction phase, there is no likelihood for shadow flicker to occur.

12.5.2 Operational Phase

As presented in **Table 12.2**, the 'worst case' model results indicate that 39 no. receptors are predicted to experience shadow flicker in excess of 30-minutes per day. However, it is again reiterated that this calculation is a 'worst case' scenario and is not representative of likely shadow flicker. As explained above in **Section 12.3.7**, the 'worst case' scenario can only occur under rare, specific combination of circumstances occurring simultaneously i.e. when the sun is at a certain position in the sky, the sun is shining, the turbines rotor is rotating and rotating parallel (directly or indirectly) to the shadow receptor.

The 'expected results' over the course of a year are also presented in **Table 12.2** (reproduced from **Annex 12.2**). Only 1 no. of the 123 no. receptors surveyed is likely to experience shadow flicker in excess of 30-hours per annum. This dwelling, H021, is predicted to experience 31.49 hours of shadow flicker per annum and just marginally above the 30-hours per year of permissible shadow flicker as prescribed in the Wind Energy Development Guidelines for Planning Authorities (2006).

The next highest prediction of shadow flicker effects relates to H022, which is predicted to experience 29.53 hours per year. Notably, both of these receptors are economically involved in the proposed development. All remaining receptors are likely to experience less than 24-hours of shadow flicker per year, with 44 no. dwellings likely to experience no shadow flicker at all.

It should be noted that even the 'expected' results are subject to the precautionary model assumptions as set out in **Section 12.3.7** and therefore likely to significantly overestimate the actual shadow flicker impact.

Dwelling ID	'Worst Case' Shadow Flicker			'Expected' Shadow Flicker		
	Permissible Levels (hours per day (hh:mm))*	Predicted Levels (hours per day (hh:mm))	Exceedance of Permitted Limit (hh:mm)	Permissible Shadow Flicker Levels (hours per year (hh:mm))*	Expected Shadow Flicker Levels (hours per year (hh:mm))	Exceedance of Permitted Limit (hh:mm)
H001**	00:30	01:01	00:31	30:00	02:34	-
H002**	00:30	01:41	01:11	30:00	11:46	-
H003	00:30	00:10	-	30:00	00:08	-
H004	00:30	00:21	-	30:00	00:35	-
H005**	00:30	01:31	01:01	30:00	13:14	-
H006	00:30	01:11	00:41	30:00	23:07	-
H007**	00:30	01:01	00:31	30:00	19:49	-
H008	00:30	00:54	00:24	30:00	15:12	-
H009	00:30	00:48	00:18	30:00	13:22	-
H010	00:30	00:33	00:03	30:00	07:38	-
H011	00:30	00:43	00:13	30:00	10:32	-
H012	00:30	00:25	-	30:00	03:54	-
H013	00:30	00:18	-	30:00	00:54	-
H014	00:30	00:21	-	30:00	01:07	-
H015	00:30	00:48	00:18	30:00	10:57	-
H016	00:30	00:00	-	30:00	00:00	-
H017	00:30	00:48	00:18	30:00	13:11	-
H018	00:30	00:32	00:02	30:00	07:30	-
H019**	00:30	00:55	00:25	30:00	12:51	-
H020	00:30	00:59	00:29	30:00	15:09	-
H021**	00:30	01:48	01:18	30:00	31:49	01:49
H022**	00:30	01:16	00:46	30:00	29:53	-
H023	00:30	00:51	00:21	30:00	13:09	-
H024**	00:30	00:55	00:25	30:00	16:32	-
H025	00:30	00:43	00:23	30:00	07:25	-
H026	00:30	00:41	00:11	30:00	04:37	-
H027	00:30	00:50	00:20	30:00	05:43	-
H028	00:30	00:52	00:22	30:00	05:47	-
H029	00:30	00:54	00:24	30:00	05:56	-
H030	00:30	01:07	00:37	30:00	07:18	-
H031	00:30	01:14	00:44	30:00	08:34	-

Dwelling ID	'Worst Case' Shadow Flicker			'Expected' Shadow Flicker		
	Permissible Levels (hours per day (hh:mm))*	Predicted Levels (hours per day (hh:mm))	Exceedance of Permitted Limit (hh:mm)	Permissible Shadow Flicker Levels (hours per year (hh:mm))*	Expected Shadow Flicker Levels (hours per year (hh:mm))	Exceedance of Permitted Limit (hh:mm)
H032	00:30	00:00	-	30:00	00:00	-
H033	00:30	00:41	00:11	30:00	01:47	-
H034	00:30	00:08	-	30:00	00:07	-
H035	00:30	00:00	-	30:00	00:00	-
H036	00:30	00:00	-	30:00	00:00	-
H037	00:30	00:00	-	30:00	00:00	-
H038	00:30	00:00	-	30:00	00:00	-
H039	00:30	00:00	-	30:00	00:00	-
H040	00:30	00:00	-	30:00	00:00	-
H041	00:30	00:00	-	30:00	00:00	-
H042	00:30	00:00	-	30:00	00:00	-
H043	00:30	00:31	00:01	30:00	02:40	-
H044	00:30	00:31	00:01	30:00	02:21	-
H045	00:30	00:44	00:14	30:00	03:39	-
H046	00:30	00:28	-	30:00	03:23	-
H047	00:30	00:30	-	30:00	05:08	-
H048	00:30	00:27	-	30:00	04:19	-
H049	00:30	00:24	-	30:00	02:34	-
H050	00:30	00:32	00:02	30:00	02:51	-
H051	00:30	00:28	-	30:00	01:47	-
H052	00:30	00:29	-	30:00	02:28	-
H053	00:30	00:29	-	30:00	03:24	-
H054	00:30	00:22	-	30:00	02:06	-
H055	00:30	00:00	-	30:00	00:00	-
H056	00:30	00:29	-	30:00	02:55	-
H057	00:30	00:39	00:09	30:00	04:44	-
H058	00:30	00:00	-	30:00	00:00	-
H059	00:30	00:00	-	30:00	00:00	-
H060**	00:30	00:00	-	30:00	00:00	-
H061**	00:30	00:00	-	30:00	00:00	-
H062	00:30	00:00	-	30:00	00:00	-
H063	00:30	00:00	-	30:00	00:00	-

Dwelling ID	'Worst Case' Shadow Flicker			'Expected' Shadow Flicker		
	Permissible Levels (hours per day (hh:mm))*	Predicted Levels (hours per day (hh:mm))	Exceedance of Permitted Limit (hh:mm)	Permissible Shadow Flicker Levels (hours per year (hh:mm))*	Expected Shadow Flicker Levels (hours per year (hh:mm))	Exceedance of Permitted Limit (hh:mm)
H064	00:30	00:00	-	30:00	00:00	-
H065	00:30	00:00	-	30:00	00:00	-
H066	00:30	00:00	-	30:00	00:00	-
H067	00:30	00:00	-	30:00	00:00	-
H068	00:30	00:00	-	30:00	00:00	-
H069	00:30	00:00	-	30:00	00:00	-
H070	00:30	00:00	-	30:00	00:00	-
H071	00:30	00:00	-	30:00	00:00	-
H072	00:30	00:00	-	30:00	00:00	-
H073	00:30	00:00	-	30:00	00:00	-
H074	00:30	00:19	-	30:00	01:49	-
H075	00:30	00:22	-	30:00	02:49	-
H076	00:30	00:25	-	30:00	02:05	-
H077	00:30	00:30	-	30:00	06:16	-
H078	00:30	00:21	-	30:00	02:06	-
H079	00:30	00:25	-	30:00	02:57	-
H080	00:30	00:29	-	30:00	03:57	-
H081	00:30	00:28	-	30:00	02:49	-
H082	00:30	00:23	-	30:00	01:53	-
H083	00:30	00:19	-	30:00	00:45	-
H084	00:30	00:27	-	30:00	02:02	-
H085	00:30	00:24	-	30:00	01:53	-
H086	00:30	00:33	00:03	30:00	03:39	-
H087	00:30	00:35	00:05	30:00	04:06	-
H088	00:30	00:29	-	30:00	02:41	-
H089	00:30	00:30	-	30:00	02:37	-
H090	00:30	00:41	00:11	30:00	02:38	-
H091	00:30	00:37	00:07	30:00	03:16	-
H092	00:30	00:47	00:17	30:00	10:19	-
H093	00:30	00:00	-	30:00	00:00	-
H094	00:30	00:30	-	30:00	03:37	-
H095	00:30	00:31	00:01	30:00	05:44	-

Dwelling ID	'Worst Case' Shadow Flicker			'Expected' Shadow Flicker		
	Permissible Levels (hours per day (hh:mm))*	Predicted Levels (hours per day (hh:mm))	Exceedance of Permitted Limit (hh:mm)	Permissible Shadow Flicker Levels (hours per year (hh:mm))*	Expected Shadow Flicker Levels (hours per year (hh:mm))	Exceedance of Permitted Limit (hh:mm)
H096	00:30	00:00	-	30:00	00:00	-
H097	00:30	00:00	-	30:00	00:00	-
H098	00:30	00:00	-	30:00	00:00	-
H099	00:30	00:00	-	30:00	00:00	-
H100	00:30	00:00	-	30:00	00:00	-
H101	00:30	00:00	-	30:00	00:00	-
H102	00:30	00:24	-	30:00	01:19	-
H103	00:30	00:23	-	30:00	01:46	-
H104	00:30	00:00	-	30:00	00:00	-
H105	00:30	00:00	-	30:00	00:00	-
H106	00:30	00:00	-	30:00	00:00	-
H107	00:30	00:00	-	30:00	00:00	-
H108	00:30	00:21	-	30:00	01:01	-
H109	00:30	00:22	-	30:00	00:50	-
H110	00:30	00:00	-	30:00	00:00	-
H111	00:30	00:00	-	30:00	00:00	-
H112	00:30	00:00	-	30:00	00:00	-
H113	00:30	00:16	-	30:00	00:48	-
H114	00:30	00:14	-	30:00	00:34	-
H115	00:30	00:00	-	30:00	00:00	-
H116	00:30	00:00	-	30:00	00:00	-
H117	00:30	00:00	-	30:00	00:00	-
H118	00:30	00:23	-	30:00	01:34	-
H119	00:30	00:22	-	30:00	01:18	-
H120	00:30	00:21	-	30:00	01:10	-
H121	00:30	00:20	-	30:00	00:40	-
H122	00:30	01:04	00:34	30:00	20:26	-
H123	00:30	01:01	00:31	30:00	18:51	-

Table 12.2: Shadow Flicker Prediction Model Results

*Permissible Shadow Flicker as per Wind Energy Development Guidelines for Planning Authorities (2006)

**Economically Involved Dwellings/Landowners

12.5.3 Decommissioning Phase

As the proposed turbines will not be operational during the decommissioning phase, there is no likelihood for shadow flicker to occur.

12.5.4 Grid Connection

None of the grid connection options have any potential to produce shadow flicker effects.

12.5.5 Cumulative & Transboundary Effects

Prior to undertaking the impact assessment modelling presented in this chapter, an appraisal of the wider area was undertaken to determine if any cumulative impacts could arise with other wind farm developments. As there are no wind energy developments within 10km of the proposed development (the Mountain Lodge, Bindoo, and Carrickallen Wind Farms are c. 12km distant at their nearest point) it is assessed that there is no likelihood for in-combination effects to occur.

It is noted that a number of small-scale/micro-generation wind turbines also exist in the wider area, particularly in Northern Ireland. However, due to their small scale and distance from the proposed development, it is assessed that there is no likelihood for cumulative effects to occur. In addition, it is assessed that the proposed development is of a sufficient distance from the all sensitive receptors in Northern Ireland such that there is no likelihood of transboundary effects.

12.6 Mitigation & Monitoring Measures

12.6.1 Construction Phase

As there is no likelihood for impacts to arise during the construction phase, no mitigation measures or monitoring proposals are required, or proposed.

12.6.2 Operational Phase

Technological mitigation is available, and widely implemented, on wind farm developments where shadow flicker levels are proven to be in excess of the recommended limits. These mitigation measures effectively limit the operation of turbines during the infrequent and rare periods when shadow flicker occurs. In short, if a particular turbine is creating shadow flicker effects at a particular receptor, then that turbine may be temporarily curtailed. This is usually achieved by turning off the turbines at predetermined times, as predicted by the shadow flicker model, when shadow flicker is proven to occur.

The wind turbines will each be fitted with shadow flicker curtailment software to facilitate their shut down as required. If the sun is shining, the software will turn off the turbine at the predetermined times when shadow flicker is predicted to occur based on the prediction model. This approach will be implemented, as necessary, to ensure that actual levels of shadow flicker do not exceed either of the relevant limits. In particular, the operation of the proposed wind turbines will be curtailed to ensure that H021 does not experience more than 30 hours per year and that no dwelling experiences shadow flicker in excess of 30 minutes on any given day.

Within 12-months of operation, a shadow flicker survey will be undertaken by a suitably qualified person to verify the results of the prediction model and to ensure the effective operation of the curtailment software. Monitoring will be undertaken when and where the model predicts shadow flicker is expected to occur. The level of turbine curtailment required to ensure this will have a negligible impact on the overall renewable energy output of the proposed development.

Where implemented, ongoing intermittent monitoring will be undertaken to continuously validate the efficacy of the technological mitigation. The data collected will include:-

- The date, time, location (turbine ID) and duration of the measurement;
- Sunlight intensity and direction;
- Wind speed and direction/rotor angle;
- Details of the equipment calibration to ensure accurate readings are taken; and
- Time, date and duration of any sensor triggered curtailment.

A number of random site visits will be carried out by a suitably qualified person at relevant times to monitor the site when shadow flicker is predicted to occur to verify the effectiveness of the technological solutions.

In addition, should any third party complaints be raised in respect of shadow flicker at any time during the lifetime of the proposed development, additional specific monitoring will be undertaken as per the methods described above.

An Outline Shadow Flicker Monitoring Programme has been prepared and is provided at **Annex 12.3**. This programme will be further developed, and agreed with the Planning Authority, prior to the commencement of development.

12.6.3 Decommissioning Phase

As there is no likelihood for impacts to arise during the decommissioning phase, no mitigation measures or monitoring proposals are required, or proposed.

12.7 Residual Effects

The above mitigation measures will ensure that any residual impacts which arise following their implementation will not result in any likely significant effects on any receptor. Technological mitigation can effectively exclude any likely significant impacts as a consequence of shadow flicker.

The proposed mitigation measures will, where necessary, ensure that shadow flicker levels which may be experienced at receptor locations fall below the prescribed limits of the *Wind Energy Development Guidelines for Planning Authorities 2006*, while the proposed monitoring will confirm the efficacy of the mitigation measures.

12.8 Summary

This chapter has assessed the likelihood for shadow flicker effects at all dwellings (123 no.) located within 10-times the overall tip height (1,800m) of the proposed turbines using a shadow flicker model. Shadow flicker is a rare phenomenon and can only occur during the infrequent coincidence of a number of specific, variable meteorological and geographic factors. The shadow flicker model is also based on a number of precautionary assumptions which significantly overestimate the likely shadow flicker impact at any receptor.

There is no likelihood for any significant effects during the construction or decommissioning phases as the proposed development will not be operational. Similarly, secondary developments associated with the wind farm, such as the grid connection options and haul route upgrades, have no likelihood to result in any shadow flicker effects.

During the operational phase, 39 no. receptors are predicted to exceed the 30-minutes per day criterion in a 'worst case' modelled scenario. The 'expected' shadow flicker hours per year at 1 no. dwelling is predicted to exceed the 30 hours per year criterion.

Technological mitigation measures are available, and widely implemented, to exclude the likelihood for shadow flicker to occur. These measures will ensure that no dwelling experiences shadow flicker levels in excess of either of the 30-minutes per day or 30-hours per year criteria. Therefore, it is concluded that the proposed development will not result in any likely significant shadow flicker effects, either individually or in combination with other existing, permitted or proposed developments.