White Hill Wind Farm

Environmental Impact Assessment Report

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 project. 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.

12.1.1 Description of the Project

In summary, the project comprises the following main components as described in **Chapter 3**:-

- 7 no. wind turbines with an overall tip height of 185m, and all associated ancillary infrastructure;
- All associated and ancillary site development, excavation, construction, landscaping and reinstatement works, including the provision of site drainage infrastructure;
- Upgrades to the turbine component haul route; and,
- Construction of an electricity substation and installation of c. 15km of underground grid connection cable between the White Hill Wind Farm and the existing Kilkenny 110kV electricity substation.

The wind farm site traverses the administrative boundary between counties Carlow and Kilkenny; with 4 no. turbines located in Co. Carlow and 3 no. turbines within Co. Kilkenny. The electricity substation is located within Co. Carlow while the majority, c. 14km, of the underground electricity line is located in Co. Kilkenny. Off-site and secondary developments; including the forestry replant lands and candidate quarries which may supply construction materials; also form part of the project.

The turbine component haul route and associated upgrade works as described in **Chapter 3**. It is envisaged that the turbines will be transported from the Port of Waterford, through the counties of Kilkenny, Waterford, Carlow and Kildare to the project site.

A full description of the project is presented in **Chapter 3**.

12.2 Statement of Authority

This chapter has been prepared by members of the GES Planning & Environment

Team, with specialist technical input provided by Cormac McPhillips, Technical Services Manager at GES. Cormac has significant experience of preparing shadow flicker prediction models for existing and permitted wind energy developments, including 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 2006*

This 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* ('the 2006 Guidelines') 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"*

The likely effects of shadow flicker have been central to the environmental constraints analysis process undertaken, and described at **Chapter 2**, and the iterative design process described therein demonstrates the careful site selection and layout process which has been followed.

The 2006 Guidelines state that the likelihood of shadow flicker being experienced at distances greater than 10-times rotor diameter from a turbine is low. However, and in accordance with the precautionary principle, an extremely conservative study area of 10-times overall tip height (i.e. 1,850m) has been selected. All dwellings within this study are will be assessed for shadow flicker effects.

Other elements of the overall development, including grid connection infrastructure and construction phase haul routes, are not capable of generating shadow flicker effects and thus have been screened out from further assessment.

12.3.2 *Draft Revised Wind Energy Development Guidelines 2019*

The 2006 Guidelines specify that shadow flicker shall not exceed 30-minutes per day or 30-hours per year at a particular dwelling. In the event that shadow flicker is predicted to exceed either of these thresholds, mitigation measures shall be installed to switch off turbines at times when exceedances are predicted to occur.

The *Draft Revised Wind Energy Development Guidelines 2019* ('the Draft 2019 Guidelines') propose to fully eliminate the occurrence of shadow flicker at all dwellings, places of work and schools through the installation of automated turbine shut down software.

While the Draft 2019 Guidelines remaining in draft form, and have not been formally adopted, the Developer has, in response to concerns raised by local residents, committed to the implementation of mitigation measures to fully eliminate shadow flicker at dwellings, places of work and schools. Details of these mitigation measures are provided at **Section 12.6.2**.

12.3.3 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, which is determined by the speed of the 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 proposed wind turbine has a typical rotational speed of c. 12rpm (revolutions per minute) and three rotor blades. The maximum passing frequency is, therefore 0.6Hz (36 times per minute), which is well below the accepted level where nuisance is likely to occur. The effects of passing frequencies have, therefore, not been considered in this assessment.

12.3.4 Receptor Survey

The location of all properties within 1,850m (10-times overall tip height) of a proposed wind turbine was recorded using Ordnance Survey Ireland (OSI) data, a detailed planning registry search and a physical survey of the area. A total of 129 no. receptors within 1,850m of a proposed wind turbine were identified; the locations of which are illustrated at **Annex 12.1**. The topography of the local area, the project site and the elevation of nearby receptors was also modelled using OSI data.

12.3.5 Impact Prediction Model & Assumptions

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

It is important to note that shadow flicker is a relatively minor and short-lived phenomenon which only occurs in the very rare instances when a combination of a number of very specific meteorological and physical conditions happen concurrently, as follows:-

- the sun is shining and is at a low angle (after dawn and before sunset);
- there is sufficient direct sunlight to cause shadows (i.e. no cloud, mist, fog);
- the turbine is directly between the sun and the receptor, and within a distance that the shadow has not diminished below perceptible levels;
- there is no screening vegetation or other structures between the turbine and the receptor which would diminish shadow below perceptible levels; and,
- there is enough wind energy to ensure that the turbine blades are moving.

The concatenation of these conditions to cause shadow flicker at any receptor is highly unusual and even the occasional events that do occur usually go entirely unnoticed.

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 the Kilkenny Meteorological Station was used to assess the number of sunshine hours (see **Table 12.1**).

Mean Daily Duration (hours/day)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.68	2.20	3.08	4.72	5.31	4.94	4.67	4.36	3.78	2.74	2.15	1.32

Table 12.1: Historic Average Daily Sunshine Hours (Kilkenny Meteorological Station)

A simple calculation using the above recorded data shows that the probability of sunshine is approximately 3.4 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 likelihood of shadow flicker effects when the 'worst case' scenario is adjusted to the 'expected' scenario.

There is a great difference in light levels between a shadow at a short distance and a shadow at a long distance. The intensity 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 intensity of the shadow can be ignored. Sunshine is, in Ireland, 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 proposed wind turbine, a Vestas V162-7.2, 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 7.8m/s at 104m (adjusted for the hub/nacelle height of the proposed wind turbines). Typically in Ireland, wind speed is between 3m/s and 25m/s for 85% of the time. Therefore the turbines are likely to be operational for 85% of the year.

The shadow flicker model, however, assumes that the turbine rotors are rotating at all times (i.e. 100% of the time). Therefore, the model is highly conservative, precautionary and does not account for the turbines 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; greenhouse mode), 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 'Worst Case' versus 'Expected' Shadow Flicker

The Draft 2019 Guidelines provide that applicants should present calculations to quantify the effect of shadow flicker. As a consequence, and in order to demonstrate 'worst case' and 'expected' effects, the modelling analysis and calculations are presented in 'minutes per day' and 'hours per year'. However, the presentation of the data in this manner is problematic and can often result in a misunderstanding of the actual impact.

This is due to the fact that the long-run accurate modelling of shadow flicker in 'minutes per day' is not possible as weather conditions on a daily basis are inherently changeable over such a short timeframe and evidently cannot be predicted in advance. For example, over the course of a year, the model can assume that it will be sunny for a percentage of the year (based on historic meteorological data) and the 'worst case' predictions can be adjusted 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). As a result, the model significantly overestimates the predicted minutes of shadow flicker which will likely be experienced at any receptor on any given day and the 'minutes per day' criterion is not, therefore, representative of actual shadow flicker which will be experienced. Most dwellings will experience considerably less shadow flicker, if any at all. This approach is in full accordance with the precautionary principle.

On the other hand, modelling over a longer timeframe of one year, the 'expected' values ('hours per year') consider the probability of sunshine and predominant wind direction based on historic meteorological data. Modelling over such a longer time span is therefore more accurate and more representative of the actual levels of shadow flicker which are likely to be experienced. However, while more accurate, given the assumptions inherent to the prediction model, as set out at **Section 12.3.6**, even the 'expected hours per year' criterion represents a conservative approach.

Therefore, and as is best practice, the predicted shadow flicker values presented in this chapter are conservative 'worst case' hours per day (in accordance with a precautionary approach) and 'expected' hours per year.

12.4 Description of the Existing Environment

The receiving baseline environment is a rural upland landscape; typical of this part of west Co. Carlow and east Co. Kilkenny; and characterised by one-off dwellings, often accompanied by agricultural buildings, and fields bounded by mature hedgerows. The proposed development site and its environs are also characterised by tracts of commercial forestry plantations.

A total of 129 no. receptors have been identified within 1,850m (10-times overall tip height) of a proposed wind turbine as illustrated at **Annex 12.1**).

12.5 Description of Likely Effects

12.5.1 Construction Phase

As the proposed wind turbines will not be operational during the construction phase, shadow flicker will not occur.

12.5.2 Operational Phase

It should be reiterated that the Developer has, as described above at **Section 12.3.2**, and detailed further at **Section 12.6.2** below, committed to the incorporation of design measures to eliminate any occurrence of shadow flicker at dwellings, places of work and schools. Consequently, the below assessment is a theoretical prediction of effects which could arise in the absence of these design features.

The predicted shadow flicker effects, with 'worst case' and 'expected' values, arising from the project are detailed at **Table 12.2** below (extracted from **Annex 12.2**) for all dwellings located within 1,850m of a proposed wind turbine.

Under a 'worst case' scenario, H007 is predicted to experience 01:18 hours (78-minutes) of shadow flicker on a particular day. However, it is again reiterated that this calculation is highly conservative and is not representative of likely shadow flicker effects. As explained above in **Section 12.3.7**, the 'worst case' scenario could only occur under rare and 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; which, while also being likely to significantly overestimate the actual shadow flicker impact, are more realistic prediction of likely shadow flicker levels; are also presented in **Table 12.2** (extracted from **Annex 12.2**). In this scenario, H007 is, again, predicted to experience the greatest level of shadow flicker at 22:27 hours per year.

It should be noted that 110 no. dwellings are predicted to experience less than 10-hours of shadow flicker per year; while 36 no. dwellings are not predicted to experience any effects whatsoever.

Dwelling ID	'Worst Case' Shadow Flicker (hours per day (hh:mm))	'Expected' Shadow Flicker (hours per year (hh:mm))
H001	00:43	13:36
H002	00:52	18:08
H003	00:48	20:50
H004	01:00	08:53
H005	00:53	13:03
H006	01:09	16:28
H007	01:18	22:27
H008	00:00	00:00
H009	00:00	00:00
H010	00:48	12:15
H011	00:48	12:31
H012	00:00	00:00
H013	00:52	12:50
H014	00:46	17:29
H015	00:00	00:00
H016	00:47	07:22
H017	00:00	00:00
H018	00:51	20:35
H019	00:49	21:07
H020	00:11	00:48
H021	00:42	11:43
H022	00:44	09:36
H023	00:44	10:37
H024	00:43	18:02
H025	00:52	10:17
H026	00:45	10:24
H027	00:44	08:00
H028	00:42	11:00
H029	00:00	00:00
H030	00:00	00:00
H031	00:00	00:00
H032	00:40	08:46
H033	00:00	00:00
H034	00:00	00:00
H035	00:00	00:00

H036	00:42	09:08
H037	00:38	05:47
H038	00:00	00:00
H039	00:01	00:00
H040	00:37	04:02
H041	00:34	08:23
H042	00:43	08:01
H043	00:34	05:28
H044	00:34	10:37
H045	00:26	02:58
H046	00:41	07:32
H047	00:00	00:00
H048	00:00	00:00
H049	00:34	04:05
H050	00:00	00:00
H051	00:00	00:00
H052	00:00	00:00
H053	00:00	00:00
H054	00:34	06:23
H055	00:00	00:00
H056	00:32	03:47
H057	00:00	00:00
H058	00:29	04:27
H059	00:25	04:28
H060	00:13	00:56
H061	00:00	00:00
H062	00:26	04:04
H063	00:25	04:02
H064	00:31	04:53
H065	00:26	03:48
H066	00:27	02:09
H067	00:27	02:10
H068	00:24	03:13
H069	00:24	02:12
H070	00:00	00:00
H071	00:22	01:27
H072	00:22	01:27

H073	00:24	02:26
H074	00:00	00:00
H075	00:21	01:21
H076	00:20	01:16
H077	00:21	01:19
H078	00:22	01:06
H079	00:20	01:11
H080	00:21	01:15
H081	00:00	00:00
H082	00:00	00:00
H083	00:19	01:08
H084	00:24	03:03
H085	00:00	00:00
H086	00:18	00:45
H087	00:00	00:00
H088	00:22	01:34
H089	00:00	00:00
H090	00:00	00:00
H091	00:21	01:04
H092	00:23	01:17
H093	00:22	01:05
H094	00:24	01:13
H095	00:24	07:44
H096	00:17	00:40
H097	00:17	00:40
H098	00:09	00:11
H099	00:00	00:00
H100	00:16	00:38
H101	00:22	01:07
H102	00:20	02:04
H103	00:22	01:18
H104	00:22	01:22
H105	00:23	06:44
H106	00:00	00:00
H107	00:00	00:00
H108	00:19	02:05
H109	00:23	01:50

H110	00:22	05:55
H111	00:15	00:31
H112	00:14	00:29
H113	00:21	05:17
H114	00:00	00:00
H115	00:15	01:56
H116	00:00	00:00
H117	00:18	00:57
H118	00:14	00:29
H119	00:13	00:25
H120	00:23	01:42
H121	00:13	00:25
H122	00:22	01:28
H123	00:16	00:40
H124	00:00	00:00
H125	00:14	00:29
H126	00:10	00:13
H127	00:20	02:20
H128	00:19	01:23
H129	00:15	00:34

Table 12.2: Shadow Flicker Prediction Model Results

12.5.3 Decommissioning Phase

As the proposed turbines will not be operational during the decommissioning phase, shadow flicker will not occur.

12.5.4 Cumulative Effects

Prior to undertaking the shadow flicker prediction modelling presented in this chapter, an appraisal of the wider area was undertaken to determine if any cumulative effects could arise with other wind farm developments. In the first instance, it was identified that there are no existing or permitted developments sufficiently proximate to the project such that cumulative effects could arise. In particular, the permitted Bilboa Wind Farm is located c. 4km to the northeast of the subject development and, consequently, due to separation distance, cumulative effects cannot arise.

The proposed Seskin Wind Farm is located to the northeast of the subject project and, due to proximity, is likely to give rise to cumulative shadow flicker effects[1]. At the time of writing, final details of the proposed Seskin Wind Farm are not known; however, the Developer is aware, following engagement with the developer of the Seskin Wind Farm, of certain project details to enable the completion of a comprehensive cumulative shadow flicker assessment. In particular, the Developer has been made aware of the turbine type likely to be proposed at the Seskin Wind Farm and current

[1] The proposed Freneystown Wind Farm is assessed to be sufficiently distant such that cumulative effects will not occur.

(at the time of writing) turbine coordinates. It is understood that the proposed turbines at the Seskin Wind Farm will be the Siemens-Gamesa SG 6.0-155 with an overall tip height of 180m.

Therefore, it should be noted that the cumulative assessment undertaken within this chapter is on the basis of best-available information. It should also be noted that this cumulative assessment has been undertaken in accordance with the assumptions described at **Section 12.3.6** above; however, as it would not be appropriate to do so, no mitigation measures, should they be required, have been imposed on the proposed Seskin Wind Farm.

A detailed assessment of the likely shadow flicker effects arising from the operation of the subject project and the proposed Seskin Wind Farm has been undertaken for all receptors located within 10-times tip height of the subject proposed wind turbines (i.e. White Hill Wind Farm).

The cumulative assessment (see **Table 12.3** below and **Annex 12.3** [**Volume II**]) has again been presented in terms of 'worst case' and 'expected' results.

Dwelling ID	'Worst Case' Shadow Flicker (hours per day (hh:mm))	'Expected' Shadow Flicker (hours per year (hh:mm))
H001	00:43	13:36
H002	00:52	18:08
H003	00:48	20:50
H004	01:00	08:53
H005	00:53	15:31
H006	01:09	19:06
H007	01:18	26:41
H008	00:00	00:00
H009	00:00	00:00
H010	00:48	12:15
H011	00:48	12:31
H012	00:00	00:00
H013	00:52	12:50
H014	00:46	17:29
H015	00:00	00:00
H016	00:47	07:22
H017	00:00	00:00
H018	00:51	20:35
H019	00:49	21:07
H020	00:11	00:48
H021	00:42	11:43
H022	00:44	09:36
H023	00:44	10:37

H024	00:43	18:02
H025	00:52	16:56
H026	00:45	10:24
H027	00:44	09:57
H028	00:42	11:00
H029	00:00	00:00
H030	00:00	00:00
H031	00:00	00:00
H032	00:40	08:46
H033	00:00	00:00
H034	00:00	00:00
H035	00:00	00:00
H036	00:42	09:08
H037	00:38	05:47
H038	00:00	00:00
H039	00:01	00:00
H040	00:37	04:02
H041	00:34	08:23
H042	00:43	08:01
H043	00:34	05:28
H044	00:34	10:37
H045	00:26	02:58
H046	00:41	07:32
H047	00:00	00:00
H048	00:00	00:00
H049	00:34	04:05
H050	00:00	00:00
H051	00:00	00:00
H052	00:00	00:00
H053	00:00	00:00
H054	00:34	06:23
H055	00:00	00:00
H056	00:32	03:47
H057	00:00	00:00
H058	00:29	04:27
H059	00:25	04:28
H060	00:13	00:56

H061	00:00	00:00
H062	00:26	04:04
H063	00:25	04:02
H064	00:41	13:05
H065	00:26	03:48
H066	00:27	02:09
H067	00:27	02:13
H068	00:24	03:13
H069	00:54	19:12
H070	00:00	00:00
H071	00:22	01:27
H072	00:22	01:27
H073	00:45	20:23
H074	00:00	00:00
H075	00:21	01:21
H076	00:20	01:16
H077	00:21	01:19
H078	00:22	01:06
H079	00:20	01:11
H080	00:21	01:15
H081	00:00	00:00
H082	00:00	00:00
H083	00:19	01:08
H084	00:43	14:49
H085	00:23	05:05
H086	00:18	00:45
H087	00:20	03:13
H088	00:40	15:19
H089	00:00	00:00
H090	00:00	00:00
H091	00:21	01:04
H092	00:47	13:42
H093	00:44	15:05
H094	00:47	14:01
H095	00:24	07:44
H096	00:17	00:40
H097	00:17	00:40

H098	00:23	06:50
H099	00:00	00:00
H100	00:16	00:38
H101	00:50	15:58
H102	00:20	02:04
H103	00:45	14:14
H104	00:42	13:14
H105	00:23	06:44
H106	00:00	00:00
H107	00:00	00:00
H108	00:19	02:05
H109	00:32	13:41
H110	00:22	05:55
H111	00:15	00:31
H112	00:14	00:29
H113	00:21	05:17
H114	00:00	00:00
H115	00:15	01:56
H116	00:00	00:00
H117	00:18	00:57
H118	00:14	00:29
H119	00:13	00:25
H120	00:38	17:12
H121	00:13	00:25
H122	00:39	15:30
H123	00:28	11:04
H124	00:00	00:00
H125	00:14	00:29
H126	00:28	09:55
H127	00:20	02:20
H128	00:19	01:23
H129	00:15	00:34

Table 12.3: Shadow Flicker Prediction Model Results

While the addition of the Seskin Wind Farm increases the effects of shadow flicker at a number of dwellings; the increases are not assessed as likely to result in significant effects. Under 'worst-case' conditions, the greatest level of shadow flicker remains 01:18 at H007; while the greatest level under 'expected' conditions is 26:41, again, at H007.

12.6 Mitigation & Monitoring Measures

12.6.1 Construction Phase

As there is no likelihood of effects during the construction phase, no mitigation measures or monitoring proposals are required, or proposed.

12.6.2 Operational Phase

In the first instance, the likely shadow flicker effects have been minimised, and avoided where possible, through the iterative design process and assessment of project alternatives as described at **Chapter 2**. However; while the project strikes the best balance between the avoidance of likely significant effects and achieving the objectives of the project, shadow flicker effects remain, as discussed above.

As outlined at **Section 12.3.2** above, the Draft 2019 Guidelines propose to fully eliminate the occurrence of shadow flicker at all dwellings, places of work and schools through the installation of automated turbine shut down software. While the Draft 2019 Guidelines have not been formally adopted, the Developer has, as discussed above, committed to the implementation of design/mitigation measures to fully eliminate shadow flicker at all dwellings, places of work and schools.

Automated turbine shut down software is available and is already widely implemented to eliminate the occurrence of shadow flicker on wind farm developments where shadow flicker levels are proven to occur. Shut down software effectively limits (curtails) the operation of turbines during the infrequent and rare periods when shadow flicker occurs. The proposed wind turbines will each be fitted with automated turbine shut down software, inherent to their design, to facilitate their shut down as required.

The shut-down software will be programmed with a set of predetermined times when shadow flicker could theoretically occur; if the wind is blowing and the sun is shining. The software will determine; based on the operation, or otherwise, of each turbine; whether the wind is blowing and; based on a sunlight sensor fitted within the wind farm; whether the sun is shining.

If the wind is blowing and the sun is shining during the set of predetermined times discussed above, the software will temporarily switch off a turbine (or turbines) which is (or are) predicted to give rise to shadow flicker effects at a particular receptor. Having switched off a turbine (or turbines), the software will then recognise when the generation of shadow flicker at a receptor can no longer occur and will switch on the turbine (or turbines). This automated process will ensure that no shadow flicker, whatsoever, is experienced at any dwelling, place of work or school.

Within 12-months of the commencement of commercial operations, a shadow flicker survey will be undertaken by a suitably qualified person to verify the implementation of the turbine shut down software. Monitoring will be undertaken when and where the model predicts shadow flicker is expected to occur.

The data which will be collected during the survey will include:-

- The date, time, location (turbine ID) and duration of the measurement;
- Sunlight intensity and direction;
- Wind speed and direction/rotor angle; and,
- Time, date and duration of any sensor triggered shut down.

A site visit will be carried out by a suitably qualified person during each calendar season, to obtain representative samples of year-round conditions, to monitor the site when shadow flicker is predicted to occur to verify the effectiveness of the shut-down software.

In addition, should any third party complaints be raised in respect of shadow flicker at any time during the lifetime of the project, 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 12.4**. This programme will be further developed, and agreed in writing with the Planning Authority, as part of the discharge of pre-commencement conditions process.

12.6.3 Decommissioning Phase

As there is no likelihood of shadow flicker effects arising 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 there will be no residual effects arising from shadow flicker. The implementation of the above turbine shut down technology effectively excludes any possibility occurring whatsoever. The proposed monitoring will confirm the efficacy of the mitigation measures.

12.8 Summary

This chapter has assessed the likelihood of shadow flicker effects at all dwellings (129 no.) located within 10-times the overall tip height (1,850m) of the proposed wind 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 of any effects during the construction or decommissioning phases as the proposed wind turbines will not be operational. Similarly, secondary developments associated with the wind farm, such as the proposed grid connection infrastructure and haul route upgrade works, are not capable of causing shadow flicker.

During the operational phase, technological mitigation measures will be implemented to shut down the wind turbines at predetermined times when shadow flicker could occur (based on meteorological conditions) to exclude any possibility of shadow flicker occurring. These measures will ensure that no dwelling will experience shadow flicker and, therefore, it is concluded that the project will not result in any likely significant shadow flicker effects, either individually or in combination with other existing, permitted or proposed developments.