



# **APPENDIX K**

## **Shadow Flicker Assessment for a Proposed 100MW Wind Energy Project, Kajiado District, Kenya**

Report Prepared for

**Kipeto Energy Limited**

March 2012

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# 1 Introduction

This report addresses the potential impact of shadow flicker on properties within 1km (10 rotor diameters) from the proposed development of 68 no. GE 1.6MW turbines. The possible occurrence of shadow flicker was assessed using EMD WindPro Version 2.7.486 software. The proposed development was modelled to assess the likelihood of shadow flicker impacting on dwellings within 10 rotor diameters of a turbine.

The assessment was based on 68 no. turbines of 80 metre hub height and 100 metre blade diameter for the proposed Kipeto Wind Farm.

The potential impact for shadow flicker was assessed on 53 no. households within 1km (10 rotor diameters) of a proposed turbine.

## 2 Background

As with all tall structures, wind turbines can cast long shadows on the neighbouring area when the sun is low in the sky. During sunny conditions under certain combinations of geographical position and the time of day, the sun may pass behind the moving rotor blades and cause a shadow to flicker on and off on neighbouring properties. This is known as shadow flicker. Nearby dwellings/buildings maybe affected by shadow flicker (i.e. when a turbine blade shadow passes an open door or window within a flicker zone). The shadow flicker effect lasts only for a short period and happens only in certain specific combined circumstances such as when:

- ✔ 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; and
- ✔ The wind speed is sufficient to move the turbine blades and the turbine is operational

## 3 Planning Guidelines for Shadow Flicker

As there are no guidelines on shadow flicker available in Kenya, Irish and UK Planning Guidelines have been consulted to assess the impact of the proposed development on the local population within 10 rotor diameters of a turbine. A desktop survey of the guidance and policy in other countries such as Germany, the USA and Canada was also carried out.

In the UK, guidance on the extent of the zone of shadow flicker influence is given within the PPS 22 Companion Guide, which indicates that in the UK, this zone covers a distance of 10 rotor diameters from each turbine and between 130 degrees side of north (relative to each turbine).

Companion Guide to PPS22:

*“Although problems caused by shadow flicker are rare, for sites where existing development may be subject to this problem, applicants for planning permission for wind turbine installations should provide an analysis to quantify the effect”*

The UK shadow flicker recommendations are based on the survey by Predac, a European Union sponsored organisation promoting best practice at energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany.

The Irish 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”*

### **3.1 Update of UK Shadow Flicker Evidence Base**

#### **Department of Energy and Climate Change<sup>1</sup>**

To ensure the guidance on shadow flicker contained in 'Planning for Renewable Energy: A Companion Guide to PPS22' was up-to-date, the UK Government commissioned consultants Parsons Brinckerhoff to carry out a research project to update its evidence base on shadow flicker. The report was published in March 2011 and concluded there are no significant issues with shadow flicker in the UK.

The report states that it is widely accepted across Europe that potential shadow flicker is very low at more than 10 rotor diameters from a turbine. Therefore for Kipeto wind farm all households within 1km of a proposed turbine have been assessed for shadow flicker and noise.

Planning guidance in the UK requires developers to investigate the impact of shadow flicker, but does not specify methodologies. To enable the U.K. Department of Energy and Climate Change to advance current understanding of the shadow flicker effect, an independently commissioned report “Update of UK Shadow Flicker Evidence Base” was submitted in March 2011.

This report details the findings of an investigation into the phenomenon of shadow flicker. The report presents updated evidence which has been produced by carrying out a thorough review of international guidance on shadow flicker, an academic literature review and by investigating current assessment methodologies employed by developers and case study evidence. Consultation (by means of a questionnaire) was carried out with stakeholders in the UK onshore wind farm industry including developers, consultants and Local Planning Authorities (LPAs). This exercise was

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<sup>1</sup> [www.decc.gov.uk/.../1416-update-uk-shadow-flicker-evidence-base](http://www.decc.gov.uk/.../1416-update-uk-shadow-flicker-evidence-base)

used to gauge their opinion and operational experience of shadow flicker, current guidance and the mitigation strategies that can and have been implemented.

It has become clear that there is no standard methodology that all developers employ when introducing environmental and site specific data into shadow flicker assessments. The three key computer models used by the industry are WindPro, WindFarm and Windfarmer. It has been shown that the outputs of these packages do not have significant differences between them. All computer model assessment methods use a “worst case scenario” approach and don’t consider “realistic” factors such as wind speed and cloud cover which can reduce the duration of the shadow flicker impact.

On the issue of health effects and nuisance, it is considered that the frequency of the flickering caused by the wind turbine rotation is such that it should not cause a significant risk to health. Mitigation measures which have been employed to operational wind farms such as turbine shut down strategies, have proved very successful, to the extent that shadow flicker can not be considered to be a major issue in the UK.

## **3.2 International Policies and Guidance**

The report also contained analysis of specific shadow flicker studies and policies of several countries including Germany, the USA, Canada and Australia which are synopsised below.

### **3.3 Germany**

German guidance sets strict limits on the levels of acceptable shadow flicker effect, using a worst case scenario limited to a maximum of 30 hours per year or 30 minutes on the worst affected day.

The German guidance does not specifically refer to a distance limit for shadow flicker assessments.

The 30 minutes per day rule for shadow flicker at any given receptor is based on a psychology academic survey by the University of Kiel (Pohl et al 2000).

### **3.4 United States**

The American Wind Energy Association recommends that shadow flicker impacts are mitigated by use of appropriate turbine-dwelling separation distances or screening by vegetation planting. The document also states that shadow flicker issues are less common in the United States than in Europe.

### **3.5 Canada**

Canadian guidance recommends that even within an urban environment, careful site design in the first instance and mitigation measures thereafter may manage any potential shadow flicker impacts.

### 3.6 Denmark

The Danish Wind Industry Associations website (Danish Wind Industry Association, accessed 2010):

*“The hub height of a wind turbine is of minor importance for the shadow from the rotor. The same shadow will be spread over a larger area, so in the vicinity of the turbine, say, up to 1,000 m, the number of minutes per year with shadows will actually decrease.”*

*“If you are farther away from a wind turbine rotor than about 500-1000 metres, the rotor of a wind turbine will not appear to be chopping the light, but the turbine will be regarded as an object with the sun behind it. Therefore, it is generally not necessary to consider shadow casting at such distances.”*

### 3.7 Australia

In Australia it is accepted that that shadow flicker is unlikely to be a significant issue if a separation distance of 500 m is maintained between the turbine and any dwelling or urban area. However studies have noted that while shadow flicker can affect local amenity but is uncommon in Australia.

## 4 Methodology

The prediction model used in this assessment to calculate the impact of shadow flicker was carried out using WindPro V2.7 software, a detailed computer model which can estimate the possible occurrence of shadow flicker at the 53 households identified within 1km. The software calculates how often and in which intervals of the year a specific receptor will be affected by shadows generated by one or more of the wind turbines.

The results of the model are presented in Appendix 13.1. It should be noted that sunshine is weakened by mist, clouds, vegetation growth and buildings in the surrounding area when the position of the sun is lower than 3°. To account for this, the sun's minimum angle has been set at 3° in the shadow flicker calculation model. The topography of the subject lands was modelled using 30m digital elevation data.

The shadow flicker model makes a number of assumptions to predict the shadow flicker at each dwelling. These are:

- Every house is a “Green house” - The reference to ‘Green House Mode’ as referred to in the analysis, signifies that the receptor is modelled as a surface measuring 0.75m x 0.75m which faces in all directions i.e. a glass house and as such is a worst case scenario for shadow flicker impact.
- The model takes into account that the sun is not always shining, hence shadow flicker cannot occur all the time. Therefore to provide a realistic calculation the model is inputted with statistical sunshine data from the Nairobi Dagor Etti met station from 1969-1993 to calculate the probability of sunshine.

- The model takes into account that the wind is not always blowing from the same direction and therefore the turbine rotor is not always at right angles to the shadow flicker receptor. The wind direction data for 12 sectors, which is derived from an 80m anemometer mast located on the proposed site, was entered into the model. Table 13.2 sets out the wind direction data.
- The model assumes that the landscape is bald assuming and that there are no obscuring features or vegetation screening around the residences. Such features would minimise views of the development and hence reduce or eliminate the potential for shadow flicker.

In reality the assumptions result in a conservative analysis as:

- Not all residences will have windows facing onto the wind farm;
- The wind turbine will not always be rotating;
- Some dwellings may be screened by vegetation.

The results of the analysis from WindPro V2.7 are conservative as the above factors are not taken into consideration in the model. The shadow flicker results calculated over estimates the number of shadow flicker hours per annum experienced at the identified receptor. To provide a more realistic assessment the following has been taken into account in the software analysis.

#### 4.1 Wind Speed Distribution - Turbine Downtime

The wind turbines blades only have the potential to cause shadow flicker when rotating.

The model does not take into consideration when the turbine is non-operational due to:

- grid availability;
- turbine maintenance;
- the wind resource is low/insufficient, below cut in speed at 3m/sec or the wind resource is high/storm winds, cut out speed at 25m/sec.

In the GED's experience the proposed turbines are likely to be non-operational for 8.5% of the year due to these constraints. Therefore it is estimated that the turbines will be operational for 91.5% of the year. The model assumes that the turbines are **operating at 100% of the year.**

#### 4.2 Wind Direction Distribution

Wind Direction is also a factor in the occurrence of shadow flicker. A wind turbine directs the rotor at right angles to the wind direction i.e. turns the rotor to face the wind, when there is sufficient wind. The wind direction is therefore the determining factor for the position of the rotor and also for the position of the rotor in relation to the sun.

The Wind Rose data based on the met data from an 80m anemometer mast located on the proposed site is used in the assessment. The Wind Rose data recorded the following:

**Table 1: Wind Direction at the Subject Lands**

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE
Hours in one year	9	166	0	2,234	3,960	1,629	0	517
Direction	S	SSW	SW	WSW	W	WNW	NW	NNW
Hours in one year	158	44	0	26	9	8	0	0

The prevailing winds in the area are predominately easterly winds as indicated in the above table. It is unlikely that the wind turbines will constantly face into or away from the sun given the different wind

### 4.3 Passing Blade Frequency

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

Studies have been found that the frequencies of flicker that produce a nuisance are between 2.5 Hz and 40 Hz (Clarke 1984). The GE1.6 100 proposed for the Kipeto Wind Farm typically has variable rotor speeds of between 9.75 - 16.18 r.p.m. (rotations per minute). The rotor consists of three blades, and so the maximum blade passing frequency is 0.819 Hz (cycles per second), which is well below the lower limit of 2.5 Hz quoted above. The blade passing frequency is calculated as follows:

$$\text{Blade passing frequency} = 16.18 * \frac{3}{60} = 0.819 \text{ Hz}$$

Using this method of calculation it was concluded that the frequency of shadow flicker is very low and unlikely to cause significant nuisance.

#### 4.3.1 Property Location and Orientation of Receptors

The level of shadow flicker experienced in a property is dependent on the receptor being positioned in the such a way that light streaming into a property is blocked by a turbine when the light source i.e. the sun is at a particular height in the sky.

The location of all the properties near the proposed Kipeto Wind Farm Site was recorded from G.P.S. co-ordinates taken by personnel from GED and Kurrent technologies in 2011. All properties within 10 rotor diameters of a wind turbine were included in the analysis. The topography was modelled using 30m digital elevation data. The GE 1.6 100 turbine (80m hub and 100m rotor diameter) is assumed for the proposed development of the Kipeto Wind Farm.

A shadow flicker contour map was created using WindPro. The shadow flicker map was based on a “glass-house” model which assumes the shadow flicker receptor is always facing the direction in which will experience the most shadow flicker. This

map was used to identify all dwellings that may experience more than 30 hrs of shadow flicker per year.

The shadow flicker calculation makes a number of simplifications and assumptions and as such the results represent a worst-case scenario. For example, the model assumes a situation where the sun is always shining, wind blowing all the time, and where the wind and the turbine rotor keep tracking the sun by yawing the turbine exactly as the sun moves. Model assumptions also include the following:

- The model uses 30m elevation digital data as its only topographical reference. Simulations are run on a “bald landscape” without allowing for the obscuring effect of vegetation between the location of the residence and the position of the sun in the sky. Furthermore, the model does not consider any obscuring features around residences itself, which would minimise views of the site and hence reduce the potential for shadow flicker.
- The model operates on the assumption that sunny conditions coincide with the times of which shadow flicker will occur at each dwelling. During periods of cloudy, over-cast conditions shadow flicker will not occur.

## 5 Shadow Flicker Analysis Results

The cumulative impact of the proposed Kipeto Wind Farm of 68 no. turbines was assessed for shadow flicker impact. Table 13.5.1 below shows the prediction shadow flicker hours at each of these households.

**Table 2: Shadow Flicker at Households located with 10 Rotor Diameters of a Proposed Turbine at Kipeto Wind Farm**

		<i>Worst Case</i>	<i>Worst Case</i>	<i>Worst Case</i>	<i>Expected</i>
<i>ID</i>	<i>Name</i>	<i>hr/year</i>	<i>days/year</i>	<i>Max hrs/day</i>	<i>hrs/year</i>
A	H1	0:00	0:00	0:00	0:00
B	H2	0:00	0:00	0:00	0:00
C	H3 Landowner	0:00-	0	0:00	0:00
D	H4 Landowner	0:00-	0	0:00	0:00
E	H5	0:00-	0	0:00	0:00
F	H6	0:00-	0	0:00	0:00
G	H7 Landowner	64:37:00	120	00:46	24.13
H	H8 Landowner	81:12:00	136	00:45	38:51
I	H9 Landowner	85:36:00	210	00:34	39:34
J	H10 Landowner	36:24:00	100	00:31	18:23
K	H11 Landowner	06:16	28	00:17	1:45

		<i>Worst Case</i>	<i>Worst Case</i>	<i>Worst Case</i>	<i>Expected</i>
<i>ID</i>	<i>Name</i>	<i>hr/year</i>	<i>days/year</i>	<i>Max hrs/day</i>	<i>hrs/year</i>
L	H12 Landowner	47:38:00	110	00:32	16:03
M	H13	0:00	0:00	0:00	0:00
N	H14 Landowner	27:11:00	71	00:30	13:30
O	H15 Landowner	60:43:00	135	00:41	28:44
P	H17 Landowner	08:24	35	00:17	4:57
Q	H20 Landowner	27:33:00	84	00:32	14:14
R	H21 Landowner	49:12:00	168	00:37	21:37
S	H22	0:00	0:00	0:00	0:00
T	H23	0:00	0:00	0:00	0:00
U	H24	0:00	0:00	0:00	0:00
V	H25 Landowner	10:07	34	00:21	4:11
W	H26	0:00	0:00	0:00	0:00
X	H27 Landowner	14:08	38	00:28	7:44
Y	H28	0:00	0:00	0:00	0:00
Z	H29	0:00	0:00	0:00	0:00
AA	H30	0:00	0:00	0:00	0:00
AB	H31	0:00	0:00	0:00	0:00
AC	H32	0:00	0:00	0:00	0:00
AD	H33	0:00	0:00	0:00	0:00
AE	H34 Landowner	-	0:00	0	0:00
AF	H35	0:00	0:00	0:00	0:00
AG	H36 Landowner	14:38	62	00:16	4:14
AH	H37 Landowner	33:0:00	92	00:25	15:51
AI	H38	28:19:00	84	00:30	14:23
AJ	H40 Landowner	89:34:00	164	00:46	44:58
AK	H41	0:00	0:00	0:00	0:00
AL	H42 Landowner	24:01:00	72	00:25	12:00
AM	H43 Landowner	29:35:00	66	00:40	15:15
AN	H44 Landowner	06:43	34	00:15	2:30
AO	H45	62:14:00	136	00:35	28:20:00

		<i>Worst Case</i>	<i>Worst Case</i>	<i>Worst Case</i>	<i>Expected</i>
<i>ID</i>	<i>Name</i>	<i>hr/year</i>	<i>days/year</i>	<i>Max hrs/day</i>	<i>hrs/year</i>
AP	H46	0:00	0:00	0:00	0:00
AQ	H47	11:19	43	00:19	05:50
AR	H48 Landowner	07:49	26	00:22	4:42
AS	H49	14:04	52	00:19	06:52
AT	H50	0:00	0:00	0:00	0:00
AU	H51	0:00	0:00	0:00	0:00
AV	H52	0:00	0:00	0:00	0:00
AW	H53	0:00	0:00	0:00	0:00
AX	H54 Landowner	71:36:00	156	00:35	29:41
AY	H55 Landowner	81:53:00	136	00:45	38:07
AZ	H56	48:32:00	74	00:45	29:18:00
BA	H57	0:00	0:00	0:00	0:00
BB	H58	6:05	48	0:09	2:09
BC	H59	0:00	0	0:00	0:00

## 6 Proposed Mitigation Measures of Shadow Flicker

The probability of shadow flicker causing a nuisance is extremely low, the figures provided are predicted hours of shadow flicker, but once all de-rating factors are taken into consideration, the actual hours of shadow flicker are extremely low

The analysis shows

- 14 no. households that are predicted to exceed 30min per day
- 4 no. households that is predicated to exceed 30hrs per year
- 4 no. households that are to exceed both 30min per day and 30hrs per year

In total, nine houses are expected to exceed the recommend shadow flicker limits of 30min per day or 30hrs per year based on the glass house model. Out of these nine houses, eight are financially involved in the project.

As stated in the methodology, these predictions are based on each dwelling being modelled as a “glass house”. A detailed receptor survey shall be carried out on each of the 9 no. households at the micro-siting stage and the location of each receptor shall be fed into the model in order to calculate shadow flicker hours at each receptor/window.

If it is found that shadow flicker impact exceeds 30 minutes per day or 30 hrs per year after detailed analysis, then the head of each household will be made aware of the impact and all relevant information pertaining (such as the information contained in this chapter). The head of the household will be requested to give their consent in writing to accept a higher shadow flicker limit.

Should the head of the household not consent to acceptance of the higher shadow flicker limit, the standard mitigation measure will be applied which is to fit a sensor to the impacted receptor. The sensor will cause the turbine responsible to shut down if the receptor receives more than 30hrs shadow flicker per year or more than 30min per day. This mitigation measure has been employed at many wind farms in the past.

Landscape features, such as trees and hedging could also be used to prevent or limit the potential for shadow flicker.

## 7 Summary

This section of the EIS addresses the potential impact of shadow flicker on properties within 1km (10 rotor diameters) from the proposed development. The possible occurrence of shadow flicker was assessed using *WindPro* software, by modelling the proposed development and assessing the likelihood of shadow flicker impacting on dwellings with 10 rotor diameters of a turbine.

As with all tall structures, wind turbines can cast long shadows on the neighbouring area when the sun is low in the sky. During sunny conditions under certain combinations of geographical position and the time of day, the sun may pass behind the moving rotor blades and cause a shadow to flicker on and off on neighbouring properties. This is known as shadow flicker. The shadow flicker effect lasts only for a short period and happens only in certain specific combined circumstances such as when:

- 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; and
- The wind speed is high enough to move the turbine blades and the turbine is operational.

Irish UK and other international guidelines on shadow flicker have been consulted where wind energy is well established. Most guidelines state that shadow flicker impact is not an issue at receptors which are greater than 10 rotor diameters from a turbine. It appears to be generally accepted that shadow flicker should not exceed 30 hours per year or 30 minutes per day.

The assessment predicted that nine households could possibly be affected by shadow flicker for more than 30 hours per annum or 30 minutes per day. In any case in the unlikely event that excessive shadow flicker does occur at any receptor, sensors can be used to stop the responsible turbine when required. This technical solution has been employed on other wind projects very effectively in the past.

Studies have been found that the frequencies of flicker that produce a nuisance are between 2.5 Hz and 40 Hz. The wind turbine of the GE 1.6 100 proposed for the wind energy scheme typically has a maximum blade passing frequency of 1.075 Hz (cycles

per second), which is well below the lower limit of 2.5 Hz found to cause a nuisance. Using this method of calculation it was concluded that the frequency of shadow flicker is very low and is unlikely to cause nuisance.

## 8 References

1. DoEHLG (2006) *Planning Guidelines for Wind Farm Developments*. Department of Environment, Heritage and Local Government (Ireland)
2. (<http://www.windpower.org/en/tour/env/shadow/index.htm>)
3. Clarke A.D. (1984). *A Case of Shadow Flicker / Flashing: Assessment and Solution*.