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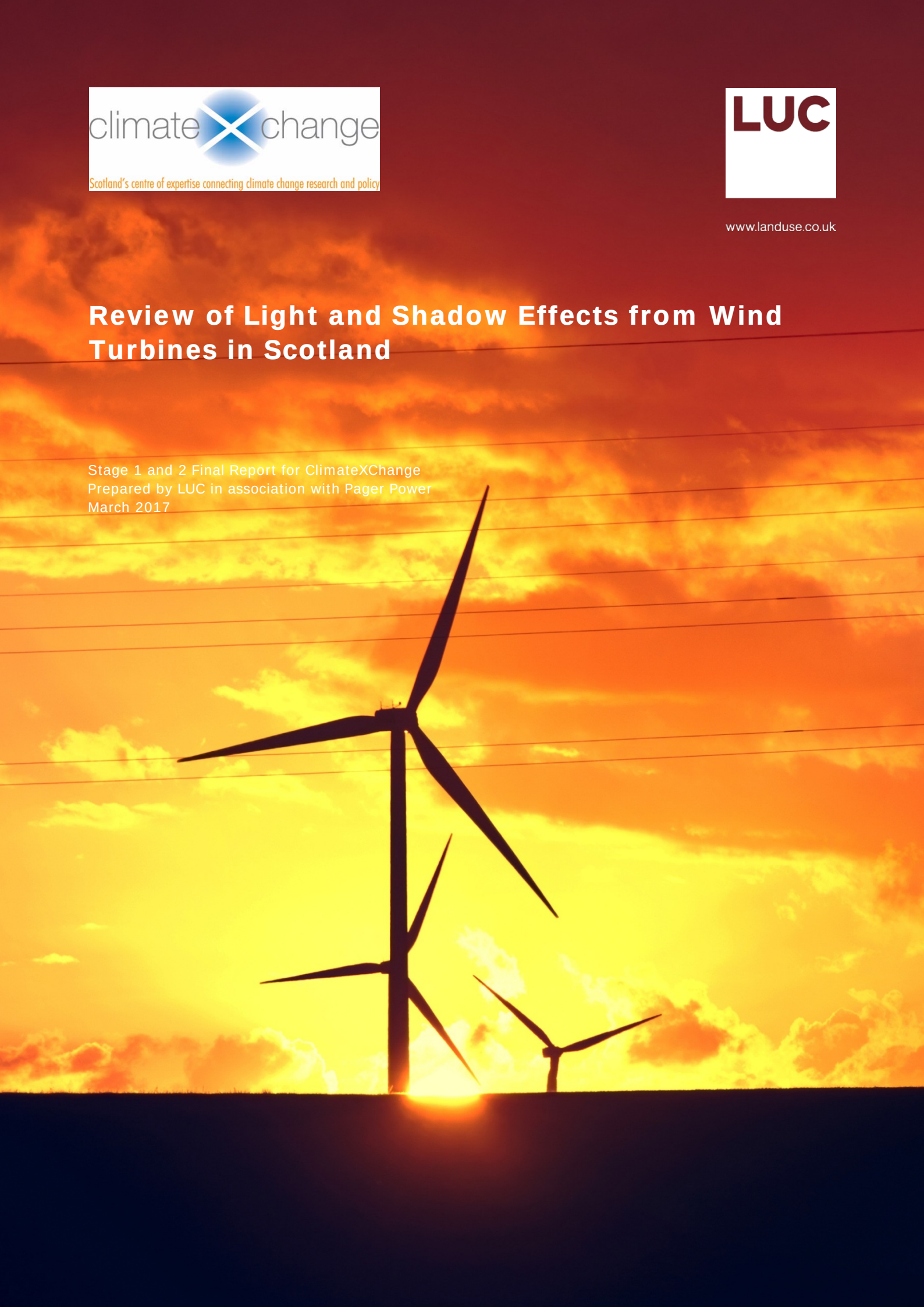
Review of Light and Shadow Effects from Wind Turbines in Scotland

Stage 1 and 2 Final Report for ClimateXChange
Prepared by LUC in association with Pager Power
March 2017



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Contents

Executive summary

LUC, in association with Pager Power was commissioned by ClimateXChange in March 2016 to undertake a review of how light and shadow effects from wind farms are considered in the development planning process in Scotland. ClimateXChange published the report *Wind Farm Impacts Study* in July 2015, which made a number of recommendations for better guidance on predicting and mitigating the impacts of light and shadow flicker effects from wind turbines. This report aims to contribute to meeting these recommendations.

- Stage 1 of the project involved a review of guidance and tools (including modelling software that are currently available and in use in Scotland), and a literature review to examine the following:
    - to describe the origins, rationale, and use of the 10-rotor diameter distance threshold for shadow flicker;
    - to explore the definition of different types of receptors to light and shadow related effects;
    - to understand the extent to which assessments are based on worst case and / or likely case scenarios;
    - the understand the definition of significance of exposure to effects of light and shadow related effects;
    - to understand how assessment takes latitude into account.

Stage 2 of the work examined the approach to light and shadow effects in the Scottish planning system for five case study planning authorities through:

- analysis of the approach to shadow flicker within five planning applications for wind turbines;
- analysis of the policy framework for shadow flicker within the case study planning authorities.

The second stage of the work also carried out a focused literature review of public perceptions of light and shadow effects and presentation and communication of light and shadow issues to non-specialists.

The literature review explored:

- Origins of the 10 x rotor blade diameter distance threshold;
- Other factors relevant to the 10 x rotor blade diameter distance;
    - Shadow flicker and photo sensitive epilepsy
    - Twenty percent coverage of the sun
    - Setback distances in other countries
    - Shadow dissipation and atmospheric interference
    - Relationship between noise thresholds and shadow flicker
    - Timing of shadow flicker
- Definitions of receptors;
- Significance of effects and use of worst case and likely case scenarios in assessments;
- High latitude assessments.

The Stage 2 review of practice and literature, plans and SPG for the case studies examined:

- Definition of shadow flicker;
- Definition of shadow throw;

- Night time lighting;
- Acknowledgement of reflected light issues;
- Reference to separation distances and site specific issues;
- Reference to ten x rotor diameter;
- Reference to 130 degrees either side of north;
- Significance thresholds;
- Definition of receptors;
- Impacts on receptors;
- Parameters when shadow flicker may occur;
- Reference to worst case and likely case scenarios and factors taken into account in calculating likely case scenario;
- How latitude is taken into account;
- Computer modelling used;
- Cumulative effects;
- Reference to policy and guidance;
- Mitigation.

Recommended content of guidance on shadow flicker

Recommendation 1: Definition of Shadow Flicker

There needs to be consistency between guidance documents and planning policy on the definition of shadow flicker. The most widely used definition of shadow flicker within guidance documents is as follows:

"*Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the* ***effect or impact*** *is known as "shadow flicker*".

Recommendation 2: Definition of Shadow Throw

The literature review identified that experience of shadows outdoors is not clearly recognised within policy and guidance, and the case studies identified limited reference to this effect. Although this is not identified as a significant issue, it is recommended a definition of the outdoor effects of light and shadow related effects is included for clarity. A possible definition is '*a moving shadow across open ground'*.

Recommendation 3: Acknowledgement of reflected light issues

It is recognised that reflected light issues are not identified as a significant issue within the guidance documents, literature or case studies. For completeness, guidance should include acknowledgement of the issue of reflected light.

Recommendation 4: Night time lighting

No significant issues associated with night time lighting were identified in the study. The guidance could acknowledge impacts of night time lighting through cross reference to Scottish Natural Heritage guidance. It is recommended that guidance should clarify the likely requirement for visible lighting, and how potential landscape and visual effects should be addressed.

Recommendation 5: Definition of parameters when shadow flicker may occur

The guidance should explicitly set out the parameters when shadow flicker may occur and which are required for likely case scenario modelling. There appears to be significant variation in the

factors taken into account when calculating 'likely case' shadow flicker, and the case study review identified a lack of clarity in presentation of findings. The guidance should explicitly set out the parameters which are required for likely case scenario modelling.

Recommendation 6: Reference to the degrees either side of north affected by shadow throw

Although the Scottish guidance does not refer to the parameter of 130 degrees either side of north, some of the case study examples referenced this figure, in line with other UK guidance. Scottish guidance should not include reference to the occurrence of shadow throw 'within 130 degrees either side of north'. In line with the recommendation that shadow flicker assessment should be based on significance thresholds, guidance should avoid reference to limiting the area of assessment.

Recommendation 7: Exclusion of reference to the 10 rotor diameter distance

Although a number of other factors may contribute to the significance of shadow flicker potentially being greatest closer to the wind turbines, the ten rotor diameter distance threshold does not appear to have robust evidence within the literature examined.

Secondly, there is frequent misapplication of the ten rotor diameter distance as a limit within which shadow flicker modelling is applied.

Recommendation 8: Thresholds for exposure to shadow flicker and use of worst case and likely case scenarios

The German guidelines are clear on the exposure thresholds for both worst case and likely case scenarios of 30 hours per year or 30 minutes a day worst case and eight hours a year likely case. These thresholds are most widely quoted, although some countries have set their own limits.

The case study review has identified inconsistency in the definition and application of 'significance' in relation to predicted shadow flicker both worst case and likely case, and the application of a precautionary approach in the decision making process. There is a need for guidance on the thresholds of exposure to shadow flicker in Scotland.

Recommendation 9: Definition of different types of receptors to light and shadow related effects

The case study review identified that there needs to be clarity on the different approaches to assessing significance of levels of effect at financially involved properties. This is an established difference in noise assessment, however it is unclear how appropriate this is in relation to shadow flicker, particularly in light of the lack of clarity in assessments on 'significance'.

The study review was inconclusive in relation to the definition of different types of receptor based on other variables and their sensitivity to light and shadow related effects. There was some reference to residential and business use, and the interviews highlighted the need to consider impacts on rural businesses.

There is a need to include guidance on different factors which may affect the sensitivity of different types of receptor to light and shadow related effects.

Recommendation 10: Approach to assessing cumulative effects

The study found limited reference to the identification and assessment of cumulative effects, however it was identified as an issue covered in the case studies and an area where there was a lack of clarity or consistency in approach. The guidance should set out the need to consider cumulative shadow flicker and further guidance on how this should be approached

Role of plans and supplementary guidance

Local plans provide almost no coverage of shadow flicker issues. Supplementary planning guidance and other local authority guidance relevant to renewable energy provide coverage of some issues, and reflect national guidance in relation to the ten rotor diameter distance, but lack detail on key issues such as significance of effects. Furthermore the case study review identified a clear reversion in the Environmental Statements to national level guidance and documents in relation to shadow flicker with very limited reference to supplementary planning guidance.

Decision making and conditions

Four of the case studies demonstrated a precautionary approach to shadow flicker through the conditions attached to the decision. This was irrespective of the level of effects identified in the shadow flicker report. This supports the finding from the case study review of lack of clarity and accessibility of the shadow flicker reports, and the challenges of gaining a clear understanding of the extent and significance of shadow flicker.

Presentation and communication of Shadow Flicker to non-specialists

A number of issues have been identified in relation to the clarity of presentation and communication of shadow flicker at the technical level. It appears that some of these issues are transferred into other literature presented to non-specialists. The study also identified some confusion over the definition of the impact of shadow flicker in terms of amenity or nuisance.

Areas for future research

The project has identified a number of questions which could be addressed through modelling to provide robust findings to support the study conclusions, particularly in relation to the ten rotor diameter distance.

Thresholds of exposure: Modelling exposure thresholds as distance thresholds based on worst case scenario in terms of wind direction, cloud cover and window orientation. This would allow the definition of an area on a map of where exposure exceeds the threshold set out in the German guidance, and the distances at which these occur and if these are beyond ten rotor diameters. A sophisticated model would be required to account for these parameters, and the most appropriate model identified to date is WindPRO, although other models may be developed or improved in the future.

20% obscuration of the sun: Modelling how different turbine dimensions affect what distance from the wind turbine the threshold of 20% obscuration of the sun is reached. This would allow an understanding of whether the ten rotor diameter distance threshold potentially relates to the figure of 20% obscuration of the sun. Again, at this point in time the only model which allows the input of this variant is identified as WindPRO, although other models may be developed or improved going forward.

130 degrees of north: Modelling of the same dimension turbine at different latitudes to identify the area affected by shadow flicker.

Modelling shadow flicker extent in relation to receptors at significantly lower elevation than the wind turbines: This would allow evidence to be provided on the effects of topography on the extent and duration of shadow flicker.

1 Introduction

1.1 LUC in association with Pager Power was commissioned by ClimateXChange in March 2016 to undertake a review of how light and shadow effects from wind farms are considered in the development planning process in Scotland. ClimateXChange published the report *Wind Farm Impacts Study* in July 2015[1], which made a number of recommendations for better guidance on predicting and mitigating the impacts of light and shadow flicker effects from wind turbines. This report aims to contribute to meeting these recommendations.

1.2 This report sets out the findings of the study. The project brief outlined that these findings are intended to feed in to the Scottish Government thinking on how light and shadow effects are assessed and considered through the planning process, and potentially inform future guidance for developers and planning authorities.

Study scope

1.3 The scope of Stage 1 of the project is as follows:

- Review of guidance and tools (including modelling software that are currently available and in use in Scotland);
- Literature review to examine the following:
  - to describe the origins, rationale, and use of the 10-rotor diameter distance threshold for shadow flicker;
  - to explore the definition of different types of receptors to light and shadow related effects;
  - to understand the extent to which assessments are based on worst case and / or likely case scenarios;
  - the understand the definition of significance of exposure to effects of light and shadow related effects;
  - to understand how assessment takes latitude into account.

1.4 Stage 2 of this work follows on from Stage 1 and examines:

- Light and shadow effects in the Scottish planning system;
- A literature review of public perceptions of light and shadow effects;
- Discussions with development planners and environmental health officers.

1.5 Stage 3 of the work draws together the findings from both stages of the work to make clear recommendations on:

- definitions of light and shadow effects associated with wind turbine development;
- the requirement and content of guidance on the light and shadow effects associated with wind turbine development, for Scotland;
- tools and methods of predicting wind turbine light and shadow effects;
- distances, thresholds, receptors, making judgements about significance;
- role of development plans, supplementary planning guidance, decision making, conditions and monitoring in addressing shadow flicker issues;

[1]SLR and HoareLea consultatnts (2015) Wind Farm Impacts Study Review of the visual, shadow flicker and noise impacts of onshore wind farms. ClimateXChange. Available at: http://www.climatexchange.org.uk/files/3414/3578/2608/FINAL_REPORT_Wind_Farm_Impacts_Study_July_2015_ISSUE.pdf

- presentation and communication of light and shadow issues to non-specialists.

Summary of previous report findings

1.6 There have been two significant reports published in the UK on light and shadow related effects in recent years, and the key findings from these are summarised below. The second study prepared for ClimateXChange was influential on the issues being investigated through this report.

Update of UK Shadow Flicker Evidence Base, Department for Energy and Climate Change[2]

1.7 This report aimed to enable the former Department of Energy and Climate Change (DECC) to advance current understanding of the shadow flicker effect, and presents an update of the evidence base which has been produced by carrying out a thorough review of guidance, literature and assessment methodologies.

1.8 The key points are as follows:

- Planning guidance in the UK requires developers to investigate the impact of shadow flicker, but does not specify methodologies.
- The current recommendation in Companion Guide to PPS22 (2004) to assess shadow flicker impacts within 130 degrees either side of north is considered acceptable, as is the 10 rotor diameter distance from the nearest property. This is a 'one size fits all' approach that may not be suitable depending on the latitude of the site.
- There is no standard methodology that all developers employ when introducing environmental and site specific data into shadow flicker assessments.
- All computer model assessment methods (eg. WindPRO, WindFarm and Windfarmer) use a 'worst case scenario' approach and do not consider 'likely case' factors such as wind speed and cloud cover[3].
- 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[4].
- Mitigation measures employed to operational wind farms have proved successful, to the extent that shadow flicker cannot be considered to be a major issue in the UK.

1.9 The DECC report contains the majority of shadow flicker related references which were identified and reviewed for this current study, however this current study asks a number of different questions of the literature sources than were posed by the DECC report.

Wind Farm Impacts Study: Review of the visual, shadow flicker and noise impacts of onshore wind farms[5]

1.10 This document explores whether the impacts predicted by wind farm developers, at the time of planning application submission, are consistent with the impacts experienced once the wind farm is operational. It aims to inform any future decisions on changes to Scottish Government online planning guidelines and good practice on managing the impacts of wind farms on local residents.

1.11 Shadow flicker was assessed at all ten of the case study wind farms for properties where it could occur based on the distance to the turbine(s). The shadow flicker related findings were as follows:

- Some participants noted that they experienced shadow flicker even though they lived in properties beyond the distance at which shadow flicker is currently predicted to occur.

[2] Parsons Brinckerhoff (2011) Update of UK Shadow Flicker Evidence Base, Department for Energy and Climate Change

[3] Note that GH Windfarmer and WindPRO can both incorporate wind direction. WindPRO can incorporate cloud cover

[4] Specifically in relation to modern, larger turbines which rotate at a lower frequency.

[5] SLR, Hoare Lee Acoustics (2015) Wind Farm Impacts Study Review of the visual, shadow flicker and noise impacts of onshore wind farms, ClimateXChange

- There are no standard significance criteria to assess shadow flicker impacts and no statutory limit or guidance to stipulate acceptable levels of shadow flicker.
- Modelling of shadow flicker that includes data gathered through a house-by-house assessment of the potentially affected properties provides a more robust approach.
- A range of lighting effects impact people living close to wind farms, none of which were found to be clearly defined.
- A clear(er) definition of all shadow and light effects with reference to parameters such as the distances, directions, light and weather conditions in which they can occur would help both assessments and public understanding of this particular impact.
- In the process of developing new guidance, it would be beneficial to carry out further research to improve understanding of light and shadow effects on residents within 2 km.

Definitions of light and shadow related effects

1.12 Within the two documents outlined above, the following types of light and shadow effect were identified and defined. The documents acknowledge that there is no standard definition of shadow flicker, but the following text has been identified from the reports as referring to the different light and shadow effects to help provide a baseline for this report. The definitions of light and shadow related effects within the wider document base are explored in the body of the report.

Table 1.1 Definitions of light and shadow related effects within the Update of the UK Shadow Flicker Evidence Base, and the Wind Farm Impacts Study

Light and shadow related effect	Update of UK Shadow Flicker Evidence Base	Wind Farm Impacts Study
Shadow flicker	Includes two definitions used within the text: 'The term "shadow flicker" refers to the flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring properties as they turn, through constrained openings such as windows' 'blade shadows passing across windows'	generally is taken to mean shadow effects caused by the movement of rotors which occurs at distances of up to ten times the rotor diameter (10 x rotor diameter) of the relevant turbines
Shadow throw		*Includes two definitions used within the text:* 'taken to mean shadow effects which occur beyond ten rotor diameters distance' 'when individual(s) outside a building are affected by the shadow cast by turbine(s) at frequent intervals' (as defined for the questionnaire that formed part of the study)
Passing shadows	Blade shadows passing across open ground in an outdoor location	
Strobe effect / Glint and glare	'refers to the flashing of reflected light which can be visible from some distance (This phenomenon has largely been ameliorated by the development of an industry standard (light grey semi-matt) for the colour and surface finish of turbine blades, and was disregarded from the study).'	sun glinting off turbines

Light and shadow related effect	Update of UK Shadow Flicker Evidence Base	Wind Farm Impacts Study
Night time lighting	No reference	Identified as an impact, but not explored in any detail

1.13 Night time lighting is considered as a potential source of landscape and visual impact. This is not an issue which has emerged through the literature review, and therefore is identified as more appropriately explored through the review of case studies in Stage 2 of the project.

2 Methodology

Introduction

2.1 This chapter of the report sets out the method and approach to carrying out the different stages of the research.

Stage 1: Review of current guidance

Guidance

2.2 The first task in the study involved the review of the following guidance documents in the UK:

- Scottish Planning Policy (2014)[6];
- Scottish Government (Updated May 2014) Online renewables planning advice[7];
- National Planning Policy Framework Planning Practice Guidance Renewable and low carbon energy (updated 2015)[8];
- Department of Communities and Local Government (2013) Planning practice guidance for renewable and low carbon energy 2004 (withdrawn on 7 March 2014)[9];
- Best Practice Guide to PPS18: Renewable Energy (2009)[10];
- Welsh Assembly Government Practice Guidance Planning Implications of Renewable and Low Carbon Energy (2011)[11].

2.3 These documents were reviewed in a framework which draws out how they approach or refer to the following:

- Definition of shadow flicker;
- Reference to shadow throw;
- Reference to other light related effects;
- Reference to circumstances of occurrence of shadow flicker including;
  - Reference to 130 degrees either side of north;
  - Reference to 10 rotor diameter;
  - Other references to distance and shadow flicker;
- Reference to thresholds for duration of effect.

[6]Scottish Government (2014) Scottish Planning Policy. Available at: **http://www.gov.scot/Resource/0045/00453827.pdf**

[7]Scottish Government (2014) Online renewables planning advice *http://www.gov.scot/Resource/0045/00451413.pdf*

[8] Department for Communities and Local Government (2015) http://planningguidance.communities.gov.uk/blog/guidance/renewable-and-low-carbon-energy/particular-planning-considerations-for-hydropower-active-solar-technology-solar-farms-and-wind-turbines/

[9]Department of Communities and Local Government (2013) Planning practice guidance for renewable and low carbon energy (withdrawn on 7 March 2014) Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225689/Planning_Practice_Guidance_for_Renewable_and_Low_Carbon_Energy.pdf

[10] Department of Environment (2009) Best Practice Guidance to Planning Policy Statement 18 'Renewable Energy'. Available at: http://www.planningni.gov.uk/index/policy/planning_statements/planning_policy_statement_18__renewable_energy__best_practice_guidance.pdf

[11] Welsh Assembly Government (2011) Practice Guidance Planning Implications of Renewable and Low Carbon Energy. Available at: http://gov.wales/docs/desh/publications/110228planimplicationsen.pdf

2.4 The next step was to identify other relevant overseas guidance, where this is referred to in UK assessments or where it has been instrumental in informing guidance or practice.

2.5 This was undertaken by identifying a number of shadow flicker assessments from within the UK, and examining their methodology to identify what guidance documents have been referred to. This examined ten assessments (see References). This review recorded the following:

- Proposal name;
- Date;
- Local authority;
- Guidance referred to.

2.6 Any guidance identified within the documents was reviewed against the framework used for the UK guidance documents. Reference to any other documents relevant to the literature review was also noted.

Review of tools and methods

2.7 The review of tools and methods was undertaken by Pager Power, and updates the review contained in the DECC (2011) review of shadow flicker. The stages included:

- Review of the use of modelling programs and add on packages. This aimed to identify the range of programs used, identify the most popular programs, and also differing perceptions on the acceptance of different programs.
- Comparative review of the inputs to the modelling programs;
- Comparative review of the outputs to the modelling programs;
- Commentary on the potential implications of the differing inputs and related outputs for the accuracy and interpretation of the model results.

Literature review

2.8 The targeted literature review focused on exploring key issues identified by the earlier ClimateXChange research and the DECC (2011) report. It involved searches of two bodies of literature.

2.9 The first involved reviewing renewable energy supplementary planning guidance from local authorities across the UK to identify references to light and shadow related effects. This identified:

- references to receptors, definition and sensitivity of different receptors;
- reference to significance of effects;
- reference to worst case/likely case scenarios;
- references to latitude, and how this is included within modelling.

2.10 The second tranche searched for journal articles/reference material, and documents referenced within these to identify source documents for:

- origins of the 10x rotor blade diameter;
- references to receptors, definition and sensitivity of different receptors;
- reference to significance of effects;
- reference to worst case/likely case scenarios;
- references to latitude, and how this is included within modelling.

2.11 As set out in the original submission the outputs from Stage 1 included a presentation of the findings to the project steering group, covering:

- Current guidance on shadow flicker;
- Current software and tools used to predict the occurrence of shadow flicker;

- Origins, rationale and use of the 10 x rotor diameter distance threshold;
- Approaches to issues including the definition of receptors, assessment of worst case or likely case, calculation of significance and high latitude practice;
- Recommendations on how Scottish guidance, definitions, assessment methodologies and tools could be improved.

Stage 2

2.12 The second stage of the work comprised a review of practice in Scotland, particularly in terms of the way that light and shadow effects are addressed in the Scottish planning system, and a review of public perceptions of light and shadow effects.

2.13 Specifically this involved the selection and review of case studies, follow up interviews and a review of literature sources related to public perceptions of light and shadow effects.

Selection of case studies

2.14 The review of light and shadow effects in the Scottish planning system was carried out through a small case study review of a planning application for a wind energy development with shadow flicker issues for each of five planning authorities. The selection of case study planning authorities was initially based on those with a higher occurrence of wind energy development with the intention of achieving a latitudinal spread.

2.15 A request for selection of possible case studies where shadow flicker was an issue was made to the Scottish Government, and the Department of Planning and Environmental Appeals (DPEA). Discussion of the possible approach to selection of case studies was also made with some of the project steering group. However approaching the planning authorities for suggested case studies highlighted the challenges of individual planners having a sufficient overview of planning applications, and the relatively low profile of shadow flicker in comparison to other wind farm related issues.

2.16 Following challenges in the identification of specific case study examples by this approach, a revised tailored approach using Geographical Information System (GIS) analysis was employed.

2.17 The case studies were identified from GIS analysis of the LUC windfarm database, which shows the mapped locations of wind turbines and wind farms across the UK. This was combined with map data on the location of buildings to the wind turbines. This allowed the identification of wind turbines with the greatest number of buildings within 500m. This provided a clearer focus to the search for case studies where shadow flicker had been assessed in relation to nearby properties, (rather than a those with shadow flicker statements concluding that there were no properties within the required threshold for assessment).

2.18 Based on the analysis, the five local planning authorities included in this stage of the work were identified as:

- Aberdeenshire;
- Angus;
- Fife;
- North Lanarkshire;
- Perth and Kinross.

Case study analysis

2.19 The case study analysis involved analysis of the relevant planning policy framework and detailed review of online planning documentation in relation to the case study planning application. This included the relevant information from the planning application (including the Environmental Statement where relevant), the Report of Handling and Decision. The analysis for each case study was structured around the following headings, as identified from Stage 1 of the study.

- Definition of shadow flicker;
- Definition of shadow throw;
- Night time lighting;
- Acknowledgement of reflected light issues;
- Reference to separation distances and site specific issues;
- Reference to ten rotor diameter;
- Reference to 130 degrees of north;
- Significance thresholds;
- Definition of receptors;
- Impacts on receptors;
- Reference to worst case and likely case;
- Parameters when shadow flicker may occur;
- Factors taken into account in calculating likely case scenario;
- How latitude is taken into account;
- Computer modelling used;
- Cumulative effects;
- Reference to policy and guidance;
- Mitigation.

2.20 The analysis was able to draw conclusions regarding the key issues surrounding each of these topics.

Interviews

2.21 Interviews were sought with the case study planning authorities and used to test out the emerging issues and recommendations from the case study review. The interviews presented some difficulties in gaining participation from all of the case study planning authorities, due to staff changes from the relevant contacts for the case studies. Contact was made with all of the case study planning authorities and interviews or written feedback provided by two planners and two environmental health officers from three planning authorities.

Public perceptions literature review

2.22 Stage 2 of the study also sought to identify and review literature on the extent to which public perceptions of shadow flicker match predicted and actual effects and to make recommendations on how future research and guidance should aim to close any gap. This involved search and review of media articles relating to shadow flicker, wind farm opposition group material and wind industry material.

2.23 The final recommendations and conclusions draw on the findings from both stages of the project.

3 Stage 1: Review of current UK guidance

Introduction

3.1 The first stage of the project separates out the findings from the review of current UK guidance, from those of the wider literature review. Although there are key issues of overlap between the two tranches of work, it was seen as important to differentiate where appropriate. Cross references to the findings of the literature in relation to the findings from the review of guidance are provided where appropriate, and the overall conclusions in Section 6, bring the findings of both elements of the work together.

Review of current UK guidance

3.2 The review of current UK guidance aims to establish the baseline parameters used in relation to the definition and assessment of light and shadow related effects.

Definition of Shadow Flicker

3.3 The purpose of the review of the definition of shadow flicker and other light and shadow related effects in current UK guidance documents is to identify consistency or differences between the definitions. This will identify if an appropriate definition exists which could be recommended as a standard definition, as no standard definition exists.

3.4 Definitions of shadow flicker were not explored within the Update of the Shadow Flicker Evidence Base DECC (2011), although the document itself did define shadow flicker. The Wind Farm Impacts Study recommended clearer definition of light and shadow related effects, and referred to the definitions in general use, but did not analyse them or provide recommendations.

3.5 Four of the national government guidance documents defined shadow flicker as set out in the following box, with some variation between the use of the word 'effect' or 'impact'.

> Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the [**effect**[12] [13] **or impact**[14] [15]**]** is known as "shadow flicker".

3.6 Scottish Planning Policy refers to shadow flicker but does not define it. The Welsh Government document[16] provides a simplified definition, similar to the above, '*Shadow flicker can occur when the sun passes behind the rotors of a wind turbine, which casts a shadow over neighbouring properties that flicks on and off as the blades rotate*.'

3.7 The literature review raised a number of more complex issues in relation to definitions of the effect than the findings from the review of guidance. The definition of shadow flicker (and other

[12] Scottish Government (Updated May 2014) Onshore Renewables http://www.gov.scot/Resource/0045/00451413.pdf

[13] Department of the Environment Planning and Environmental Policy Group Best Practice Guidance to Planning Policy Statement 18 'Renewable Energy' August 2009 http://www.planningni.gov.uk/index/policy/planning_statements/planning_policy_statement_18__renewable_energy__best_practice_guidance.pdf

[14] National Planning Policy Framework Planning Practice Guidance Renewable and Low Carbon Energy http://planningguidance.communities.gov.uk/blog/guidance/renewable-and-low-carbon-energy/particular-planning-considerations-for-hydropower-active-solar-technology-solar-farms-and-wind-turbines/

[15] Department of Communities and Local Government (2013) Planning practice guidance for renewable and low carbon energy (withdrawn on 7 March 2014) Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/225689/Planning_Practice_Guidance_for_Renewable_and_Low_Carbon_Energy.pdf https://www.planningportal.co.uk/directory_record/719/planning_for_renewable_energy_a_companion_guide_to_pps22

[16] Welsh Assembly Government (2011) Practice Guidance Planning Implications of Renewable and Low Carbon Energy, Welsh Assembly Government http://gov.wales/docs/desh/publications/110228planimplicationsen.pdf

light related effects) needs to be comprehensive in responding to the issues which they raise for people. As such, the recommendations for the definition of shadow flicker and other light related effects is made in the conclusions, where the findings from the review of guidance and the literature review can be drawn together.

Key issues: Definition of Shadow Flicker and Shadow Throw

Shadow flicker and shadow throw (also referred to as 'passing shadows') should both be defined. The most widely used definition of shadow flicker within guidance documents is as follows:

Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the ***effect or impact*** *is known as "shadow flicker".*

A definition of the outdoor effects of light and shadow related effects was not identified within the guidance, and has emerged from the literature review and review of Supplementary Planning Guidance. A possible definition is '*a moving shadow across open ground*'.

Reference to other light and shadow related effects

3.8 Reference to other light and shadow related effects within the national government guidance documents was limited to the issue of reflected light. These were referred to by the National Planning Policy Framework Planning Practice Guidance Renewable and low carbon energy, the withdrawn DCLG Planning Practice Guidance for renewable and low carbon energy, and the Northern Ireland Department of the Environment Best Practice Guide to PPS18: Renewable Energy. The Scottish Government and Welsh Assembly Government documents do not refer to these effects.

3.9 The most detailed reference is provided by the Northern Ireland Department of the Environment Best Practice Guide to PPS18:

A109. Turbines can also cause flashes of reflected light, which can be visible for some distance. It is possible to ameliorate the flashing but it is not possible to eliminate it. Careful choice of blade colour and surface finish can help reduce the effect. Light grey semi-matt finishes are often used for this. Other colours and patterns can also be used to reduce the effect further. (See 'The Influence of Colour on the Aesthetics of Wind Turbine Generators' – ETSU W/14/00533/00/00).

3.10 In response to the review finding a lack of reference to paint colour and finish in Scottish government guidance, reference to paint colour and surface finish within other relevant Scottish guidance was then sought. Scottish Natural Heritage (SNH) (2014) Siting and Designing Windfarms in the Landscape[17], states that '*paint reflection should be minimised. Texture is an important factor in reducing reflectivity and matt or light absorbent finishes are preferable*'. It also states, '*precise colour tone and the degree of paint reflectivity should be specified at the application stage*.'

3.11 The DECC report notes references to reflected light within some of the documents within the review, but does not explore this issue in any depth.

Key issues: Acknowledgement of reflected light issues

For completeness, the guidance should include acknowledgement of the issue of reflected light, which can be most apparent under wet or icy conditions. It should refer or cross

[17] Scottish Natural Heritage (2014) Siting and Designing Wind Farms in the Landscape Version 2 http://www.snh.org.uk/pdfs/strategy/renewables/Guidance_Siting_Designing_wind_farms.pdf

reference to the use of paint colour and surface finishes which reduce this effect as in the SNH guidance.

The impacts of night time lighting of wind turbines should be kept under review.

3.12 No reference to impacts of night time lighting was identified in the government guidance documents, although it was referenced in relation to requirements by the Ministry of Defence (MOD) in Scottish Government (Updated May 2014) Onshore renewables. The MOD's Obstruction Lighting Guidance[18] sets out the circumstances when visible aviation lighting is required for wind farms located in areas used for low flying training. The Civil Aviation Authority's[19] policy statement outlines the likely requirement for aviation warning lights in the vicinity aerodromes and on structures which are 150 metres or more in height. The SNH guidance[14] also refers to turbine lighting, where it is required, and states '*such lighting, typically at the top of the tower of the wind turbine, may appear prominent in night views and be incongruous in predominantly un-lit rural areas. Where lighting is necessary it should be designed to minimise landscape and visual impacts whilst satisfying health and safety or navigation requirements*.' The document goes on to state that lighting is predicted to become more widespread as sites are explored within flight paths and as larger turbines are considered. It is notable that new and repowered wind farms are making increasing use of turbines in excess of 150 metres in height, potentially triggering the requirement for the use of warning lights. Impacts will be influenced by brightness of visible lighting, numbers of lights required, their design (some are upward facing only), flashing or steady and potential for reflection on turning blades, low cloud or in mist.

3.13 The approach to assessment of the landscape and visual impact of night time lighting of wind turbines through the EIA process may be an issue which requires on going monitoring, however this should be clarified in discussion with Scottish Natural Heritage.

Key issues: Night time lighting

The requirement for visible (as opposed to infrared) lighting should be identified at scoping stage and, where required, considered as part of the LVIA process.

Reference to parameters/ distances/ areas where it is an issue

3.14 The Scottish Government Onshore Renewables Guidance, the Welsh Assembly Government Practice Guidance on the Planning implications of Renewable and Low Carbon Energy and the Northern Ireland Best Practice Guide to PPS18 Renewable Energy all make reference to when shadow flicker will occur.

3.15 The Scottish Government Onshore Renewables Guidance states that '*It occurs only within buildings where the flicker appears through a narrow window opening. The seasonal duration of this effect can be calculated from the geometry of the machine and the latitude of the potential site*.'

3.16 The Welsh Government document states '*However, this only occurs under particular circumstances and lasts for only a few hours per day*.' The document does not expand on the circumstances when it does occur.

3.17 The most detailed explanation is provided by the Northern Ireland Best Practice Guide to PPS18, as set out in the box below:

It only occurs inside buildings where the flicker appears through a narrow window opening. A single window in a single building is likely to be affected for a few minutes at certain times of the day during short periods of the year. The likelihood of this occurring and the duration of such an effect depends upon:

- the direction of the residence relative to the turbine(s);
- the distance from the turbine(s);
- the turbine hub-height and rotor diameter;

[18] Ministry of Defence (2012) MOD Obstruction Lighting Guidance

[19] Civil Aviation Authority (2010) Policy Statement: Lighting of En-Route Obstacles and Onshore Wind Turbines

- the time of year;
- the proportion of day-light hours in which the turbines operate;
- the frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and,
- the prevailing wind direction.

Key issues: Definition of parameters when shadow flicker may occur
The guidance should explicitly set out the parameters when shadow flicker may occur, similar to the bullet points in the Northern Ireland Best Practice Guide to PPS18 above.

Reference to 130 degrees either side of north

3.18 The study brief did not specifically require an investigation of the use of figure of 130 degrees either side of north, however it is a figure which is frequently cited within the documents. The DCLG National Planning Policy Framework Planning Practice Guidance, the withdrawn DCLG Planning Practice Guidance for renewable and low carbon energy and the Northern Ireland Best Practice Guide to PPS18 all state, '*Only properties within 130 degrees either side of north, relative to the turbines can be affected at these latitudes in the UK – turbines do not cast long shadows on their southern side.*'

3.19 The DECC report noted the following in relation to 130 degrees either side of north:

> *"England's Companion Guide to PPS22 (2004) and BERR (2007), and Northern Ireland's Best Practice Guidance to PPS18 (2009) state that only properties within 130 degrees either side of north of a particular turbine can be affected by shadows. Verkuijlen & Westra (1984) confirm this assertion, stating that particularly large areas to the east-northeast and westnorthwest of the turbine experience shadows for long periods of time. Both German guidance (2002) and Verkuijlen & Westra (1984) provide figures demonstrating the azimuth extent of the shadow flicker zone. The concept of limiting the assessment to within 130 degrees either side of north is not contested (nor are any alternative assessment methodologies proposed) in any guidance documents or academic literature."*

3.20 Including reference to the occurrence of shadow flicker within 130 degrees of north does not allow for the consideration of differences between the actual shadow throw of a wind turbine in different latitudes, although the extent of this difference is unlikely to be significant. The Scottish guidance does not currently make reference to 130 degrees either side of north. This appears prudent, as it is more important that the modelling of the shadow throw is accurate, and takes latitude into account, than the guidance states a figure of 130 degrees either side of north which may or may not be technically accurate in all locations within Scotland.

3.21 The conclusions of the DECC (2011) report state that although 130 degrees either side of north and ten rotor diameters is considered acceptable, that the '*one size fits all approach may not be suitable depending on the latitude of the site'*. The shadow flicker computer models take latitude into account, however the guidance documents and SPG which use these figures as triggers for assessment or as stated limits to where shadow flicker will occur do not take the approximate nature of these figures into account.

Key issues: Reference to the degrees either side of north affected by shadow throw

Scottish guidance should continue **not** to include reference to the occurrence of shadow throw 'within 130 degrees either side of north' unless evidence from modelling proves that this statement is accurate within Scotland. An alternative approach may be to include an example of the typical pattern of shadow throw from a wind turbine, and include explanation that in northern latitudes the pattern of shadow throw is limited to the approximate area shown, but that this varies with latitude and modelling will clarify the actual area of shadow throw from a wind turbine.

Reference to 10 rotor diameter

3.22 The origins of the frequently cited occurrence of shadow flicker within ten rotor diameters of a wind turbine was one of the key issues to be investigated through Stage 1 of this study. This issue is explored in more detail in the literature review, however this stage of the work sets out how this figure is used in the guidance documents.

3.23 Only two of the guidance documents make reference to the ten rotor diameter threshold. There is no mention of a reference source for the ten rotor blade diameter in either of these documents. Scottish Government Onshore Renewables (updated May 2014) states:

'In most cases however, where separation is provided between wind turbines and nearby dwellings (as a general rule 10 rotor diameters), "shadow flicker" should not be a problem.'

3.24 The Best Practice Guide to PPS18 states that, '*Problems caused by shadow flicker are rare. At distances greater than 10 rotor diameters from a turbine, the potential for shadow flicker is very low*.' It also provides an explanation of why distance influences shadow flicker:

A105. The further the observer is from the turbine the less pronounced the effect [of shadow flicker] will be. There are several reasons for this:

- *there are fewer times when the sun is low enough to cast a long shadow;*
- *when the sun is low it is more likely to be obscured by either cloud on the horizon or intervening buildings and vegetation; and,*
- *the centre of the rotor's shadow passes more quickly over the land reducing the duration of the effect.*

A106. At distance, the blades do not cover the sun but only partly mask it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines.

Key issues: ten rotor diameter distance

Scottish guidance should not include reference to the ten rotor blade diameter distance in relation to shadow flicker. As further discussed in the literature review, there is a lack of robust evidence for the use of this figure, and it appears more appropriate to identify the factors which influence when shadow flicker is more likely to occur and when it is less likely to occur.

The guidance should focus on avoidance of harm and nuisance, which should be established by exposure thresholds, and not on limiting the extent of assessment.

References to thresholds for duration of effect

3.25 It has emerged from the literature review that thresholds for the duration of shadow flicker are a significant consideration in determining the impact. Although duration and exposure to shadow

flicker are related to distance, this study has found insufficient evidence to support the use of distance alone to define areas of search for the impacts of shadow flicker, unless new data can be provided which supports the use of distance.

3.26 Of the documents reviewed, only the Northern Ireland Best Practice Guide to PPS18 refers to a threshold for duration of effect, '*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*.' This statement is referenced to the research carried out by Predac, a European Union sponsored organisation promoting best practice in energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany. However it is noted by Haugen (2011) that the German guidance is often misquoted, as it refers to 30 hours / year worst case, and 8 hours / year likely case (further detail on this is provided in Chapter 4). PPS18 appears to reflect this observation, omitting reference to worst case or likely case in relation to the threshold. Therefore documents referring to the thresholds for exposure must be clear in the relevance of this to worst or likely case scenarios.

Key issues: thresholds for duration of effect

Guidance documents referring to exposure thresholds for shadow flicker must be explicit in their reference to limits relating to worst case and likely case scenarios.

Review of SPG

3.27 The review of national UK guidance documents did not identify many references to other sources in relation to light and shadow related effects. In order to identify if local planning authorities had referenced additional sources or developed a greater level of detail in relation to the assessment of light and shadow effects from wind turbines, a brief review of a selection of SPG within the UK was also undertaken. A list of the SPG reviewed in provided in the references. The following text highlights the key findings from the review of SPG.

Approach to light and shadow effects within the SPG

3.28 Light and shadow effects are sometimes grouped with the discussion of other impacts including noise, or under the wider heading of community or amenity impacts. This introduces the potential for confusion of impacts of noise with those of shadow flicker (see Section 4: Literature review)

Types of receptor

3.29 Within the 17 SPG reviewed, the following different types of receptor were identified (the wording from each SPG is shown separated by a forward slash):

- **Residential**: Dwelling house / residential properties / residential dwelling / dwellings / residential / nearby dwellings /dwellings/dwellings / Residential premises within 10 rotor diameters / Residential properties within 10 rotor diameters and within 130 degrees either side of north/ residential accommodation including future residents.
- **Work**: Workplace/ work place /neighbouring offices.
- **Buildings and properties**: All buildings (within 10 rotor diameters) / Occupied buildings / Regularly occupied buildings not associated with the development / Existing properties / Nearby properties [nearby not defined].
- **Transport**: trunk roads (within 10 rotor diameters) / public roads or paths identified in the Core Paths Plan (this would appear to be in relation to ice throw or turbine failure and not shadow flicker, as it is specified as the height of the turbine to blade tip, plus 10%) / road and rail networks.

- **Other**: sport and recreation facilities / important historic sites / community facility / other sensitive properties (although sensitive properties are not defined) / hospitals, schools and churches.

3.30 One SPG didn't refer to types of receptor, and another (Aberdeenshire) provided detail relating to the sensitivity of different receptors, which is discussed below.

3.31 The majority of the SPG primarily mentioned residential dwellings as receptors, although there is some evidence of greater consideration of other types of receptor (e.g. Rushcliffe Wind Energy Supplementary Planning Document). The basis for specific mention of these types of receptor is unclear without detailed case study analysis of the SPG.

3.32 It is interesting to note that the receptors identified include both indoor and outdoor receptors, when the definition of shadow flicker in most documents within this study specifies occurrence within a building.

3.33 The DECC (2011) report noted questionnaire respondent views on the issue of indoor and outdoor effects, and that these differed between developers and those doing the assessments and planning authorities, but did not draw any firm conclusions on how these should be addressed.

Key issues: shadow effects outdoors

There should be definition of shadow effects outdoors and how these should be assessed.

Sensitivity of receptors

3.34 The SPG for Wind Energy Developments in Aberdeenshire[20] provided the only example in the sample of SPG which defines sensitivity of land use adjacent to a site, as set out in the box below.

HIGH	Residential uses (including nursing houses, accommodation blocks)
MEDIUM	Non-residential uses and brownfield land within settlements
LOW	Non-residential uses and brownfield land outwith settlements

3.35 Eleven of the 17 SPG reviewed referred to receptors within 10 rotor diameters as triggering the requirement for a shadow flicker assessment, which highlights the wider use of this distance threshold within SPG.

Key issues: sensitivity of receptors

Further research should be carried out into the sensitivity of different receptors.

Worst case / likely scenario modelling

3.36 Worst case scenario modelling is when site specific factors such as prevailing wind direction, cloud cover etc. are not taken into account. Likely scenario modelling is when a range of variables are included in the modelling. There can be a large difference between modelled outcomes for exposure under worst case scenario and likely case scenario. The German guidance illustrates this, by its reference to exposure thresholds of 30 hours / year *worst* case modelling or 8 hours / year *likely* case.

3.37 In relation to identifying factors which influence the likely case scenario, two of the SPG refer to the types of window opening and the occurrence of shadow flicker, but no mention is made of how this should be taken into account. North Lanarkshire SPG notes that certain types of window openings can affect the degree of impact but makes no reference regarding how this should be considered during modelling or assessment. East Ayrshire SPG notes a narrow window opening will contribute to the occurrence of shadow flicker but makes no reference regarding how this should be considered during modelling or assessment.

[20] Aberdeenshire Council (2005) Supplementary Planning Guidance Use of Wind Energy in Aberdeenshire Part Two Guidance for Assessing Wind Energy Developmetnshttps://www.aberdeenshire.gov.uk/media/8107/2005_2windassessing06.pdf

3.38 Five of the SPG refer to the conditions under which shadow flicker may occur. They do not discuss the differences between likely case and worst case modelling.

3.39 The conditions when shadow flicker may occur as set out in the SPG reviewed are listed under each dark bullet point:

- *the occurrence and duration of shadow flicker at a particular occupied building is dependent on wind speed, wind direction and cloud cover.*
- *Shadow flicker is likely to be a seasonal occurrence, unlikely to occur during cloudy conditions.*
- *the magnitude of shadow flicker varies both spatially and temporally and depends on a number of environmental conditions including position and height of sun, wind speed direction, cloudiness and the position of the turbine to sensitive receptor. If there are no windows facing the direction of the turbine a shadow flicker assessment will not be required.*
- *Influences on the likelihood of shadow flicker occurring, and its severity include:*
  - *The direction of the dwelling relative to the turbine(s);*
  - *The distance from the turbine(s);*
  - *The turbine height;*
  - *The time of year (the effect is greater when the sun is lowest in the sky);*
  - *The proportion of daylight hours in which the turbine(s) operate;*
  - *The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon);*
  - *The prevailing wind speed and direction.*
- *The likelihood of this occurring and the duration of such an effect depends upon:*
  - *the direction of the residence relative to the turbine(s);*
  - *the distance from the turbine(s);*
  - *the turbine hub-height and rotor diameter;*
  - *the time of year;*
  - *the proportion of day-light hours in which the turbines operate;*
  - *the frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and,*
  - *the prevailing wind direction.*

3.40 This illustrates the different levels of detail provided in the SPG. Although there is recognition of the difference between worst case and likely case, the SPG do not provide clear guidance on how assessment should relate to this, or what conditions are expected to be included within modelling.

Key issues: worst case and likely case scenario

Guidance should be explicitly clear on when worst case scenario or likely case scenario is being referred to and how this relates to shadow flicker calculations and thresholds of exposure. It should also clearly refer to the importance of defining 'worst- case' or likely case.

Reference to ten rotor diameter distance

3.41 Eleven of the 17 SPG reviewed make reference to the ten rotor diameter distance threshold. There is some variation in how the ten rotor diameter distance threshold is used in SPG. It is used:

- To indicate the areas of greatest potential impact from shadow flicker;

- As a separation distance between wind turbines and nearest residential dwelling;
- To indicate the area within which a shadow flicker assessment is required.

3.42 Using the ten rotor diameter distance threshold as the cut-off for the area requiring a shadow flicker assessment automatically is not precautionary as it excludes consideration of shadow flicker in areas beyond this, and any assessment of whether or not this has the potential to be significant, even if it is unlikely. This is however indicative of the weight given to the ten rotor diameter within UK guidance.

Reference to how latitude is included in the modelling

3.43 Six of the SPG make reference to properties within 130 degrees either side of north having the potential to be affected by shadow flicker. Another SPG notes that shadow flicker relates to the angle of the sun but does not elaborate, so it is unclear if this is a reference to latitude or time of day.

Summary

3.44 Overall this illustrates the level of variation in the guidelines for shadow flicker within the SPG reviewed. In particular there is inconsistency in the identification of likely scenario contributing factors to shadow flicker, and variations in the use of language which could have significant effects on how the SPG are interpreted.

Other relevant overseas guidance

3.45 A search for other relevant guidance documents which may be informing the assessment of light and shadow effects of wind turbines was also carried out. This review was based on a search of shadow flicker assessments within the UK for any references to other literature sources or guidance documents. A list of the shadow flicker assessment documents searched is available in the list of references. This review found that there is very limited reference to any guidance. Documents identified included:

- Research by 'Predac', a EU sponsored organisation promoting best practice in energy use and supply, which draws on experience from Belgium, Denmark, France, the Netherlands and Germany. 'Spatial Planning of Wind Turbines, PREDAC - European Actions for Renewable Energies'
- German Guidance: Hinweise zur Ermittlung und Beurteilung der optischen Immissionen von Windenergieanlagen, Länderausschuss für Immissionsschutz (2002), [Notes on the determination and evaluation of the optical emissions from wind turbines].

3.46 The content of these documents is explored in the findings from the literature review. One assessment also made reference to Canadian guidance, but it was insufficiently referenced to identify.

3.47 A wider internet search of other potential documents using search terms ‘shadow’ ‘guidance’ and ‘wind’ also found no references to other guidance documents. However, this search was focused on documents available in English, and there may be other relevant documents presented in other languages which were not identified.

Review of tools and methods

3.48 This part of the report compares the technical tools for the assessment of shadow flicker that are currently available to developers. The review of tools and methods was undertaken by Pager Power and a summary is provided below. The full text is in Appendix 1.

3.49 It considers:

- How shadow flicker is defined and what related effects are to be considered.
- The factors that influence shadow flicker effects to the greatest extent.

- The most popular tools used to assess shadow flicker effects.
- The technical differences between the available tools – and the significance of these differences.
- A summary of technical considerations pertaining to eventual formal guidance on shadow flicker and related effects.

Definitions of Shadow Flicker

3.50 Precise definitions of shadow flicker from various sources are presented explored earlier in this report. The key features identified by all sources are:

- The effect is caused by the shadow of the spinning rotor periodically obstructing a view of the sun.
- The resulting effect is periodic changes in light intensity.
- The effect occurs inside a room that is lit by sunlight through a constrained opening such as a window.

Effects to Consider

3.51 The wider project is concerned with shadow flicker and related effects. The study therefore makes reference to the potential for observed changes in light intensity as a result of periodic obstruction of the sun by a turbine's rotating blades.

3.52 Shadow flicker effects can be caused by a single turbine or multiple turbines.

Technical factors that influence Shadow Flicker

3.53 The primary mechanism behind observable shadow flicker effects is obstruction of the sun by a turbine's blade. The obstruction can be full or partial.

3.54 Shadow flicker effects therefore depend on the width of the blade and its position relative to the sun and the receptor. The relative positions, in turn, are dependent on many parameters including distance, bearing, terrain elevation, time of year and wind direction among others.

3.55 The table on the following page sets out the parameters that a comprehensive modelling tool should accommodate.

3.56 Some factors, common to all models, have not been explicitly defined in order to keep the assessment output concise. This includes the latitude and longitude of the development and the path of the sun through the sky.

Table 3.1 Comparison of shadow flicker modelling software

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
Turbine Data	Incorporation of hub height	✓	✓	✓	✓	✓
	Incorporation of rotor diameter	✓	✓	✓	✓	✓
	Incorporation of blade thickness	✗	✗	✓	✗	✓
Receptor Data	Incorporation of window dimensions	✓	✗	✓	✓	✓
	Incorporation of azimuth angle	✓	✓	✓	✗	✓
	Incorporation of vertical tilt angle	✓	✓	✓	✗	✓
Terrain Model	Incorporation of earth curvature	✓	✓	✓	✗	✓
	Incorporation of a terrain model	✓	✓	✓	✗	✓
	Incorporation of structures above ground	✗	✗	✓	✗	✓
	Incorporation of intervening terrain	*Possibly*	✗	✓	✗	✓
	Incorporation of terrain / screening on the horizon	✓	✓	✓	✗	✓
	Sophisticated terrain data interpolation algorithm	✓	✓	✓	✗	✓
Wind Direction	Incorporation of wind direction	✗	✓	✓	✗	✓
Cloud Cover	Incorporation of likely cloud cover	✗	✗	✓	✗	✓

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
Sunrise / Sunset	Incorporation of sunrise and sunset times	✓	✓	✓	✗	✓
Model Output	Quantification of hours per day / per year that effects could occur	✓	✓	✓	✓	✓

Modelling and Future Guidance

3.57 Comprehensive formal guidance on shadow flicker effects is likely to define:

- Requirements for an assessment process.
- A quantified definition of an 'acceptable' impact.

3.58 The definition of an acceptable impact may be related to one or more of the following:

- Number of hours per day.
- Number of hours per year.
- Severity of impact.

3.59 Modelling tools should therefore:

- Be able to assess worst-case scenarios based on the geometric locations of the sun, the turbines and the receptors.
- In order to evaluate the severity of the impact, the change in observed intensity must be quantified in some way. A reasonable approach would be to define this in terms of percentage of sun obscuration e.g. if the widest part of the blade obscures less than 50% of the sun under worst-case conditions, the impact is considered negligible[21].

[21] The value of 50% is for explanation purposes only, there is no recommendation within this report with regard to acceptable limits.

4 Literature review findings

Introduction

4.1 The findings of the literature review are structured around the key issues which were set out in the project brief:

- to describe the origins, rationale, and use of the 10 x rotor diameter distance threshold for shadow flicker;
- to explore the definition of different types of receptors to light and shadow related effects;
- to understand the extent to which assessments are based on worst case and / or likely case scenarios;
- the understand the definition of significance of exposure to effects of light and shadow related effects;
- to understand how assessment takes latitude into account.

Origins of the 10 x rotor diameter distance threshold

4.2 The literature review focused on references to the origins of the 10 x rotor blade diameter threshold, but through the course of the review, it was also identified that there are a number of other factors which potentially correlate approximately to the ten rotor blade diameter distance. These include:

- The distance threshold related to triggering photosensitive epilepsy;
- The inter-relationship between distance thresholds for noise and visual impact from wind turbines, and that for shadow flicker;
- The percentage coverage of the sun by the turbine blade[22];
- The reduction in shadow intensity with distance; and
- The frequency at which shadow flicker will occur. The closer a receptor is to a wind turbine (within the pattern of shadow fall) the greater the potential occurrence of shadow flicker. For distances further from a wind turbine the number of times a year and the duration of the shadow flicker effect are reduced. This seems to lead to the distinction between levels of shadow flicker which cause harm vs those that cause annoyance. This is explored under the section heading 'significance of effect' (see paragraph 4.29).

4.3 The earliest reference to the 10 x rotor blade distance threshold is found in an article by Clarke (1991)[23] . This article includes the comment that the minimum separation distance for wind turbines from habitations should be **approximately** 10 blade diameters. The synopsis for the article states that in relation to the problem of shadow flicker and flashing from the blades of a turbine; '*turbines should be sited at least 10 x diameters from habitations, and more if sited to the southeast or west / southwest, and the shadow path identified.*' The use of the words 'at least' should be noted. This is further reinforced through the following quote from the article *'Clearly it is best to avoid the problem in the first place by attention to careful siting. Wind turbines close to habitations, e.g. ten diameters distance should not be sited to the east or south east, or west or south west of habitations, unless the shadow path has been identified and does not fall on the windows of habitations or occupied buildings*.'

[22] This needs to be considered within the context of turbines with greater blade length becoming more prevalent.

[23] Clarke A.D, (1991), A case of shadow flicker/flashing: assessment and solution, Open University, Milton Keynes

4.4 This highlights the need to consider the impacts at a distance greater than ten rotor diameters within different compass directions to the turbine.

4.5 The summary comments in the document on the siting of turbines states:

4.6 '*The minimum separation distance for wind turbines from habitations should be approximately 10 blade diameters. This is emerging from experience and research as a standard guideline, in order to reduce problems of visual impact, noise, shadow disturbance and safety*.'

4.7 The reference to '*visual impact, noise, shadow disturbance and safety*' illustrates the blurring of multiple impacts in relation to separation distance between wind turbines and people within this article and is an issue further explored in paragraph 4.22 .

4.8 A key point to emerge from the review of the frequently cited article by Clarke (1991) is the potential for the interpretation of the key points from the article to have been summarised and their original sense distorted. There is evidence of this within the article itself between the main text and the synopsis. The ten rotor blade distance is referred to as an approximate separation distance, not a set limit. Equally the research cited in the article as supporting the ten rotor diameter separation distance includes only one reference to documents specifically related to shadows from wind turbines (Verkuijlen and Westra[24]). The other references include studies related to the effect of flicker on people, including in relation to traffic tunnel lighting and visually induced seizures. Although the studies in relation to the effects of flicker on people are important, it is not clear from the article how these studies relate to the ten rotor diameter distance.

Other factors relevant to the 10 rotor blade diameter distance

Shadow flicker and photo sensitive epilepsy

4.9 The relationship between the 10 x rotor diameter and the effects of shadow flicker on those with photosensitive epilepsy has emerged from the literature examined. In relation to the effects of light flicker Clarke (1991) makes reference to the issue of wind turbine rotation and epileptic convulsions. He notes '*most medium and large wind turbines have a rotation rate of between 30 r/min and 60 r/min, and smaller turbines often have a faster rotation. Most turbines in use today are two or three bladed, constant speed types, producing shadow flicker rates in the range of 1-3 Hz. Variable speed turbines may produce a 2-6 Hz flicker rate. Therefore the shadow flicker from turbines has frequencies that could in the right conditions produce light flicker effects to susceptible persons*. '

4.10 Smedley, Webb, and Wilkins, (2010)[25] looked at the potential risk of epileptic seizures from wind turbine shadow flicker under various meteorological conditions. They found that large turbines rotate at a rate below that at which the flicker is likely to present a risk of epileptic seizure, although there is a risk from smaller turbines that interrupt sunlight more than three times per second. For the scenarios considered in the research, they found the risk is negligible at a distance more than about 9 times the maximum height reached by the turbine blade, a distance similar to that in guidance from the UK planning authorities.

[24] Verkuijlen E. Westra, C.A. Shadow Hindrance by Wind Turbines Proceedings of European Wind Energy Conference, European Wind Energy Association October 1984

[25] Smedley, Andrew R. D.; Webb, Ann R.; Wilkins, Arnold J. (2010) Potential of wind turbines to elicit seizures under various meteorological conditions, Epilepsia, 51 (7), 1146- 1151

Key points in relation to origins of the ten rotor blade diameter distance

The original references to ten rotor blade diameter distance separation between wind turbines and habitations by Clarke (1991) is presented as an approximate or minimum distance to avoid disturbance, and should not be interpreted as a limit at which disturbance from shadow flicker can occur.

Within the text of the original article by Clarke (1991) there is blurring of the impacts of *visual impact, noise, shadow disturbance and safety* in relation to the ten rotor diameter separation distance.

Clarke (1991) does not make reference to distance and the effect of wind turbines and epileptic convulsions commenting only on the frequency of flicker and speed of blade rotation.

Twenty percent coverage of the sun

4.11 The German guidelines (2002)[26], the Swedish guidance (2012)[27] and the WindPro User Guide (2010) all refer to the requirement for 20% coverage of the sun for shadow flicker to occur. The following paragraphs explore the context for this figure.

4.12 According to the German guidelines, the limit of the shadow is set by two factors:

- The angle of the sun over the horizon must be at least 3 degrees.
- The blade of the wind turbine must cover at least 20 % of the sun.

4.13 It is not clear from the German guidelines of the origin of the 20% reference.

4.14 An explanation and source reference for of the 20% coverage of the sun was identified within a shadow flicker assessment for a wind farm in Lempster, United States, '*Dobesch and Kury (2001) and 'out of the box' wind project analysis software packages such as WindPro, work on the basis that when less than 20% of the sun is masked by the turbine blades the difference of the radiation-intensity between shadow minimum and shadow maximum is so low that the people don't notice it unless they are looking directly at the sun*.'[28]

4.15 The source of Dobesch and Kury (2001) is referenced in other English speaking documents as Basic Meteorological Concepts and Recommendations for the Exploration of Wind Energy in the Atmospheric Boundary Layer, Central Institute for Meteorology and Geodymanics (ZAMG), Vienna, Austria. However as the document will have been written in German, and the actual wording of the document title in German has not been identified, despite considerable searching, it has not been possible to find the original article, and therefore understand the source.

4.16 It is not clear if the work by Dobesch and Kury influenced the German guidelines, although it may be possible to establish this through discussions with the German authorities. Communication with WindPRO was not able to identify this source.

4.17 Of the three shadow flicker models examined, only WindPRO allows inclusion of the figure of obscuration of the sun in the modelling. It is possible that 20% obscuration of the sun relates to rotor diameter and distance, and therefore this is put forward as a recommendation for additional modelling.

Setback distances in other countries

4.18 Haugen (2011)[29] undertook a review of wind energy policies and recommendations about wind turbine setbacks, noise, shadow flicker and other possible concerns in major wind energy producing countries outside the U.S. (not including China, India or Japan due to translation

[26] https://www.umwelt.sachsen.de/umwelt/download/laerm_licht_mobilfunk/WEA-Schattenwurf-Hinweise_LAI.pdf

[27] http://www.boverket.se/globalassets/publikationer/dokument/2013/vindkraftshandboken.pdf

[28] Superna Energy L.L.C. (2006) Lempster Wind Project Shadow Impact Assessment, Lempster Wind, LLC and Community Energy, Inc www.nhsec.nh.gov/projects/2006-01/documents/28_shadow_flicker_assessment.pdf

[29] Haugen KMB. (2011) International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns. St. Paul, MN: Minnesota Department of Commerce: Energy Facility Permitting (2011). p. 1–43.

difficulties). The report sought to keep the issues of setback distances due to noise impacts separate from setback distances for shadow flicker. The report concluded '*Very few countries have mandatory wind turbine setback distances between wind turbines and homes. Instead of set wind turbine setback distances, many countries regulate how close wind turbines may be located to residences through noise limits or shadow flicker limits*.'

4.19 This identifies the focus on using limits of exposure and not set distances. However, because this research focused on mandatory limits, and it therefore does not identify references to the ten turbine diameter distance within the UK. It is therefore possible that other references to distance and shadow flicker that sit within guidance documents which were not identified in relation to other countries.

Shadow dissipation and atmospheric interference

4.20 A further influence on the distance which shadow effects can be detected is air turbidity. An article by Freund (2002) [30] in the wind industry magazine DEWI[31] [English translation] highlights the causes and effects of this:

> *Depending on the concentration of aerosol particles (dust, smoke, water droplets) the atmosphere is more or less turbid. Shadows are a function of air turbidity. On a clear day, low turbidity means shadows are longer, and when turbidity is high their extent is less. The haze factor is subject to considerable temporal fluctuation, including the change in the water vapour content of air with temperature, air mass change and daily and seasonal variations. The extent of shadows also depends on the inclination of the exposed area. The direct radiation component of the sun is intense on a vertical surface. Shadows falling on surfaces of different inclination should be dealt with differently*.

4.21 The effect of light refraction in the atmosphere is also referred to in the German guidance, as a factor which is not taken into account in worst case scenario modelling. This is another factor which further contributes to a reduction in shadow effect with distance from the wind turbine.

Relationship between noise thresholds and shadow flicker

4.22 A German magazine article published in DEWI magazine 1998[32] makes reference to the interaction between shadow flicker limits and noise thresholds. It states that for the earlier generations of smaller turbines of 500 / 600kW, the noise limits seemed to be the deciding factor to define the limits in distance to the nearest dwelling. The article notes that for the larger wind turbines the manufacturers state that there is not an according increase in noise output compared to the earlier turbines, therefore noise will no longer be the limiting factor on distance, and shadow impact will play a larger role in future assessment of wind farms in planning. Wind farm technology has moved on significantly since 1998, however this article indicates that earlier research relating to the impacts of shadow flicker (in the field) may also have been inadvertently affected by the impact of noise from wind turbines.

4.23 The relationship between noise and shadows is further supported by Haugen (2011). Haugen (2011) notes that [field] studies done in Germany regarding shadow flicker which looked at shadow flicker exposure, stress, behaviours and coping found increased levels of exposure time correlated with increased stress levels and negative effects with those experiencing over 15 hours of actual shadow flicker having decreased quality of life and high levels of daily annoyance. However it was noted that stress levels and annoyance increased as the distance to the turbines decreased **in all directions**, not only the directions where shadow flicker occurs due to

[30] Freund 2002. Hans-Dieter Freund, FH Kiel/University of applied sciences. Einflusse der Lufttrubung, der Sonnenausdehnung och der Flugelform auf dem Schattenwruft von Windergieanlagen. DEWI magazin nr 20/2002 (Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines)

[31] DEWI is a performance, measurement, efficiency, research and education provider in the field of wind energy. It has been issuing a company magazine, the DEWI Magazin, twice per year since 1992. It includes articles on DEWI's research activities and other company news, but it is also used by external institutions for the publishing of their research results.

[32] Osten, T., and Pahlke, T. (1998). Schattenwurf von windenergieanlagen: wird die gebraeuschabstrahlung der MW-Anlagen in den Schatten gestellt? (Shadow impact on the surrounding of wind turbines). DEWI Magazin, Nr. 13, August 1998. Pp 6-12. Shadows of wind turbines : Will the greater use of large turbines be put in the shade? http://www.dewi.de/dewi/fileadmin/pdf/publications/Magazin_13/02.pdf

sunset/sunrise. This implies that the noise from wind turbines has a greater impact on stress levels than shadow flicker.

Timing of shadow flicker

4.24 A Swedish study which aimed to understand the impact of wind turbines on noise, shadows and landscape was based on interviews of residents in three neighbourhoods with wind turbines in Gotland[33]. The study found that in one of the case study areas although none of the respondents in Klintehamn had calculated shadowing (under worst case scenario) of more than 30 hours a year and a maximum of 30 minutes a day, 24% are fairly or very annoyed by shadows. In Nasudden 17% of the respondents had more than 30 hours /year facade worst case, but only 4% are fairly or very annoyed by shadows. The text states that one possible explanation for so many of those in Klintehamn being annoyed by shadows could be that most of the respondents live south east of the turbines and will get shadow flicker in the evenings during the period April to September (90% of respondents) that is when the shadows are most intense and most people are at home. Respondents that are not annoyed by shadows, even though they have a large calculated shadow flicker duration have shadows during the morning or during winter. Respondents that are annoyed by shadows, even though their calculated shadow impact is small, experience this effect during the evening.

4.25 The study concluded that it is more important at what time of day and year the shadows fall, than the total calculated time in hours a year of shadow impact.

4.26 A new rule was introduced in Sweden by Boverket (the Swedish national agency for planning the management of land and water resources, urban development and housing), for the calculation of shadow impact, which states that the calculation should be made for the building lot (garden) instead of the window[34].

Key issues: other factors relevant to the ten rotor diameter distance

Impacts of noise potentially confuse reporting of nuisance with shadow flicker impacts.

Time of day is potentially relevant to the experience of shadow flicker, although this depends on the lifestyle of the affected occupants.

Consider shadow impacts on the garden ground of a property.

Smedley et al (2010) refer to the risk of epileptic seizures and distance from wind turbines, of about nine times the height of the turbine blade. However all articles referring to wind turbines and epileptic convulsions state that large commercial sized wind turbines rotate at a rate below that likely to trigger epileptic seizures.

Definitions of receptors

4.27 Very little discussion of sensitivity of different types of receptors was found within the literature review, and this is an area where the findings from the review of SPG (see paragraph 3.34) provide a greater level of detail. The key issue seems to be the effect on people in general, and research to identify more sensitive groups has not been identified through this literature review.

4.28 Through the literature review an EIA for a wind farm in Ireland[35] identified in addition to receptors typically referred to, impacts on properties within 10 rotor diameters of a proposed turbine which included unoccupied buildings, permitted dwellings not yet constructed, and equestrian facilities.

[33] Environmental Case Study of Wind Turbines in the Living Environment(VINDKRAFTENS MILJÖPÅVERKAN FALLSTUDIE AV VINDKRAFTVERK I BOENDEMILJÖ), Widing, A., Britse G., Wizelius T., Centrum för Vindkraftsinformation Institutionen för naturvetenskap och teknik, Gotland University, Sweden, 2004 [English translation of abstract] http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Ljud/sammanfattning/Fallstudie%20sammanfattn050630.pdf

[34] Planering och Provning av Vindkraftverk på land och i kustnära vattenområden", Boverket, 2012, (Wind Energy Handbook, Planning and testing of wind turbines on land and in coastal waters)

[35] http://maighnewindfarm.ie/environmental/environmental-impact-study/volume-2-main-eis

Key issues: exposure thresholds and types of receptor

The recommendation for the threshold for sensitivity in the German guidelines appears to be based on a laboratory study of adults.

The literature review has not identified any issues with different types of receptor having higher sensitivity. This would appear to be a gap in the knowledge base. It would be interesting to study the shadow flicker assessments of wind turbines within closer proximity to urban areas, to identify what issues have arising associated with exposure by different types of receptor (e.g. children, people with mental health issues etc.).

Significance of effects and use of worst case and likely case scenarios in assessments

4.29 The literature review found that the significance of effects of shadow flicker is closely entwined with the use of worst case and likely case assessment.

4.30 The literature review examined references to exposure thresholds, and this found that the use of thresholds of exposure is not widespread, but for the countries which have an exposure threshold it is often based on the German guidelines. Haugen (2011) identified the use of the threshold for exposure in Australia, Germany and Ireland.

4.31 The German guidelines are the most commonly cited, and Haugen (2011) noted that the maximum 30 minutes/day or 30 hours/year for worst case scenario, and the 8 hours/year actual amounts of shadow flicker are a nationwide requirement in Germany as they are now part of the "Federal Emission Control Act (BLmSchG)", but have been used in case law and state and federal standards as well.[36]

4.32 In Australia, only two states have addressed shadow flicker with Victoria guidelines recommending no more than 30 hours per year shadow flicker exposure, and South Australia stating that shadow flicker must be considered to a distance of 500m.

4.33 Ireland Wind Energy Development Guidelines (2006) were subject to a targeted review [37] in relation to noise, proximity and shadow flicker which set out a number of proposed revisions in 2013. The revisions require a shadow flicker study for properties within 10 rotor diameters from each individual turbine. Previous to these revisions the 2006 guidance advised that houses and workplaces within 500m of a wind turbine should not be exposed to more than 30 hours per year or 30 minutes per day of shadow flicker. The references to a separation distance of 500m between any commercial scale wind turbine and the nearest point of the curtilage of any property in the vicinity is made with regard to amenity considerations, and not specifically shadow flicker.

4.34 The literature review identified that Swedish guidance[38] also repeats the German guidelines and states, '*The theoretical shadow time of disturbance to sensitive buildings should not exceed 30 hours per year and that the actual shadow time should not exceed 8 hours per year, and 30 minutes a day*.'

[36] Haugen KMB. (2011) International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns. St. Paul, MN: Minnesota Department of Commerce: Energy Facility Permitting (2011). p. 1–43.)

[37] Environment, Community and Local Government Proposed Revisions to Wind Energy Development Guidelines 2006 Targeted Review in relation to noise, proximity and shadow flicker – December 11th 2013 http://www.environ.ie/sites/default/files/migrated-files/en/Publications/DevelopmentandHousing/Planning/FileDownLoad%2C34769%2Cen.pdf

[38] "Planering och Provning av Vindkraftverk på land och i kustnära vattenområden", Boverket, August 2008, (Planning and testing of wind turbines on land and in coastal waters) (Boverket is Boverket is the national agency for planning, the management of land and water resources, urban development, building and housing in Sweden).

4.35 Guidelines published by PREDAC[39] provide recommendations on shadow flicker exposure, and provides examples of thresholds of exposure within other European countries. '*It is recommended at neighbouring dwellings and offices that flickering shadows are not exceeding 30 hours /year or 30 min. per day with normal variation in wind directions and with clear sky. (This follows the German norm of 30 hours a year at clear sky).'*

4.36 The report by PREDAC also identified the following thresholds:

- Wallonie, Belgium: 30 hours a year or 30 minutes a day (the PREDAC report does not clarify if this is worst case scenario);
- Denmark: 10 hours a year with average cloud cover;
- The Netherlands: When there is more than 20 minutes per day, 17 days per year (5 hours 40 min/year calculated, with clear sky), at neighbours it is regarded as a nuisance, which is unacceptable, and a standstill device is requested.

4.37 The German Guidelines provide a reference source for the threshold of 30 minutes a day exposure to shadow flicker. It refers to a laboratory study of the University of Kiel (2000)[40](Pohl, Faul and Mausfeld), it was found that even a one-off exposure to shadow effects for 60 minutes can lead to stress responses. Therefore for precautionary reasons the daily shading duration is limited to 30 minutes.

4.38 It is important to note that the laboratory study followed on from a field study by the same authors in 1999. The relevance of a laboratory study is that this removes any other variables (particularly noise influences from wind turbines) in relation a stress response. However it was noted in another document that these results were not published in a peer reviewed journal[41].

4.39 Further investigation of the origins of the exposure threshold in the Netherlands and Belgium may identify additional evidence base.

4.40 In relation to health effects of wind turbines, the University of Salford report (2013) [42] into the health effects of wind turbines stated, '*Health effects from other wind turbine related sources such as shadow flicker have been reported in several studies and guidelines to be less of a problem. Careful wind farm design and operational restrictions are suggested to be sufficient to minimise the impact.* This report did not include reference to any laboratory studies in relation to shadow flicker.

4.41 Within the UK a number of documents typically conclude that the impacts of shadow flicker are not significant because it is relatively straightforward to mitigate the effects. However this statement is based on the assumption that the impacts are accurately identified through the assessment process.

[39] Predac (undated) Spatial Planning of Wind Turbines Guidelines and Comparison of European experiences. This publication is part of the PREDAC project with support from EU Commission, 5th RTD Framework Programme, 2002-2004. The recommendations in this paper are from the expert group working on Work Package 8 of PREDAC. http://www.cler.org/IMG/pdf/WP8_ANG_guide.pdf

[40] J. Pohl, F. Faul, R. Mausfeld, Belästigung durch periodischen Schattenwurf von Windenergieanlagen, Laborpilotstudie, Institut für Psychologie der ChristianAlbrechts-Universität, Kiel 15.05.2000 http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Skuggor/Utredningar/Laborstudie%20Schattenwurf.pdf

[41] Twardella D (undated) Bedeutung des Ausbaus der Windergie fur die menschliche Gesundheit Consequences of wind energy for Health, Bayerisches Landesamt fur Gesundheit and Lebensmittelsicherheit [Bavarian State Office for Health and Food Safety]

[42] Von Hunerbein S,. Moorhouse A., Fiumicelli, D., Baguley D. (2013) Report on Health Impacts of Wind Turbines, Report for Scottish Government http://usir.salford.ac.uk/29183/1/HealthEffects_Final_IQ1-2013_20130410.pdf

Key points: significance of effects

The origins for the German thresholds for exposure to shadow flicker are based a laboratory study of adults which identified a stress response to exposure of 60 minutes to shadow flicker effects.

With the exception of the work by Pohl et al (2000) no other studies have been identified which attempt to isolate the effects of shadow flicker from other experiences associated with proximity to wind turbines.

It is important to note the German threshold relates to 30 hours / year worst case, and 8 hours / year likely case, and the need to clearly differentiate between the parameters for the two thresholds.

High latitude assessments

4.42 The models for the calculation of shadow flicker take into account the latitude of the location, therefore if latitude is factored into the model the area of shadow flicker can still be accurately predicted. However if the area of shadow calculation is limited to e.g. 130 degrees either side of north, this could result in areas which could experience shadow flicker being excluded from the calculation.

4.43 Modelling could identify how relevant the ten rotor diameter distance is at different latitudes. However, any distance based on multiples of rotor diameter will be indicative only because it does not factor in other parameters that influence potential effects.

5 Stage 2 Review of Practice and Literature

Introduction

5.1 The focus of the second stage of the work is to explore through a review of the case studies and literature:

- The findings from Stage 1, including identified uncertainties around the accuracy of current impact assessment methods;
- Definitions of light and shadow effects and impacts used in the planning process and in engagement/consultation with residents;
- The extent to which light and shadow effects and impacts are featured in pre-application consultation with residents;
- The available evidence on how residents understand and perceive light and shadow effects; and
- Recommendations of a precautionary approach to setting any thresholds for light and shadow effects.

5.2 These aspects are explored through the analysis of the five case study planning authorities of:

- Aberdeenshire;
- Angus;
- Fife;
- North Lanarkshire;
- Perth and Kinross.

Review of plans and SPG

5.1 As detailed in the methodology, the planning context for each case study was reviewed against a series of headings identified from the Stage 1 literature review. This included a review of the local plan, and relevant supplementary planning guidance (SPG) / supplementary guidance (SG). Only one local plan[43] (which was the adopted plan at the time of the case study planning application) made reference to shadow flicker, through a policy for wind energy developments and the need to demonstrate '*there is no unacceptable detrimental effect on residential amenity, existing land uses or road safety by reason of shadow flicker, noise or reflected light*.' It should be noted that due to the dates of some of the planning applications, the exact version of documents at the time of the decision making process was not always available. The following paragraphs summarise the findings of the review of the SPG / SG or other guidance relevant to renewable energy planning applications. A list of the relevant local plans and supplementary guidance is included in the references. One of the case studies included both supplementary guidance and supplementary planning guidance.

Definition of shadow flicker

5.2 The case study review examined if shadow flicker was defined, and how it was defined relative to the definitions identified through Stage 1. Two of the documents reviewed do not define shadow flicker. Other definitions of shadow flicker included:

'*the strobe effect of light flashing through the moving blades'.*

[43] Angus Local Plan Review (Adopted 2009) https://archive.angus.gov.uk/localplan/review.htm

'where the moving shadow flicker appears through a narrow window opening.'

5.3 One document defines both shadow flicker and separates out the strobe effect.

'Shadow flicker is caused by low sun behind the rotating blades of a turbine. The shadow created by the rotating blades can cause alternating light and dark shadows to be cast on roads or nearby premises, including the windows of residences, resulting in distraction and annoyance to the residents.

A related phenomenon, strobe effect, is caused by the chopping of sunlight behind moving blades, similar to the effect of the setting sun behind trees when driving along a roadway in the winter. Both of these phenomena are factors in the visual impact of a wind turbine project, and they could also be considered a nuisance to nearby property owners.'

5.4 Only one of the documents defines shadow flicker in line with the definition used in four of the national government documents (as outlined in chapter 4): '*under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties.*'

5.5 The variation in definition of shadow flicker supports the recommendation identified from Stage 1 of the report for the need for a definition of shadow flicker.

Definition of shadow throw

5.6 Only one planning authority referred to the issue of shadow flow in planning guidance. The authority's SPG clearly defines the difference between shadow flicker and shadow throw, and makes it clear that shadow throw is experienced outside and that turbines should be sited to avoid this effect on inhabited properties.

5.7 The absence of wider references s may be indicative of a lack of awareness of issues related to shadow throw, but in line with the recommendation identified from Stage 1 of the report supports the need for clarity on this issue.

Night time lighting

5.8 Only one document refers to lighting, noting that it may be required for civil or military aviation safety for larger turbines; usually at top of towers and may appear prominent in night views, and that shields can help minimise impacts.

5.9 The lack of coverage of this issue in the other case study documents suggests it is not currently perceived as an issue in the majority of the case study planning authorities. However, the increasing size of turbines, in particular the use of turbines of 150m or more in height, is likely to mean this will be a more significant issue in the future.

Acknowledgement of reflected light issues

5.10 Three authorities' documents do not refer to reflected light. Of the remaining authorities, one refers to the preference for a semi-matt finish to reduce the reflection of light, and another to turbine colour and the use of a non-reflective finish. Another of the documents refers to turbines causing flashes of light, and that this can be ameliorated but not eliminated.

5.11 There is a lack of consistency in coverage of reflected light issues in the case study guidance documents. Where it is provided in the case study examples, coverage of this issue is more extensive than that provided in national level Scottish government planning guidance.

Reference to separation distances and site specific issues

5.12 Case study authorities' planning guidance was reviewed for any references to the need to take site specific issues into account when identifying separation distances, or the proposal of alternative separation distances to any references to ten rotor diameters. One document states; '*The desirable separation distance will be dependent on a range of factors, including topography, safety issues, noise, shadow-flicker, shadow-throw and the size of the turbines*.'

5.13 Another document requires an assessment of potential shadow flicker and shadow throw for all dwellings within a 1000m radius[44] of the proposed location of each wind turbine. It also states that taking all other factors into account it is not anticipated that development would be less than 400m from the nearest dwelling, and it is possible that a greater separation distance will be required.

5.14 Two of the documents do not refer to separation distances or site specific issues to be taken into account when setting separation distances.

5.15 One of the documents refers to the general rule of ten rotor diameters as set out in the Scottish Government Guidance, but also states, '*Detailed information on site specific circumstances based upon the likely effects of shadow flicker as well as noise and visual impact may challenge this general approach. In any case developments will be assessed based upon their individual merits and against the criteria in section 8*.'

5.16 Illustrating a further variation, another of the documents also refers to a separation distance of 20 times height to blade tip in relation to operational impacts of wind turbines on residential amenity (including shadow flicker)[45].

5.17 The case studies show some variation in their recognition of the need to take site specific issues into account. There is an apparent awareness of the need to take this approach in the wording of two of the guidance documents.

Reference to ten rotor diameter

5.18 As discussed in relation to Stage 1 of the study, reference to ten rotor diameters is a key area of investigation, and an area of frequent misinterpretation. One of the documents states '*A distance of at least 10 rotor diameters is a general rule beyond which shadow flicker should not be a problem*.' Another document also specifically refers to the separation distances in PAN45 of 10 rotor diameters, but also states '*…although the local topography and the position of the turbine in relation to the dwelling(s) should be taken into consideration during any assessment*.'

5.19 One documents refers directly to the Scottish Government on–line guidance for Onshore Wind Turbines and that problems of shadow flicker can be resolved through separation between wind turbines and nearby dwellings (as general rule 10 rotor diameter). It then reiterates that turbines should generally be a minimum of 10 times rotor diameter from sensitive properties to avoid the potential effects of shadow flicker.

5.20 A document refers to the general rule of ten rotor diameters as set out in the Scottish Government Guidance, and another refers to the ten rotor diameter separation distance within PAN45 as a distance beyond which there should be no problem with shadow flicker.

5.21 One of the documents notes that shadow flicker can affect properties which are positioned within 130 degrees of north and located up to 10 times the rotor diameter from the turbine, which suggests shadow flicker is not an issue beyond this distance.

5.22 Overall, the case study guidance documents tend to reflect the intention of the national level guidance that ten rotor diameters is an approximate distance, with only one appearing to categorically rule out effects beyond this distance.

Reference to 130 degrees either side of north

5.23 Identification of any references to 130 degrees either side of north within the case study guidance documents was carried out to identify if this was being used as a method of defining the assessment area for shadow flicker. Of the case study guidance documents only one refers to shadow flicker within 130 degrees of north, defining it as a set area within which shadow flicker may occur.

[44] It should be noted that larger turbines now use rotors with a diameter of more than 100m, meaning this threshold is less precautionary than the usual 10x rotor diameter figure

[45] Overall turbine height is not always an indicator of rotor size and the potential for shadow flicker. Some turbines make use of larger diameter rotors mounted on shorter towers, increasing wind capture whilst limiting increases in height.

Significance thresholds

5.24 Guidance on significance thresholds provides consistency in the assessment of effects. Four of the documents do not refer to significance thresholds. One refers only to general impacts on residential amenity, including shadow flicker. Another includes a generic table for assessing the significance of impacts from wind energy, but not specifically in relation to shadow flicker.

5.25 One document states that, '*Wind turbines that result in significantly adverse, and therefore unacceptable impacts on residential amenity will not be supported*'. However the text does not provide greater detail on what level of shadow flicker is significantly adverse, other than referring to direct impacts on individual properties.

5.26 It is clear that the local authority guidance documents provide limited guidance on what levels of exposure to shadow flicker are significant.

Definition of receptors

5.27 The literature review confirmed that the severity of shadow flicker impacts varies according the nature of receptors and factors such as time of day. Definition of these different types of receptor is therefore necessary to inform the assessment of effects, although limited examples were identified within the planning authority guidance reviewed. Two of the documents do not define receptors. One refers to the sensitivity of adjoining land use based on residential or non-residential use. Another refers to sensitive properties which it defines as residential properties including care homes; educational buildings, hospitals, cemeteries; some visitor facilities and accommodation; and proposed development areas. One of the documents specifically states '*Turbines should not be sited where they are likely cause detrimental or significant shadow flicker at dwellings or other sensitive properties*', but does not define what other sensitive properties are.

5.28 One of the documents refers to the prediction of shadow flicker on sensitive locations '*such as roads or dwellings around proposed developments.*'

5.29 There is some variation in the guidance documents which refer to 'sensitive' receptors, but it unclear how these are defined. One of the examples attempts to define a wider range of receptors, including people outdoors.

Impacts on receptors

5.30 None of the case studies refer to the types of impact on receptor.

Parameters when shadow flicker may occur

5.31 Reference to the parameters when shadow flicker may occur was identified in Stage 1 of the study as providing additional clarity on the specific circumstances required for shadow flicker to occur. However none of the case study guidance documents refer to these.

Reference to worst case and likely case scenarios and factors taken into account in calculating likely case scenario

5.32 None of the guidance documents refer to worst case and likely case scenarios.

How latitude is taken into account

5.33 Only one of the documents refers to the fact that latitude is taken into account in the shadow flicker calculation models.

Computer modelling used

5.34 Only one of the documents refers to computer modelling within the context of the assessment being undertaken by means of mathematical modelling.

Cumulative effects

5.35 Only one of the documents refers to '*…any cumulative impacts on amenity'* but not specifically shadow flicker.

Reference to policy and guidance

5.36 The extent to which other policy and guidance is referred to within the guidance documents was examined to identify which higher level documents inform the guidance. Two of the documents do not refer to policy and guidance. Two documents refer to PAN 45, and another refers to Scottish Government Guidance (but does not specify further). One document refers to national planning guidance contained within SPP (Scottish Planning Policy) (2010) and online renewables advice including 'Onshore wind turbines'.

Mitigation

5.37 The coverage of the approach to mitigation within the guidance documents was examined in order to identify how the guidance on mitigation influences the approach to mitigation in the case studies.

5.38 Three of the documents do not refer to mitigation.

5.39 Two of the documents refer to the need to avoid locating turbines where they cause shadow flicker, and refer to mitigation firstly in the form of turbine shutdown and secondly through other screening.

5.40 One of the documents also states that shadow flicker can be minimised by appropriate turbine positioning in relation to residential properties and low sun positions and separation distances from residential properties.

5.41 The inclusion of the proposed approaches to mitigation within the local guidance documents provides a clear framework to developers and planners, however the use of this approach is not consistent within the case study examples.

Review of case study planning applications

5.42 Detailed case study analysis was carried out on the shadow flicker assessments for five wind turbine / farm planning applications for the five planning authorities. The case studies included:

A) A single 94m to tip turbine, decided 2010, supported by an Environmental Report[46].

B) A single 67m to tip turbine, decided 2016, supported by an Environmental Statement.

C) A single 127m to tip turbine, decided 2013, supported by an Environmental Statement.

D) A single 127m to tip turbine, decided 2011, amended 2012, planning application supported by a separate shadow flicker report.

E) Four wind turbines 115m to tip, decided 2015, supported by an Environmental Statement.

5.43 The case study results are presented under the main headings as identified from the Stage 1 literature review, as are the findings from the interviews. The interviews involved discussions and written responses with planners and environmental health officers from three of the case studies. As set out in the methodology, the interviews discussed the emerging conclusions and recommendations from Stage 1 of the project and the findings from the case studies.

Definition of shadow flicker

5.44 Case study A Environmental Report reflects the standard definition of shadow flicker used in the four national government guidance documents.

5.45 Case study B Environmental Statement (ES) provides a definition of shadow flicker as used in the DECC (2011) *Update of the Shadow Flicker Evidence Base*, and does not reflect to wording of the planning authority's SPG which is less detailed and refers to a 'strobe effect'.

5.46 Case study C Environmental Statement provides a simple definition of shadow flicker which broadly reflects the standard definitions used.

[46] Although not a formal Environmental Statement for the purposes of the Environmental Impact Assessment (Scotland) Regulations (1999)

5.47 Case Study D shadow flicker report which accompanies the final planning application (relating to a reduction in turbine height) does not define shadow flicker, although it was defined in the report accompanying the previous planning application. The wording used in the definition does not directly reflect the standard definitions in national guidance, however it still reflects the important factors relevant to the issue.

5.48 Case study E Environmental Statement quotes the definition of shadow flicker as given by BERR, 2007, '*Shadow flicker can arise from the passing of the moving shadow of a wind turbine rotor over a narrow opening such as the window of a nearby residence'*. The Development Management Committee report also refers to the definition within the SPG.

5.49 The definition of shadow flicker demonstrates a reversion to the national guidance documents over the local documents, but also variation in the definitions used.

Definition of shadow throw

5.50 The case study A Environmental Report refers to moving shadows, but does not describe the impacts of shadow throw on amenity.

5.51 The Environmental Statement for case study B also refers to moving shadows outside, and defines that these are not shadow flicker. The ES does not reflect the SPG which identifies that shadow throw should be taken into account in the siting of the development.

5.52 None of the remaining case studies refer to shadow throw.

5.53 There appears to be limited coverage or recognition of shadow throw within the case studies.

Night time lighting

5.54 Four of the case studies make no reference to night time lighting. Case study C makes no reference within the planning policy or ES, but a condition is applied requiring lighting on the turbine, and the specifications of this. This reflects the fact that night time lighting is referenced in the planning authority's SPG.

5.55 The case study review findings suggest that night time lighting is not currently a significant issue, except in certain geographical locations. However, the trend towards taller turbines is likely to mean more frequent use of lighting to satisfy the requirements of the MOD and CAA. While this may sometimes employ infrared lighting which is invisible to the naked eye, visible lighting may be required under some circumstances.

Acknowledgement of reflected light issues

5.56 Three of the case studies make no reference to reflected light issues.

5.57 Case study C makes no reference in the planning policy or ES with regard to reflected light, but a condition is included that requires non reflective paint with a semi matt finish. Again, the condition appears to reflect the coverage of this issue within the relevant authority's SPG.

5.58 The Environmental Statement for case study E refers to the flashing of reflected light from turbines with a gloss finish, but does not expand further.

5.59 The case study review findings suggest that reflected light is not considered to be a significant issue.

Reference to separation distances and site specific issues

5.60 The ES for case study B uses a 1km distance for assessing shadow flicker, as set out in the SPG.

5.61 Three of the case studies do not refer to separation distances and site specific issues.

5.62 Case study D does not refer to separation distances, however in the final shadow flicker report for the reduction in turbine height the definition of receptors is based on a Zone of Visual Influence (ZVI).

Reference to ten rotor diameter

5.63 Case study A Environmental Report text shows the typical modification of the wording from the Scottish Government Guidance, presenting the ten rotor diameters as a limit, not a guideline; *'Flicker effects have been shown to occur only within 10 rotor diameters of a turbine. Therefore if a turbine has 71m diameter blades, the potential shadow flicker effect could be felt up to 710m from a turbine.'* The ES goes on to say, '*Therefore, for this assessment, it has been assumed that properties within 10 rotor diameters (<700m) have a high sensitivity to shadow flicker, while properties further away from the project are deemed to be outside the region of potential effect and are not included in the assessment.'*

5.64 Case study B ES includes the statement that the Scottish Government's web based renewables advice suggests that shadow flicker should not pose problems beyond a distance of 10 rotor diameters from a wind turbine. This broadly reflects the intended meaning of references to ten rotor diameters in the guidance document, suggesting this is the area of greatest impact.

5.65 The case study C Environmental Statement refers to the limitation of the assessment to within 10 rotor diameters, illustrating the transposition of what is written in the guidance as a likely distance, into a threshold; *'In line with the Scottish Government Web-based Renewables Advice and Update of Shadow Flicker Evidence Base, the assessment area was limited to a radius of 10 rotor diameters from the turbine location and to 130 degrees either side of north*.'

5.66 Case study D planning amendment refers to the limitation of shadow flicker effects, and therefore the assessment, to ten rotor diameters, ' *In line with the recommendations of PAN45 and the March 2011 report, shadow flicker effects have been calculated up to a distance of 10 times the maximum rotor diameter of the proposed turbine*.' The shadow flicker report for the planning application for a reduction in turbine height does not refer to ten rotor diameters distance.

5.67 Case study E Environmental Statement simply states that '*Shadow flicker may occur up to ten rotor diameters from the turbines*,' suggesting that the ten rotor diameter distance is used as a threshold. The development management planning committee report also discusses distance and quotes BERR (2007) '*Only dwellings within 130 degrees either side of north relative to a turbine can be affected and the shadow can be experienced only within 10 rotor diameters of the wind farm.*'

5.68 The case studies highlight the frequent use of ten rotor diameters as a maximum threshold for undertaking shadow flicker assessment, and use of this to limit the assessment area, without taking any other factors, such as topography, into account.

Reference to 130 degrees either side of north

5.69 The Environmental Report for case study A makes no reference to 130 degrees either side of north.

5.70 The ES for case study B notes that properties within 130 degrees of north are included in the assessment, from which it can be assumed that properties outwith this range were excluded from the assessment, although this is not made explicitly clear.

5.71 The case study C Environmental Statement refers to 130 degrees either side of north, in relation to the *Update of the UK Shadow Flicker Evidence Base* report, but does not specify if or how it was used in the assessment.

5.72 The case study D planning amendment (2011) refers to 130 degrees either side of north; '*in the UK generally only properties within 130 degrees either side of north, relative to the turbines, can be affected*.' The shadow flicker report for the reduction in turbine height (2012) does not mention 130 degrees either side of north.

5.73 The ES for case study E states, '*Shadow flicker may occur … within 130 degrees either side of north. Within this area there are several residential properties where shadow flicker may potentially occur and a shadow flicker assessment has been undertaken outlining potential impacts and necessary mitigation*.' This suggests that it was used as a limit for the assessment.

5.74 Therefore the case studies suggest that some of the shadow flicker reports interpret the current guidance as supporting the limitation of the assessment area to within 130 degrees of north.

There is some uncertainty in how 130 degrees of north is being applied in other case studies, although it is referred to.

Significance thresholds

5.75 The Environmental Report for case study A refers to significance thresholds, stating,

' The Danish Wind Energy Association web site suggests that in Germany up to 30 hours of actual shadow flicker during the times a property is occupied is likely to be tolerable. Therefore with similar reasoning as above it has been assumed that more than 30 hours of flicker predicted when mitigation has been taken into account represents a high magnitude of impact, while more than 30 hours without mitigation represents a medium magnitude. Below 30 hours of predicted flicker without mitigation, the magnitude is low, becoming negligible when mitigating factors are applied.'

5.76 However this is another example of the recurrent mis-application of the German threshold without careful reference to worst case or likely case exposure.

5.77 The case study B Environmental Statement refers to the Northern Ireland's Best Practice Guidance to Renewable Energy, which recommends that shadow flicker at neighbouring offices and dwellings within 500m should not exceed 30 hours per year. The ES clearly demonstrates the exposure levels at the affected properties.

5.78 Case study C makes no reference to significance of shadow flicker effects in general or the significance of the predicted shadow flicker levels within the ES, which appear high.

5.79 The case study D (2011) planning amendment refers to the significance of effects but does not define them for the purpose of the report. The shadow flicker report for the reduction in turbine height (2012) does not refer to significance, which makes the interpretation of the assessment findings difficult.

5.80 The case study E Environmental Statement makes reference to significance thresholds in some detail:

'There is no national planning policy or guidance in Scotland which deals with 'exposure' to shadow flicker effects in terms of acceptable of duration. In Northern Ireland guidance recommends that shadow flicker at offices and dwellings within 500m should not exceed 30 hours per year or 30 minutes per day (DOENI 2009). This is based on research by Predac, a European Union sponsored organisation promoting best practice in energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands and Germany. Although there is no policy or guidance which sets out the limits it is generally considered that exceedance of 30 hours over the course of a year or 30 minutes in a single day is considered as significant under the EIA Regulations.'

5.81 However, as with the case study B example noted above, no reference is made to worst case or likely case scenario.

5.82 The case studies make it clear that greater clarity on significance of effects is required and in particular definition of when worst case and likely case scenarios are referred to.

Definition of receptors

5.83 Two of the case study ES both differentiate between financially involved or not financially involved properties.

5.84 Case study A does not make specific reference to receptors and their sensitivity.

5.85 Case study C refers to receptors, making reference to *The Update of UK Shadow Flicker Evidence Base.* The ES refers to the assessment of non-residential receptors, and refers to the varying sensitivity of receptors. The ES states that it does not attempt to vary the sensitivity of receptors, in order to reduce uncertainty created by making assumptions about sensitivity. This highlights the need for guidance on sensitivity of different receptors.

5.86 The case study D planning amendment does not define receptors. The later shadow flicker report relating to the reduction in turbine height identifies receptors based on a ZVI but does not otherwise define them.

5.87 The case studies highlight a lack of clarity in the definition of receptors to shadow flicker, and how this would affect sensitivity to effects. The case studies also raise the issue of the different treatment of financially involved properties, and the challenges of establishing the financial involvement.

Impacts on receptors

5.88 Case study a highlights inconsistencies within the Environmental Report between the text showing the periods when shadow flicker may occur, and the tables showing the length of time each day shadow flicker may be experienced. For example the maximum hours per day exposure to shadow flicker is shown as 0.6 hours (which is 36 minutes) but the times of day shown in the text when shadow flicker could occur (only in the late afternoon) are for time periods of less than 36 minutes.

5.89 The case study B Environmental Statement summary text on shadow flicker excludes reference to financially involved properties, one of which experiences more than 30 hours per year worst case, and 6 hours per year likely case, which is illustrated in the table within the document. It appears misleading to exclude reference to this property in the summary text on the basis of financial involvement. It is unclear how the cumulative shadow flicker has been calculated.

5.90 Case study C assessment of shadow flicker impacts on receptors is poorly presented, with no reference to the types of receptor, the significance of the effect, or to exposure thresholds.

5.91 Comparing the figures presented in the ES with the threshold (identified in the Stage 1 report for this study) of 30 hours per year worst case shows that 15 of the properties experience more than 30 hours per year worst case cumulative effect. It is not possible from the ES findings to identify daily exposure. The ES presents the shadow flicker exposure as total hours and also as a percentage of time, which appears to be an unusual approach.

5.92 Furthermore, the figures in the text about the percentage of time which shadow flicker would be experienced appear to be based on the number of hours in a year, and not the number of daylight hours in a year. Percentage time exposure to shadow flicker at these properties is given as 2.8%, 4.4% and 3.8%. However to put these figures in context, given 8760 hours in a year, the worst case threshold of 30 hours a year equates to 0.34% of annual hours.

5.93 Case study D identifies one property which could experience shadow flicker effects (based on a search area of ten rotor diameters). It is unclear if the levels of exposure to shadow flicker are worst case or likely case, as the text in the shadow flicker report (2011) does not use the terminology 'worst case'. The impacts on receptors are over 30 hours a year, 30 minutes a day. The shadow flicker report for the reduction in turbine height (2012) identifies the property most affected, and worst case the property most affected receives 6 hours of shadow flicker a year, over 26 days, at a maximum duration of 0.20 hours a day, which is not defined as significant.

5.94 The case study E Environmental Statement identifies four properties as having more than 30 hours a year worst case, and three properties as having more than 30 hours a year shadow flicker (realistic –based on sunshine hours only) experiencing 41 hours, 37 hours and 36 hours.

5.95 The ES goes on to add; *'It should be noted that all four properties which could theoretically* [worst case] *experience significant effects are financially involved with the project and three of which are under the ownership of the site landowner'*. The case study also raises additional issues in relation to financial interest of affected properties. For this case study a report (commissioned by the council) reviewing the noise impact assessment, raised queries over some of those properties noted as having a financial interest as not having any formal agreement in place.

5.96 Although carried out in relation to noise, the query over actual financial interest would also appear to apply to all of the properties which could experience shadow flicker for more than 30 hours a year worst case. A condition was included requiring any change of owner or occupier of properties deemed as having a financial interest in the development to be notified to the Planning Authority, and confirmation of continuing financial involvement verified. The condition, although put in relation to noise, also implicitly applies to properties experiencing high levels of shadow flicker, although it is unclear if this is intentional.

5.97 The case studies identify there are a variety of approaches taken to presenting shadow flicker effects. Opportunities to improve the clarity and consistency of the presentation of effects would be helpful in ensuring clear understanding of the results.

Parameters when shadow flicker may occur

5.98 Two of the case studies include text on the parameters when shadow flicker may occur, which reflects that in the Northern Ireland Best Practice Guide, and also refers to the effect of distance on shadow dissipation and proportion of the sun covered by the turbine blade.

5.99 Case study C refers to the parameters required for shadow flicker to occur including turbine dimensions, weather and other mitigating effects and the trajectory of the sun.

5.100 Case study D defines the factors which influence shadow flicker as relevant to worst case experience of shadow flicker for the shadow flicker reports for both 2011 and 2012, but does not define the parameters for shadow flicker to occur in the same way as the other case studies. The shadow flicker report (2012) is the only case study example which refers to the fact that shadow flicker calculations are only made when 20% or more of the sun is covered by the blade (this reflects the WindPRO computer model parameters).

5.101 Case study E Environmental Statement broadly reflects the parameters set out in the other case studies but excludes some of those included in the longer list, as illustrated in Table 5.1 overleaf.

Table 5.1 Parameters used in the case studies to define when shadow flicker may occur

Parameters	Case study A	Case study B	Case study C	Case study D	Case study E
The direction of the residence relative to the turbine(s)	✓	✓	✓		
The distance from the turbine(s)	✓	✓	✓		✓
The turbine hub-height and rotor diameter	✓	✓	✓		✓
The time of year	✓	✓	✓ (trajectory of the sun)		
The proportion of day-light hours in which the turbine operates	✓	✓	x		
The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon)	✓	✓	✓ (weather and other mitigating effects)	Sun is always shining with sufficient intensity to cast clear shadows	✓
The prevailing wind direction.	✓	✓	✓ (weather and other mitigating effects)	Refers to worst case assumption that wind direction is always parallel to the sun-turbine-receptor alignment	
Window sizes and orientations			✓ (taken into account in computer programme)	Properties have windows at north, south, east and west.	✓
Landform and elevation differences between the turbine and receptors			✓(taken into account in computer programme)		
Speed of blade rotation					✓

5.102 The case studies are not always clear on setting out the parameters required for shadow flicker to occur.

Reference to worst case and likely case scenarios

5.103 Two of the case studies provide the likely case and worst case scenario. One case study does not appear to present likely case exposure figures. Case study D identifies that the results in the planning amendment (2011) shadow flicker report are worst case, and the shadow flicker report

for the reduction in turbine height (2012) clearly refers to the worst case scenario. Case study E presents both worst case and 'sunshine corrected' hours [taking only sunshine hours as the additional factor].

5.104 The case studies illustrate the need for clarity in the presentation of both worst case and likely case scenario results. However they also highlight the need to link this to significance, as when levels of exposure to shadow flicker are presented without any discussion of significance, reference to worst case and likely case scenario has less meaning.

Factors taken into account in calculating likely case scenario

5.105 Case study A sets out the same factors for calculating likely case scenario as for case study A below, using location specific data to inform the annual hours of sunlight (35%). The property which experiences 25.7 hours worst case shadow flicker, and is then calculated as 5 hours for the adjusted scenario, which works out at a correction factor of 19% similar to case study B.

5.106 Case study B Environmental Statement sets out the correction factors used in calculating the likely case scenario. These include:

- *Average sunlight hours for the location (32% of daylight hours);*
- *% of time the wind turbine can be expected to turn (90%);*
- *According to the Danish Wind Energy Association website, shadow flicker is reduced to 63% of the maximum possible if the wind turbine is assumed to be randomly yawed relative to the sun position.*

5.107 The shadow flicker report then calculates that 0.32 x 0.90 x 0.63 gives a correction factor of 18%, indicating that likely case shadow flicker is 18% of the calculated total.

5.108 Case study C provides information on what information could be taken into account in the likely case scenario, but does not then appear to apply it. The shadow flicker report mentions a figure of 35% of worst case shadow flicker hours being realistic. Even applying this figure to the predicted hours of shadow flicker, ten of the receptors would still experience in excess of 30 hours a year likely case, well in excess of the 8 hours a year likely case set out in the German guidelines.

5.109 Case study D does not specify factors to take into account in calculating likely case scenario in either shadow flicker report, although it defines the assumptions which inform the worst case.

5.110 Case study E likely case calculations only take sunshine hours into account, and not the percentage of time the blades are rotating, although this is mentioned. The ES references 15% of the time as the blades not rotating, for comparison the case study A example uses 10%. It is unclear from the case studies where these figures are sourced.

How latitude is taken into account

5.111 Latitude is taken into account in the computer modelling.

Computer modelling used

5.112 Case studies A, B and D (2011) used REsoft WindFarm. Case studies C and D (2012) case studies used WindPRO and case study E used WindFarmer.

5.113 The shadow flicker reports for case studies A and E both set out the factors taken into account in the computer modelling. The use of all of the different models illustrates that there does not appear to be a strong preference for the use of one computer model (within the small sample of case studies examined).

Table 5.2 Computer modelling used in the case studies

Case study	REsoft WindFarm	WindFarmer	WindPRO
A	✓		
B	✓		
C			✓

Case study	REsoft WindFarm	WindFarmer	WindPRO
D (2011)	✓		
D (2012)			✓
E		✓	

Cumulative effects

5.114 Case study B includes consideration of cumulative shadow flicker effects with a nearby wind farm. Cumulative receptors are identified as those within 1km of the neighbouring wind farm, and within 1km of the applicant's wind turbines. The two properties are not predicted to show any increase in shadow flicker cumulatively, but it is unclear from the text how the cumulative shadow flicker was calculated. The use of 1km distance for calculating cumulative effects reflects the guidance in the SPG, however it is unclear if this is a direct relationship.

5.115 Case study C presents cumulative shadow flicker in the ES in text form and in tables but it is unclear as to how exactly it has been taken into account.

5.116 Case studies A and D do not mention cumulative impacts in relation to either shadow flicker report. It may be that there are no turbines which could contribute to these, but it is not clear if these have been considered.

5.117 Case study E clearly states that there are no cumulative shadow flicker impacts expected from the proposed development, due to sufficient separation distance from any operational or proposed developments.

5.118 The case studies demonstrate a varied approach to the consideration of cumulative effects and also a lack of clarity and consistency in the approach.

Reference to policy and guidance

5.119 References to policy and guidance were reviewed to identify which documents were informing the approach to shadow flicker assessment within the case studies. Case study A ES only refers to PAN 45 (2002), not the wider range of guidance, however the original application was submitted in 2009, and therefore pre-dates several of the other guidance documents.

5.120 Case study B Environmental Statement refers to the whole suite of relevant guidance: Scottish Executive Planning Advice Note, PAN 45 (revised 2002) (now revoked): Renewable Energy Technologies, the planning authority's Supplementary Planning Guidance, Best Practice Guidance to Planning Policy Statement 18: Renewable Energy, Department of the Environment (Northern Ireland), (2009) and the UK Shadow Flicker Evidence Base, DECC (2011).

5.121 Case study C only refers to the Scottish Government web based Renewables Advice.

5.122 Case study D (2011) refers to PAN 45 (2002), and the UK Shadow Flicker Evidence Base, DECC (2011), but the 2012 shadow flicker report does not refer to policy and guidance.

5.123 The case study E Environmental Statement refers to The Scottish Government web-based guidance on Onshore Wind (2014), replacing PAN 45, the report by consultants Parson's Brinkerhoff for the Department of Energy and Climate Change (DECC 2011) reviewed the UK evidence base on Shadow Flicker and Planning for Renewable Energy: A Companion Guide to PPS 22 (2004).

5.124 The case studies demonstrate a varied approach to referencing other relevant policy and guidance.

Mitigation

5.125 The overall duration and significance of the effect of shadow flicker in case study A Environmental Report is assessed as negligible. The condition applied to the decision takes a precautionary approach which provides protection for any experience of shadow flicker that has not been identified through the assessment process, requiring shut down during conditions conducive to shadow flicker.

5.126 In case study B Environmental Statement no mitigation is proposed. The ES identifies that one property experiences more than 30 hours a year worst case, but that the duration of exposure is below 30 hours a year for the 'realistic' adjustment. This is misleading because the likely case threshold according to the German guidelines should be eight hours, not thirty.

5.127 The report of handling and decision take a precautionary approach and include a standard condition requiring the shut down of turbines following a complaint. Interestingly, the reason given in the report of handling for the inclusion of the condition is given as, '*In the interests of retaining a level of control over any changes in the shadow flicker from the wind turbines, or any differences in the actual shadow flicker from that projected for the site*.'

5.128 The case study C wind turbine appears to generate a high level of shadow flicker. The ES text does not appear to recognise the significance of this potential effect. It states that shadow flicker mitigation is not required in UK policy. The ES text sets out a mitigation strategy which places the burden of proof of the experience of shadow flicker on the receptor and not the developer. The condition included in the decision although covering '*any of the surrounding residential properties to the site of the wind turbine*', does not appear to offer a high level of protection to residents as it refers back to the text in the ES requiring the receptor to log all occurrences of shadow flicker.

5.129 The developer proposed the shadow flicker mitigation for the case study D wind turbine (2011) as only to be implemented in the event of a complaint. Contrary to this, the condition in the decision requires the mitigation for shadow flicker to be implemented before the turbine is operational. This represents greater emphasis by the planning authority on mitigating impacts on the potential receptors, and not in favour of the developer. There is no mitigation proposed in relation to the 2012 shadow flicker report, or in the planning report as the shadow flicker impacts were not assessed as significant [and are below eight hours a year].

5.130 Case study E Environmental Statement explores in some detail possible approaches to turbine shutdown based on predicted shadow flicker and the use of control systems which respond to light conditions. They also refer to vegetation planting and provision of blinds. The development management committee report includes a planning condition requiring the developer to submit a scheme for an operational protocol for the assessment of any complaints of shadow flicker. This is recognised in the development management committee report as not being an ideal condition, but reflecting that of a condition applied by a Scottish Government reporter to another wind farm. As with the previous case studies, this condition appears to attempt to compensate for any deficiencies in the assessment, including the locations affected by shadow flicker occurrence (including locations beyond ten rotor diameters), and deficiencies in the assessment of significance of shadow flicker. However the efficacy of the operational protocol would be dependent on its content.

5.131 The case studies present some clear examples of the planning authorities compensating for the potential deficiencies in the shadow flicker assessment.

Summary of issues from the case studies

5.132 To summarise the issues from the case studies:

- Apparent differences in the ways information is presented in different parts of the shadow flicker report.
- Frequent mis-application of the 30 hours a year worst case threshold for experience of shadow flicker as a likely case threshold (therefore underestimating the significance of impacts, as it should be 8 hours likely case if referring to the German guidelines).
- Some variation in distance thresholds applied in guidance documents (SPG for two of the case studies use distances greater than ten rotor diameters), but general use of ten rotor diameters within ES (with one exception which uses a ZTV to identify receptors). This illustrates a reversion to national guidance over local guidance documents.
- Use of the ten rotor diameter threshold as a limit, not an approximate distance within the shadow flicker assessments.
- Lack of reference to what levels of shadow flicker are 'significant' within assessments.

- Differentiation between discussion of significance shadow flicker effects at financially involved and not financially involved properties (reflecting what is common in noise assessments).
- Lack of clarity in how cumulative effects of shadow flicker are calculated.
- Variation in the factors taken into account in calculating 'likely case' scenarios, and how this is actually calculated, (definite need for guidance to make this more consistent).
- Variation between planning authorities in approaches to conditions. Example of one case study taking a precautionary approach to the robustness of the assessment results and applying conditions to allow issues of future shadow flicker to be addressed even where predicted effects are negligible. The case study E example also provides a 'catch all' condition which allows any future complaint to be addressed. Another example (case study C) where the condition simply repeats proposed mitigation from an ES which seems heavily biased against any potential receptors providing a burden of proof.

Interview findings

5.133 The interviews were based around the emerging conclusions from the Stage 1 literature review and informed by the results of the case study review.

Definition of shadow flicker

5.134 All of the respondents agreed a need for a clear definition of shadow flicker in order to provide clarity and consistency. One respondent noted that the definition needs to clarify indoor effects and outdoor effects, and that clarity on the parameters where shadow flicker is likely to occur would be useful including reference to latitude.

5.135 Another respondent noted use of the definition in the Scottish Government Guidance and lack of awareness of the inconsistency between documents.

Definition of shadow throw

5.136 The respondents for two case studies did not have experience of the issue of shadow throw. One respondent suggested that it would need to have an amenity impact if it was something to be further explored. An EHO agreed it would be helpful to have a definition and know how to deal with it.

5.137 One of the case study EHO has received complaints regarding what would be termed shadow throw. Some residents complain/comment on shadow throw affecting their enjoyment of their garden or the effect on roads/driving. Some residents also comment that their horses are adversely affected/spooked. It was suggested that residents may consider shadow throw to be shadow flicker and that further clarification would help.

Night time lighting

5.138 One development planner was not aware of issues relating to night time lighting, but mentioned the night time impacts of shadow flicker from the Little Raith wind farm and the Mossmorran flare stack.

5.139 A development planner had no experience of complaints regarding night time lighting post development, although he noted that this is a concern when developments are proposed. It was noted that these impacts are easily mitigated through the use of infrared lighting.

5.140 An Environmental Health Officer noted that they had received adverse comments in respect of the lighting used on the top of the nacelle for aircraft warning purposes. Giving the example of a very small number of cases commenting that this lighting makes them feel "uneasy" in the dark and that it is like "two eyes" looking down on you.

Acknowledgement of reflected light issues

5.141 One respondent was not aware of any examples of reflected light issues and suggested that it was not a planning issue, pertaining to amenity or safety, and questioning the different between light

reflection from a wind turbine and any other structure. It was also suggested that if the SNH guidance provides coverage of this issue, there is perhaps not a need for further guidance.

5.142 One of the case studies had not received any complaints regarding reflected light but noted that they routinely request a matt finish in conditions for wind turbine developments.

5.143 Another respondent was aware of a complaint relating to reflected light from a nearby wind turbine, and agreed that acknowledgement of reflected light issues would be helpful.

10 rotor diameter distance

5.144 Both the development planner and Environmental Health Officer (EHO) for one case study suggested the guidance could remove the reference to ten rotor diameters, because they were aware of examples of shadow flicker at greater distance. It was suggested it would be appropriate to have more of an evidence based assessment with a focus on factors which influence shadow flicker such as topography and wind direction.

5.145 A development planner felt that references to this distance should reflect what is proportionate and effective.

5.146 An EHO was used to working with the ten rotor diameter distance as a limit and agreed it would be useful to have clarity on this in the guidance.

5.147 One of the respondents identified a case study example[47] of shadow flicker being reported and confirmed beyond ten rotor diameters distance from a development.

Case Study example of shadow flicker beyond ten rotor diameters

Full planning permission was granted for the erection of a small wind farm comprising turbines of 80m rotor diameter.

For the original turbines the closest was 1540m from the property experiencing shadow flicker. The resident of this property stated that they experienced shadow flicker on a significant number of occasions.

Several extensions to the wind farm were approved subsequent to the original application resulting in a development of twice the number of turbines in the original planning application. The extensions comprise turbines with the same hub height, tip height and rotor diameter as the original planning application.

The extensions brought three turbines to within 1km of the complainant. One turbine is located 790m from the complainant – 10m within the 10 times rotor diameter.

Shadow flicker monitoring was undertaken by the operator at the affected property for the period between the months of October and February.

This recorded a large number of shadow flicker events – on a small number of days up to three shadow flicker events were recorded, therefore shadow flicker was being caused by more than one turbine.

The total recorded shadow flicker in the recording period was less than twenty hours. The duration of the individual shadow flicker events are all less than 30 minutes.

Reference to the degrees either side of north affected by shadow throw

5.148 A development planner agreed that clarity was needed on the use of this threshold but that there could be a definition of the area where impacts would not occur.

5.149 Two respondents were not aware of 130 degrees either side of north being used as a cut off.

Thresholds for exposure to shadow flicker

5.150 A development planner expressed caution over the definition of significance, which is subjective, as different individuals have different tolerance. They identified that if figures are provided then

[47] As the example is subject to an ongoing complaint the case details have been anonymised.

the reasoning behind how the significance figures are arrived at needs to be robust. They agreed guidance on thresholds of significance would be helpful when dealing with complaints, particularly at a later date. Shadow flicker can always be mitigated, and the concern would be if shadow flicker shut down was going to affect the overall productivity of the turbine (this approach is used in relation to noise, if significant periods of shutdown will negate the operation of the turbine then an application is recommended for refusal). Thresholds would need to be set out within the Scottish Government guidance.

5.151 An Environmental Health Officer (EHO) noted they would welcome clarity on what constitutes significant shadow flicker as this would improve consistency in assessment and consistency in review.

5.152 A development planner suggested that if the German guideline for thresholds of exposure has been robustly tested and is applicable in this country then this would be reasonable, and another agreed that it would be helpful to have information on significance thresholds set out in the guidance.

Financially interested properties

5.153 A development planner noted that financial interest shouldn't count in shadow flicker, because as with noise, the financial interest can change and there is often a lack of verification of a stated financial interest.

5.154 Another development planner suggested that the treatment of financially interested properties should be on a case by case basis.

'In most instances they could be provided with mitigation by the applicant as part of any agreement they had. Noise is different as this could make a dwelling uninhabitable or cause serious health issues. If shadow flicker was likely to be so bad that it would have the same impact then criteria would be needed.'

5.155 An Environmental Health Officer agreed it would be useful to have some clarification on how to define and treat financially interested properties and the overlap of this issue with noise.

Definition of different types of receptors to light and shadow related effects

5.156 A development planner noted that sensitive receptors are classed as dwellings but many people live and work in the rural area of the planning authority. There are many rural businesses and shadow flicker could impact on these. It is important to draw out the potential impacts on rural business but perhaps no need for further research into sensitive receptors.

5.157 An Environmental Health Officer agreed there needs to more clarity regarding different types of receptor and how to consider individuals who are sensitive to changes in light, epilepsy, mental health illness, etc. Also, with many people now working/employed in their own home or in a rural environment some clarity on whether these types of receptor should be considered would be helpful, and suggested possible different thresholds of significance.

5.158 An Environmental Health Officer suggested that they would treat hospital/school as same sensitivity as residential, but that more guidance on sensitivity of receptors would be helpful.

Definition of parameters when shadow flicker may occur 'Likely case' modelling

5.159 A development planner agreed that it would be useful to include a clear statement of the parameters required for the occurrence of shadow flicker and the factors then used in likely case scenario calculation.

5.160 Another development planner agreed there was a need for consistency in the presentation of likely case and worst case and that it makes it easier for development management to assess. It was noted that the severity of impacts presented in assessments can change in significance from the assessment through to the conclusion. Planning officers are aware of the issues surrounding the presentation of results and add conditions accordingly. It was specifically recommended that in calculating likely case scenarios it would be important to add topography or the elevation of the turbine above the receptor.

5.161 An EHO supported the need for very clear guidance on how a shadow flicker assessment should be done and presented. Noting that currently, unless local authorities have the proprietary modelling software, they are unable to replicate consultants shadow flicker assessments and are therefore very much constrained into accepting assessments at face value. It was highlighted that as with noise impact assessments for wind turbines, the acceptance of reports at face value is highly likely to mean acceptance of a poorly undertaken and often inaccurate assessment. They made the following suggestion to address this issue:

'*I think it would help enormously if the Scottish Government could provide free to use (or subsidised) simple modelling tools to local authorities to enable consultants' assessments to be checked and properly appraised (e.g., similar to the freely available tools provided for basic air quality assessment purposes).'*

5.162 An EHO noted they usually dealt with 'reasonable worst case'. The respondent agreed that clarity on the factors to take into account and how to identify likely case scenario would be helpful.

Greater reliance on distance thresholds set out in national guidance than local guidance

5.163 A development planner commented that the guidance in the planning authority dates from the middle of the last decade, and several parts of the guidance are effectively out of date as they do not refer to the current evidence base. The distance threshold used in the guidance is not referenced as to how this figure was identified. An EHO explained the greater reliance on distance thresholds in national guidance than local SPG as what would normally be held up at inquiry.

Cumulative effects

5.164 The respondents did not have any experience of complaints where there are cumulative issues, but agreed that guidance on cumulative effects should be provided to ensure consistency. It was noted that as sites become more tightly packed together (due to availability of land) that cumulative issues may become problematic.

Mitigation

5.165 One of the case studies applies a model condition to address shadow flicker (and to compensate for lack of specialist knowledge) to most large wind turbine planning consents. It was also indicated that it would be helpful to determine where the expertise should lie (i.e., with Planning staff or Environmental Health staff) and whether shadow flicker is a public health issue or solely an amenity issue.

5.166 Another respondent suggested that the planning authorities include the 'catch all' condition in relation to shadow flicker simply to cover all bases, and that as a technical issue, planners are reliant on advice from Environmental Health on shadow flicker.

Public perceptions of light and shadow effects

5.167 The second part of the Stage 2 focuses on academic and grey literature relating to public perception of light and shadow effects. Issues to considered include:

- The extent to which non-specialists understand the difference between shadow flicker, other light related effects and wider landscape and visual effects.
- A review of the way that shadow flicker and other light related wind turbine effects are addressed in the grey literature. This will include identification and review of media articles, material produced by groups opposing wind developments, material produced by wind energy developers and trade associations and materials published by 'neutral' third party organisations (e.g. British Horse Society)

5.168 The search for relevant literature sources to inform Stage 2 of the project identified some challenges in relation to finding relevant documents which refer to shadow flicker. Shadow flicker is a marginal topic area for which there is a limited recognition and reporting. In relation to impacts on the public, the other impacts arising from wind turbines are typically of greater magnitude than those for shadow flicker and receive greater levels of coverage.

5.169 The literature search for stage 1 of the study also provided coverage of the issues in relation to the way people experience, perceive and are affected by light and shadow effects (which was originally intended to form part of Stage 2).

Media articles

5.170 A small number of media articles have been identified through the Stage 2 literature review in relation to shadow flicker, these include articles referring to wind turbines and shadow flicker in general, and those referring to specific wind farms and issues experienced at those locations.

5.171 An article reported in *The Guardian*[48] in 2012 refers to guidance and the distance shadow flicker can be experienced '*Planning guidelines state that shadow flicker can impact on residents who live within a distance 10 times greater than the blade's diameter*.' The article also explores the frequency of flicker produced by large turbines and how this flicker is lower than that required to trigger seizures. It also states that '*there is limited scientific evidence of association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects*'. However this article demonstrates the repetition of duration of experience of shadow flicker (30 minutes a day) without defining whether this is worst case or likely case exposure.

5.172 An article in *The Telegraph*[49] describes shadow flicker as an occurrence through constrained openings such as windows, and notes that the scale of the problem depends on a number of factors such as wind speed and direction, the position and point of the sun, and cloudiness. It also refers to the limited occurrence of shadow flicker, and the effectiveness of mitigation, in particular turbine shut down systems. This illustrates recognition of the factors influencing the occurrence of shadow flicker and the effectiveness of mitigation if correctly applied.

5.173 A related article[50] also in *The Telegraph* sets out the different impacts of wind turbines covering noise, flicker, blade glint and radiation. It explains that shadow flicker has not been found to have health effects, but that it can cause 'significant nuisance'. In relation to blade glint it reiterates that this is no longer an issue due to paint finishes used by manufacturers.

5.174 An article relating to one experience of shadow flicker in Ireland[51] reported in *The Journal* does not mention any other light related effects, but reports on the shadow flicker within a household located within a reported 330m of a wind turbine. The article reports the respondents as saying they were not warned about the shadow flicker from the wind farm, and that they experience significant negative effects from the shadow flicker. It is reported that the whole house is affected during a shadow flicker occurrence, and that blinds provide insufficient mitigation. They also note that complaints to the wind farm operator have not resolved the shadow flicker issues. Interestingly, the same article also refers to the noise experienced from the wind farm, and indicates that noise levels are quite intrusive. This potentially supports the previously identified link between shadow flicker nuisance and noise.

5.175 An article produced by PagerPower also relates the issue of shadow flicker relating to flare stacks at Mossmorran and Little Raith wind farm in Fife[52]. This article highlights the occurrence of shadow flicker in relation to the flare stack, and that unlike shadow flicker from the sun, the light source does not move relative to the receptor. Although this is a very location specific issue, the article highlights the need to consider other sources of shadow flicker. The article makes reference to distance, but states that the affected zone of shadow flicker from a non-moving points source '*may be more or less than ten times rotor diameter.'*

[48] Wind Myths: turbines can damage your health 28th February 2012 https://www.theguardian.com/environment/2012/feb/28/wind-turbines-damage-health

[49] Shadow Flicker: rotating blades can cause headaches 17th March 2011 http://www.telegraph.co.uk/news/earth/earthnews/8386273/Shadow-flicker-rotating-blades-can-cause-headaches.html

[50] Can wind farms really make you ill? The evidence 17th March 2011 http://www.telegraph.co.uk/news/earth/earthnews/8386397/Can-wind-farms-really-make-you-ill-The-evidence.html

[51] The Journal '"It's a disaster": Family affected by windfarm's turbine flicker ' February 7th 2015 http://www.thejournal.ie/athea-wind-farm-1915304-Feb2015/

[52] Flare Stacks and Wind Turbine Shadow Flicker D Scrivener (undated) available at: http://www.pagerpower.com/news/wind-turbine-shadow-flicker-flare-stacks/

5.176 A review of the public information on Binn Eco Park Wind Farm includes a supporting document on the benefits of the proposal[53]. However there are no references to the environmental impacts of the wind farm within this document which focuses solely on the economic and climate change benefits. Associated newspaper coverage of the decision[54] did not make reference to shadow flicker, although health risk, noise nuisance and impacts on the environment were mentioned.

Wind farm opposition groups

5.177 A search of wind farm opposition group material on shadow flicker was also undertaken. *Save Straiton for Scotland* raised specific concerns about the misrepresentation of shadow flicker from Linfairn Wind farm[55]. A member of the group undertook a critical review of the shadow flicker report for the wind farm. The text raises specific concerns relating to the parameters applied in the calculation of the shadow flicker extent from Linfairn Wind Farm, which are limited to ten rotor diameters. The commentary highlights that the ten rotor diameter threshold was used as a cut off in the calculation of the extent of shadow flicker, and that particularly in the case of this wind farm located at the south end of a valley, with the majority of properties at a lower altitude than the wind turbines, the extent of shadow flicker is greater.

5.178 A wind farm action group in Wales[56] makes more generic references to light and shadow effects. Text on the website includes '*The strobe effect when sun is behind the rotating blades can, according to medical opinion, cause dizziness, headaches and trigger seizures*.' This conflicts with the current evidence which concludes that the frequency of modern larger turbines does not trigger epileptic seizures. It follows this statement with, '*Shadow flicker and reflected light from the blades can also cause problems. These light disturbances are experienced inside the home as well as outside*,' but does not provide comment on what problems are caused or the distances at which they may be experienced.

5.179 Wind Aware Ireland[57] sets out the social, economic and environmental impacts of wind turbines. In relation to shadow flicker, the website quotes the Minnesota Department of Health (2009) stating that shadow flicker can be an issue both indoors and outdoors. It misquotes that in England the recommended shadow flicker setbacks for current wind turbine designs are 10 rotational diameters. It also states examples of seizures induced by wind turbines on small wind farms in the UK, and that '*anecdotal evidence would suggest that shadow flicker causes stress and annoyance*'.

Developers and trade associations[58]

5.180 The Irish Wind Energy Association[59] website provides a summary of the environmental impacts of wind energy. In relation to shadow flicker it states, *'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.'* This appears to support the use of ten rotor diameters as the assessment area, and not looking beyond this area. It also states '*A guideline of not more than 30 hours of shadow flicker per year is suggested for dwellings,*' without defining if this is worst case or likely case.

5.181 The Danish Wind Energy Association[60] includes information on shadow flicker, within a wider discussion of setback distances in relation to noise. '*It is recommended that the calculated average of shadow hours on neighboring houses do not exceed 10 hours per year. If the shadow*

[53] http://www.elpower.co.uk/sites/www.elpower.co.uk/files/subpage/binn_eco_park_wind_farm_-_supporting_document.pdf

[54] https://www.thecourier.co.uk/news/local/perth-kinross/251443/locals-angered-after-councillors-overrule-advice-in-approving-binn-eco-park-wind-turbines/

[55] Save Straiton for Scotland Misrepresentation of Shadow Flicker for Linfairn Wind farm J.S. Nolan, supporter Save Straiton for Scotland, Feb 2015 https://savestraiton.files.wordpress.com/2015/02/appendix-vii-misrepresentation-of-shadow-flicker-for-linfairn-wind-farm.pdf

[56] Mynedd Llansadwrn Action Group http://www.turbineaction.co.uk/wind-turbine-issues/shadow-flicker-and-strobe-effect-even-indoors.html

[57] http://www.windawareireland.com/social-issues/

[58] The British Wind Energy Association Renewable UK, and the European Wind Energy Association did not yield any results for searches in relation to shadow flicker on their websites.

[59] http://www.iwea.com/index.cfm/page/environmentalimpacts#q72

[60] http://www.windpower.org/en/policy/plannning_and_regulation.html

limit is exceeded the wind turbine owner may alternatively be required to shut down the wind turbine in critical periods'.

5.182 A document on the above website titled *Technological solutions to reduce the environmental impacts of wind energy systems*[61] includes comment on the coating of wind turbine blades with a matt surface to avoid issues of light reflection. In relation to shadow flicker it states that, '*In Denmark the distance from the wind turbine to the house should be less than 2 km to qualify as shadow flicker. The guideline in Denmark is that up to 10 hours per year is tolerated. For nearshore wind farms it has no practical relevance due to the distance.'*

Other material

5.183 The British Horse Society (BHS) carried out a survey[62] in 2012 of equestrians' experiences with wind turbines in order to inform the BHS response to proposed turbine developments as well as informing BHS policies and guidance to developers. This survey informed the preparation of a Scottish Wind Farm Advice Note[63] by the BHS. The survey and advice note recognise that there are many factors relating to wind turbines which may startle or unsettle a horse, including the noise and sight of the moving blades. The survey also identified horses' reaction to shadows on the ground where a horse is required to pass, and reactions varied from taking little notice to fearful. The British Horse Society has a particular focus on safety, and in relation to distance at which shadows are experienced states within the Advice Note that '*shadows can affect ground a considerable distance from the turbine at certain times of day or year, when the sun is very low*'.

5.184 Therefore no specific mention of distance which shadows from turbines can be experienced is made. The only references to distance are for set-back distances relevant to turbine failure.

5.185 A survey carried out by the University of Ulster and Chartered Institute of Environmental Health (Ireland)[64] assessed community views on wind energy generation focusing on perceptions of environmental quality by the residents of two neighbourhoods, one situated within 3km of an operational wind farm site and the other situated within 3km of a proposed wind farm site. The respondents in Site 1 (proposed site) were asked to rate their concern about a number of issues related to wind farms on a scale of 1 to 5. 70.9% of respondents were not concerned at all about noise during construction. 60.9% were not concerned at all about Radio or TV signal interference. 67.3% were not concerned at all about shadow flicker effect. No information on shadow flicker on the operational wind farm site was recorded.

Stage 2 Conclusions

Understanding the difference between shadow flicker, other light related and wider landscape and visual effects

5.186 The literature review did not identify any confusion between shadow flicker and other light related and wider landscape and visual effects among non-specialists. The Stage 1 literature review did however identify the relationship between the experience of noise and annoyance related to wind turbines. This was also identified within another article by the Journal of the Acoustical Society of America (2016) on annoyance associated with shadow flicker and experience of wind turbine noise[65]. This article suggested that experience to one type of impact (noise) from wind turbines may also increase sensitivity to other impacts. In addition setback distances for wind turbines in relation to noise are also sometimes referred to in text which refers to shadow flicker. Therefore the interrelationship between noise and shadow flicker is related, but presents opportunities for further misinterpretation.

5.187 From the articles reviewed evidence was not found for any consistent misunderstanding in relation to shadow flicker by non-specialists. However the one of the respondents suggested there was some confusion of shadow flicker and shadow throw.

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[61] Report from Megavind (2016) Technological solutions to reduce the environmental impacts of wind-energy systems

[62] www.bhs.org.uk/~/.../bhs/.../wind-turbine-experiences--bhs-2012-survey-results.ashx?...

[63] www.bhs.org.uk/~/media/bhs/files/.../wind-farms-in-scotland--bhs-advice-note.ashx?...

[64] University of Ulster and Chartered Institute of Environmental Health (Ireland) (2012) Living with Wind Turbines an investigation into public perceptions and experiences of affected communities

[65] The Journal of the Acoustical Society of America, (2016), Estimating annoyance to calculated wind turbine shadow flicker is improved when variables associated with wind turbine noise exposure are considered.

Presentation of shadow flicker and other light related turbine effects in the media / organisation publicity material

5.188 It is apparent that there is some innate confusion over the application of the ten rotor diameter distance, and variation in its use as a threshold (whereby the interpretation is that significant shadow flicker effects will not be experienced beyond this distance, and therefore are not assessed beyond this distance) or a guideline (the most significant shadow flicker effects will be experienced within this distance, but shadow flicker may also be experienced beyond this distance).

5.189 The minor changes to the language in various guidance documents when referring to the ten rotor diameter distance have led to its original meaning being altered in some instances, and in the propagation of this through various types of documentation.

5.190 As concluded from the Stage 1 literature review, there is a lack of evidence to support the use of ten rotor diameters as a cut off, and this is entirely down to misinterpretation of the original reference to this distance.

5.191 The case study review has added further evidence to the issues identified from the literature review surrounding the definition and approach to the assessment of light and shadow flicker in the planning process and the presentation of these effects.

5.192 No evidence was found of alternative presentation of shadow flicker issues in engagement and consultation with residents, and evidence was not found on the extent to which light and shadow effects and impacts are features in pre-application consultation with residents. The literature review in particular explored the evidence for how residents understand and perceive light and shadow effects.

5.193 The study did not identify evidence on the extent to which public perceptions of shadow flicker match predicted and actual effects.

6 Conclusions and Recommendations

Stage 1 and 2 conclusions and recommendations

6.1 This section of the report sets out the combined conclusions from Stage 1 and 2 of the study, drawing together the findings from the literature review, case study analysis and interviews and specifically exploring:

- recommendations on the content of draft planning guidance on light and shadow effects;
- the definition of light and shadow effects and significance of impacts;
- the assessment of light and shadow effects and significance of impact; and
- the communication of light and shadow effects and impacts with residents.

General conclusions

6.2 The literature review has highlighted the risks associated with government guidance documents repeating information from other sources, without full investigation of the original source documents. Guidance documents should include reference sources where appropriate, particularly to support recommendations, or guidance documents should be supported by a more detailed research report.

6.3 Accuracy of the repetition of information from source documents also needs to be ensured, as highlighted by the issues associated with the German exposure thresholds where the omission of reference to 'worst case' or 'likely case' is critical.

Recommended content of guidance on shadow flicker

Recommendation 1: Definition of Shadow Flicker

6.4 There needs to be consistency between guidance documents and planning policy on the definition of shadow flicker. The most widely used definition of shadow flicker within guidance documents is as follows:

"Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the ***effect or impact*** *is known as "shadow flicker*".

6.5 Based on the review of shadow flicker definitions the above definition is identified as covering the key aspects of shadow flicker, and aligned with the definition in national guidance documents, and therefore appropriate.

Recommendation 2: Definition of Shadow Throw

6.6 The literature review identified that experience of shadows outdoors is not clearly recognised within policy and guidance, and the case studies identified limited reference to this effect. The extent to which shadow throw is an issue in Scotland is potentially limited, however for clarity shadow throw (also referred to as 'passing shadows') should be defined. A definition of the outdoor effects of light and shadow related effects was not identified within the guidance, and has emerged from the literature review and review of SPG. A possible definition is '*a moving shadow across open ground'*.

6.7 As noted in the earlier conclusions for Stage 2, the definition of the impact of shadow throw in terms of impacts on safety, amenity or nuisance may influence how this effect is dealt with in the planning system.

Recommendation 3: Acknowledgement of reflected light issues

6.8 It is recognised that reflected light issues are not identified as a significant issue within the guidance documents, literature or case studies. For completeness, guidance should include acknowledgement of the issue of reflected light, which can be most apparent under wet or icy conditions. It should refer or cross reference to the use of paint colour and surface finishes which reduce this effect, as in the SNH guidance.

Recommendation 4: Night time lighting

6.9 No specific issues associated with night time lighting were identified in the study, other than the inclusion of a condition relating to this in one of the case studies, and some reference in the interviews to this being raised as a minor issue. The guidance could acknowledge impacts of night time lighting through cross reference to Scottish Natural Heritage guidance[66]. With increasing turbine size in new and repowered wind farms, it is more likely that schemes will trigger requirement for lighting under CAA or MOD rules. This requirement may be satisfied by infrared lighting but in some cases visible red flashing or constant lighting may be required. It is recommended that guidance should clarify the likely requirement for visible lighting, and how potential landscape and visual effects should be addressed.

Recommendation 5: Definition of parameters when shadow flicker may occur

6.10 The guidance should explicitly set out the parameters when shadow flicker may occur and which are required for likely case scenario modelling. The bullet points in the Northern Ireland Best Practice Guide to PPS18 identify some of these parameters, the parameters are also identified by Pager Power (see Appendix 1), and the case study review identified some additional parameters. These are identified as follows.

6.11 Parameters affecting the occurrence of shadow flicker:

- The direction of the residence relative to the turbine(s).
- The distance from the turbine(s).
- The turbine hub-height and rotor diameter.
- Blade width.
- The time of year.
- The proportion of day-light hours in which the turbine operates.
- The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon).
- The prevailing wind direction.
- Window sizes and orientations.
- Landform and elevation differences between the turbine and receptors.
- Speed of blade rotation.

6.12 In relation to calculating likely scenario, percentage operational time (dependent on wind strength and operational maintenance factors) can be applied to the final figure of the quantification of hours / day or / year that effects could occur and is not required to be part of the model calculations.

6.13 The study found that some of the modelling software allows incorporation of factors which will generate a more realistic outcome, but others require these factors to be calculated and applied to the modelled ‘worst case’ result.

6.14 There appears to be significant variation in the factors taken into account when calculating ‘likely case’ or ‘realistic’ shadow flicker, and the case study review identified a lack of clarity in presentation of findings. The guidance should explicitly set out the parameters which are required for likely case scenario modelling.

[66] Scottish Natural Heritage (2014) Siting and Designing Wind Farms in the Landscape Version 2.

6.15 Use of a matrix would allow the shadow flicker assessment to note what factors have been taken into account in the calculation, whilst clearly set against a standard list. An example of the factors included in the case studies is provided in Table 7.2 below.

Table 6.1 example matrix showing factors taken into account in calculating likely case scenario based on case study examples.

Factors influencing occurrence of shadow flicker likely case scenario calculation	Sources of data in case study examples
Average sunlight hours for the location	EU funded Satel-Light European Database of Daylight and solar radiation Met office data for nearest location Figures cited in the shadow flicker assessments are in the region of 35% of daylight hours being sunshine hours
Average % of time the turbine is operational	Cited in examples as 90% and also 85%. It is unclear if this reflects maintenance downtime only.
Yaw angle	This can be location specific based on wind direction data (which would give a different likely case factor for different receptors, depending on their location), or an assumed factor based on random yawing (taken from Danish wind energy website as 63%)

Recommendation 6: Reference to the degrees either side of north affected by shadow throw

6.16 Although the Scottish guidance does not refer to the parameter of 130 degrees either side of north, some of the case study examples referenced this figure, in line with other UK guidance. However, it was unclear how or if it was applied to the case studies. The review of the computer models identified that latitude is an integral element of the calculation, and therefore so long as no steps are taken to exclude properties which fall outside of this, the modelling will allow for any factors relating to latitude.

6.17 Scottish guidance should not include reference to the occurrence of shadow throw 'within 130 degrees either side of north'. In line with the recommendation that shadow flicker assessment should be based on significance thresholds, guidance should avoid reference to limiting the area of assessment. It may be appropriate to include explanation that the pattern of shadow effect varies with latitude and modelling will clarify the area of shadow effect from a wind turbine.

Recommendation 7: Exclusion of reference to the 10 rotor diameter distance

6.18 Although a number of other factors may contribute to the significance of shadow flicker potentially being greatest closer to the wind turbines, the ten rotor diameter distance threshold does not appear to have robust evidence within the literature examined.

6.19 Secondly, there is frequent misapplication of the ten rotor diameter distance as a limit within which shadow flicker modelling is applied. Although it is recognised that shadow flicker effects may be greatest within the ten rotor diameter distance, assessment of cumulative effects needs to consider properties beyond this distance.

6.20 There was some variation in the distance thresholds applied in guidance documents relevant to the case studies (two sets of supplementary guidance use distances greater than ten rotor diameters), but a general use of ten rotor diameters to limit the assessment of shadow flicker

within environmental statements (with one exception which used a zone of theoretical influence to identify potential receptors, but the distance the shadow was calculated for appears to be 2km). This illustrates a reversion to national guidance over local guidance documents and therefore it is not possible to ascertain if shadow flicker effects beyond ten rotor diameters are occurring for the case studies.

6.21 Scottish guidance should not include reference to the ten rotor blade diameter distance in relation to shadow flicker due to the misapplication of this figure even when presented in current guidance as the area where impacts are most likely to occur. It appears more appropriate to identify the factors which influence when shadow flicker is more likely to occur and when it is less likely to occur, based on local conditions. The guidance should focus on avoidance of harm and nuisance, which should be established by exposure thresholds, and not on limiting the area of assessment.

Recommendation 8: Thresholds for exposure to shadow flicker and use of worst case and likely case scenarios

6.22 The German guidelines are clear on the exposure thresholds for both worst case and likely case scenarios of 30 hours per year or 30 minutes a day worst case and eight hours a year likely case. These thresholds are most widely quoted, although some countries have set their own limits. It would be potentially useful to engage in more detailed discussions with officials in Belgium and Netherlands to understand the origins of the thresholds they use. Discussions with German officials may allow identification of the origin for the 20% coverage of the sun threshold quoted.

6.23 There appears to be a lack of clarity within existing guidance and literature on when worst case and likely case predictions are referred to, and this was reflected in the case studies. Guidance documents referring to exposure thresholds for shadow flicker must be explicit in their reference to limits relating to worst case and likely case scenarios. The German approach is based on setting significance thresholds based on exposure thresholds, and not on a generic distance threshold.

6.24 The origins of the German thresholds for significance of exposure are based on findings from a laboratory study which measured the stress response of adults exposed to shadow flicker. However the scale of this study was limited in extent, and the study was noted in another literature source as not having been published in a peer reviewed journal.

6.25 Furthermore, using exposure thresholds relies on accurate prediction of shadow flicker by the computer models, and ensuring the modelling is not unnecessarily limited.

6.26 Of the three computer models which are widely used in relation to shadow flicker, only WindPRO was identified as allowing for likely case scenario modelling. Therefore any requirements within guidance for likely case scenario modelling would have a significant impact on the use of the different models.

6.27 The case study review has identified inconsistency in the definition and application of ‘significance’ in relation to predicted shadow flicker both worst case and likely case. This is reflected both in the presentation of shadow flicker results and in their interpretation by planners. Due to the lack of guidance on significance, the case study review found that planners are in a difficult position when reviewing shadow flicker assessment findings, even when the findings are presented clearly.

6.28 In the majority of the case study examples the planning authority compensates for any flaws in the assessment process through the use of a precautionary condition which allows for mitigation of any shadow flicker, even when the assessment suggests no significant impacts. In one example there is greater reliance on the ES findings and the proposed mitigation within this.

6.29 The interviews identified support for guidance on assessing the significance of shadow flicker effects. Guidance on significance would need to be used to support the required mitigation. If turbine shutdown is required this may need to be combined with any shut down required in relation to noise to identify potential impacts on the overall productivity of the turbine.

Recommendation 9: Definition of different types of receptors to light and shadow related effects

6.30 The case study review identified that there needs to be clarity on the different approaches to assessing significance of levels of effect at financially involved properties. This is an established

difference in noise assessment, however it is unclear how appropriate this is in relation to shadow flicker, particularly in light of the lack of clarity in assessments on 'significance'.

6.31 The study review was inconclusive in relation to the definition of different types of receptor based on other variables and their sensitivity to light and shadow related effects. There was some reference to residential and business use, and the interviews highlighted the need to consider impacts on rural businesses.

6.32 There is a need to include guidance on different factors which may affect the sensitivity of different types of receptor to light and shadow related effects.

Recommendation 10: Approach to assessing cumulative effects

6.33 The study found limited reference to the identification and assessment of cumulative effects, however it was identified as an issue covered in the case studies and an area where there was a lack of clarity or consistency in approach. The guidance should set out the need to consider cumulative shadow flicker and further guidance on how this should be approached.

Summary of recommendations

- The guidance should define shadow flicker.
- The guidance should define shadow throw.
- The guidance should refer to reflected light issues and night time lighting, with reference to SNH guidance.
- The guidance should set out the parameters when shadow flicker will occur and factors to be taken into account in calculating likely case scenario.
- The guidance should not include reference to 10 rotor diameter distance, reflecting that this has been misinterpreted.
- The guidance should not include reference to 130 degrees either side of north, as it potentially limits the assessment area, although this effect is unlikely to be significant.
- The guidance should outline significance thresholds to apply to shadow flicker assessment results.
- The guidance should advise against the use of factors which may limit the area of assessment, prior to identifying potential significance, and ensure the consideration of site specific factors such as topography.
- The guidance should provide clarity on the approach to financially involved properties, however this may be an issue best addressed primarily in relation to noise impacts from wind turbines.
- The guidance should provide structure for undertaking shadow flicker assessments to assist planners and environmental health officers in the review and interpretation of these findings.
- The guidance should provide a recommended approach to identifying receptors and the different types of receptor which may be affected by shadow flicker.
- The guidance should outline an approach to assessing cumulative shadow flicker.

Role of plans and Supplementary Planning Guidance

6.34 The case study review identified very limited reference to shadow flicker within the local plans examined, with only one of the local plans making passing reference to the issue.

6.35 The supplementary planning guidance and other local authority guidance relevant to renewable energy demonstrated variation in the detail and coverage of issues relevant to shadow flicker. For example the definitions of shadow flicker were not all consistent with those used in the national planning guidance documents.

6.36 In relation to the issues surrounding separation distances and the use of the ten rotor diameter distance, the majority of the SPG demonstrate the correct terminology without changing the original intended use of the distance as a guideline, not a cut-off. Two of the SPG also included text relating to the variability of separation distances and specific reference to topography. This is an important point of detail as issues relating to the influence of topography on increasing the distance at which shadow flicker may be experienced have been raised as a potential issue.

6.37 None of the SPG explored significance thresholds in relation to shadow flicker, which highlights a key gap in the interpretation of shadow flicker effects. In relation to the definition of receptors, some of the SPG attempted to define sensitive locations, but provided limited detail.

6.38 The SPG did not explore issues around the parameters when shadow flicker may occur, worst case and likely case scenarios, issues associated with latitude and cumulative effects, beyond only cursory references.

6.39 Three of the SPG provide specific text on mitigation which demonstrates a hierarchy of locating turbines to avoid shadow flicker, mitigation through restricted operation of the turbine during conditions when shadow flicker may occur, and other mitigation measures such as screening or blinds.

6.40 In summary, local plans provide almost no coverage of shadow flicker issues. Supplementary planning guidance and other local authority guidance relevant to renewable energy provide coverage of some issues, and reflect national guidance in relation to the ten rotor diameter distance but lack detail on key issues such as significance of effects. Furthermore the case study review identified a clear reversion in the Environmental Statements to national level guidance and documents in relation to shadow flicker with very limited reference to supplementary planning guidance. This reliance on national level guidance and documents further underlines the importance of clear national guidance or standards for shadow flicker.

Decision making and conditions

6.41 The case studies present a clear picture of the way in which shadow flicker is addressed in the decision making process and in the associated conditions. Four of the case studies demonstrated a precautionary approach to shadow flicker through the conditions attached to the decision. This was irrespective of the level of effects identified in the shadow flicker report. This supports the finding from the case study review of lack of clarity and accessibility of the shadow flicker reports, and the challenges of gaining a clear understanding of the extent and significance of shadow flicker. One of the case studies referred to the proposed mitigation within the Environmental Statement, with more limited scope, illustrating a less precautionary approach than applied in the other examples.

Presentation and communication of Shadow Flicker to non-specialists

6.42 A number of issues have been identified in relation to the clarity of presentation and communication of shadow flicker at the technical level. Shadow flicker reports are by their nature technical, but also include confusion of issues around terminology, significance and distance thresholds. It appears that some of these issues are transferred into other literature presented to non-specialists. For example the issue of shadow flicker triggering photo sensitive epilepsy is not associated with the blade frequency of the modern larger turbines, but is referred to within media articles. Reference to shadow flicker by the wind industry tends to focus on the limited area likely to be affected, and that effects can be mitigated.

6.43 The study also identified the issue of combined environmental effects from wind farms, and the potential effects of increased sensitivity to shadow flicker when noise impacts were also occurring.

6.44 More generally, and supported by the interviews, there is some confusion over the definition of the impact of shadow flicker. For planning and environmental health this is how it relates to

defining the impact of light and shadow effects from wind turbines in terms of amenity or nuisance, and also public understanding of issues such as shadow throw.

Areas for future research

6.45 The project has identified a number of questions which could be addressed through modelling to provide robust findings to support the study conclusions, particularly in relation to the ten rotor diameter distance. These are:

6.46 **Thresholds of exposure**: Modelling exposure thresholds as distance thresholds based on worst case scenario in terms of wind direction, cloud cover and window orientation. This would allow the definition of an area on a map of where exposure exceeds the threshold set out in the German guidance. This would allow identification of where it is possible to experience more than 30 minutes a day shadow flicker, the distances at which these occur and if these are beyond ten rotor diameters. A sophisticated model would be required to account for these parameters, and the most appropriate model identified to date is WindPRO, although other models may be developed or improved going forward.

6.47 **20% obscuration of the sun**: Modelling how different turbine dimensions affect what distance from the wind turbine the threshold of 20% obscuration of the sun is reached. This would allow an understanding of whether the ten rotor diameter distance threshold potentially relates to the figure of 20% obscuration of the sun. Again, at this point in time the only model which allows the input of this variant is identified as WindPRO, although other models may be developed or improved going forward.

6.48 **130 degrees of north**: Modelling of the same dimension turbine at different latitudes to identify what area is affected by shadow flicker.

6.49 **Modelling shadow flicker extent in relation to receptors at significantly lower elevation than the wind turbines:** This would allow evidence to be provided on the effects of topography on the extent and duration of shadow flicker.

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Appendix 1 Review of tools and methods: Comparison of Shadow Flicker Models by Pager Power

As part of this study, Pager Power carried out a comprehensive review intended to compare and contrast the technical tools for the assessment of shadow flicker that are currently available to developers. This Appendix presents the contents of Pager Power's report.

Glossary

Term	Meaning
Angular size	This is a term that relates to the apparent size of an object based on how much of an observer's field of view is taken up by the object. For example, if lines were drawn from a point on the Earth to either side of the sun, the angle between those lines would be half a degree. This means the angular size of the sun is 0.5° from Earth. Another way of saying this would be that the sun subtends an angle of half a degree to an observer on Earth.
Azimuth angle	This angle describes the direction that something is facing. The angle is measured clockwise from north. A window that faces directly east has an azimuth angle of 90 degrees. A window that faces directly south has an azimuth angle of 180 degrees.
Interpolation algorithm	Terrain or surface data typically comprises known height values at regular intervals across a region. OS Panorama data, for example, provides terrain height above mean sea level every 50 metres throughout the United Kingdom. Very often, locations of interest are positions in between the points with known heights. This means that a calculation is required to determine the height based on the surrounding points. There are various approaches to doing this, known as 'interpolation algorithms.
DSM	Digital Surface Model. This is a set of data that provides height information, relative to sea level, of a surface. DSM data therefore includes obstructions such as buildings and forestry, which can be relevant for visual screening purposes.
DTM	Digital Terrain Model. This is a set of data that provides height information, relative to sea level, of the terrain. This relates to the 'bare Earth' case, without reference to obstructions such as buildings and forestry. If a building with a height of 20 metres is located on terrain that is 10 metres above sea level, the DTM data would give a value of 10 metres. DSM data for the same location would give a value of 30 metres.
Vertical tilt angle	This angle relates to windows in the case of shadow flicker modelling. It describes whether the window is vertical or whether it is angled backwards or forwards. A 'normal' window that is angled at 90 degrees to the ground would have a vertical tilt of 0 degrees.
ZVI	Zone of Visual Influence.

Introduction

Assessment overview

In order to gain planning consent, wind farm developments in Scotland must demonstrate that there will not be unacceptable levels of impact in a variety of areas – including shadow flicker and related effects.

However, the guidance around how to assess shadow flicker and how to define an 'acceptable' impact is lacking.

The purpose of this report has been to:

- Investigate the parameters that contribute to shadow flicker impacts.
- Identify the most popular models that are available for assessing shadow flicker.
- Compare the available models to each other and consider whether they capture the important technical parameters pertaining to shadow flicker.

Definitions of shadow flicker

Table 1: Definitions of shadow flicker from three relevant sources.

Source	Definition
#1 Update of UK Shadow Flicker Evidence Base Parsons Brinckerhoff March 2011	*The term "shadow flicker" refers to the flickering effect caused when rotating wind turbine blades periodically cast shadows over neighbouring properties as they turn, through constrained openings such as windows.*
#2 National Policy Statement for Renewable Energy Infrastructure (EN-3) Department of Energy and Climate Change July 2011	*Shadow flicker is the effect caused when an operating turbine is located between the sun and a receptor, such as a dwelling or place of work. The effect occurs when the shadow of the rotating blades falls over the dwelling causing the light intensity within specific affected rooms of the occupied building to fluctuate.*
#3 Planning for Renewable Energy, A Companion Guide to PPS22[67] Office of the Deputy Prime Minister July 2013	*Under certain combinations of geographical position and time of day, the sun may pass behind the rotors of a wind turbine and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the effect is known as 'shadow flicker'. It only occurs inside buildings where the flicker appears through a narrow window opening.*

[67] Note that this guidance has officially been withdrawn as of March 2014 – however the technical content pertaining to Shadow Flicker is still relevant for the purpose of this report.

Note that neither the National Planning Framework (NPF-3) for Scotland nor Scotland's National Marine Plan provides a definition of shadow flicker.

It can be seen that the precise wording of the definitions varies between various sources. Two of the three sources (#1 and #3) in Table 1 (on the previous page) explicitly state that effects are observed only when sunlight illuminates a room through a constrained opening (in #3 specified as a narrow window). To an extent, the remaining source (#2) implies this same scenario by referring to the light intensity 'within specific affected rooms' but does not elaborate further.

This report is an investigation of modelling tools for shadow flicker and related effects – specifically any effects related to changing light intensities due to the spinning blades obstructing sunlight.

Therefore, the investigation has considered the ability of the modelling tools to evaluate reliably the effect of rotating turbine blades on light intensity at surrounding locations.

How shadow flicker is caused

Overview

In order to model potential shadow flicker effects accurately, it is important to understand the physical parameters that cause the issue.

The key considerations are set out in the following sub-sections.

Angular Size of the Sun

When viewed from earth, the sun subtends an angle of just over half a degree. This means that if lines were drawn from earth to either side of the sun, the angle between the lines would be 0.5 degrees. Figure 1 below illustrates this.

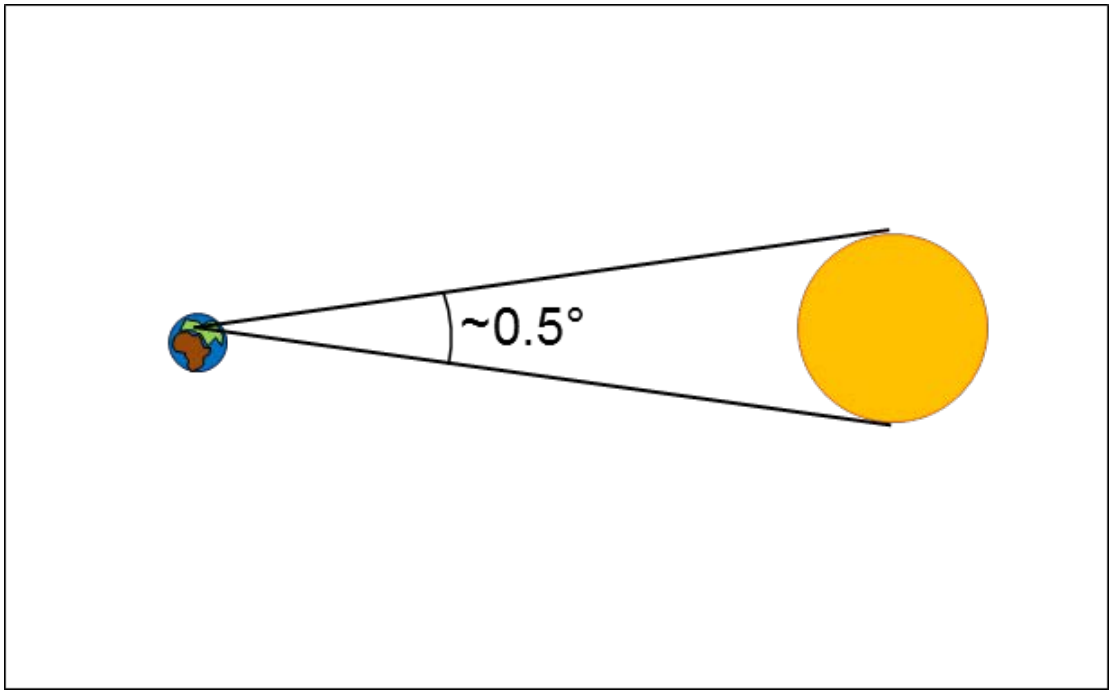

Figure 1: Angular size of the sun

This means that something with an angular size of up to half a degree will partially obscure the sun. An object with an angular size of over half a degree will entirely obscure the sun.

To put this in context, a person's field of vision is typically about 200° horizontally and 135° vertically[68].

If an object intermittently obscures the sun, the observed light intensity will fluctuate. This will be the case for partial or full obscuration. The greater the extent of the obscuration, the more noticeable the effect.

Wind Turbines Obscuring the Sun

There are two ways that a wind turbine rotor can be said to obscure the sun:

1. The turbine rotor, seen as a disc, having an angular size of at least half a degree. This would lead to partial obscuration of the sun.
2. The turbine blade having an angular size of at least half a degree (vertically). This would lead to total intermittent obscuration of the sun.

[68] Guidance on Signal Positioning and Visibility Issue One, December 2003. Railway Guidance Group Note.

These scenarios are illustrated in figures 2 and 3, which are below and on the following page respectively.

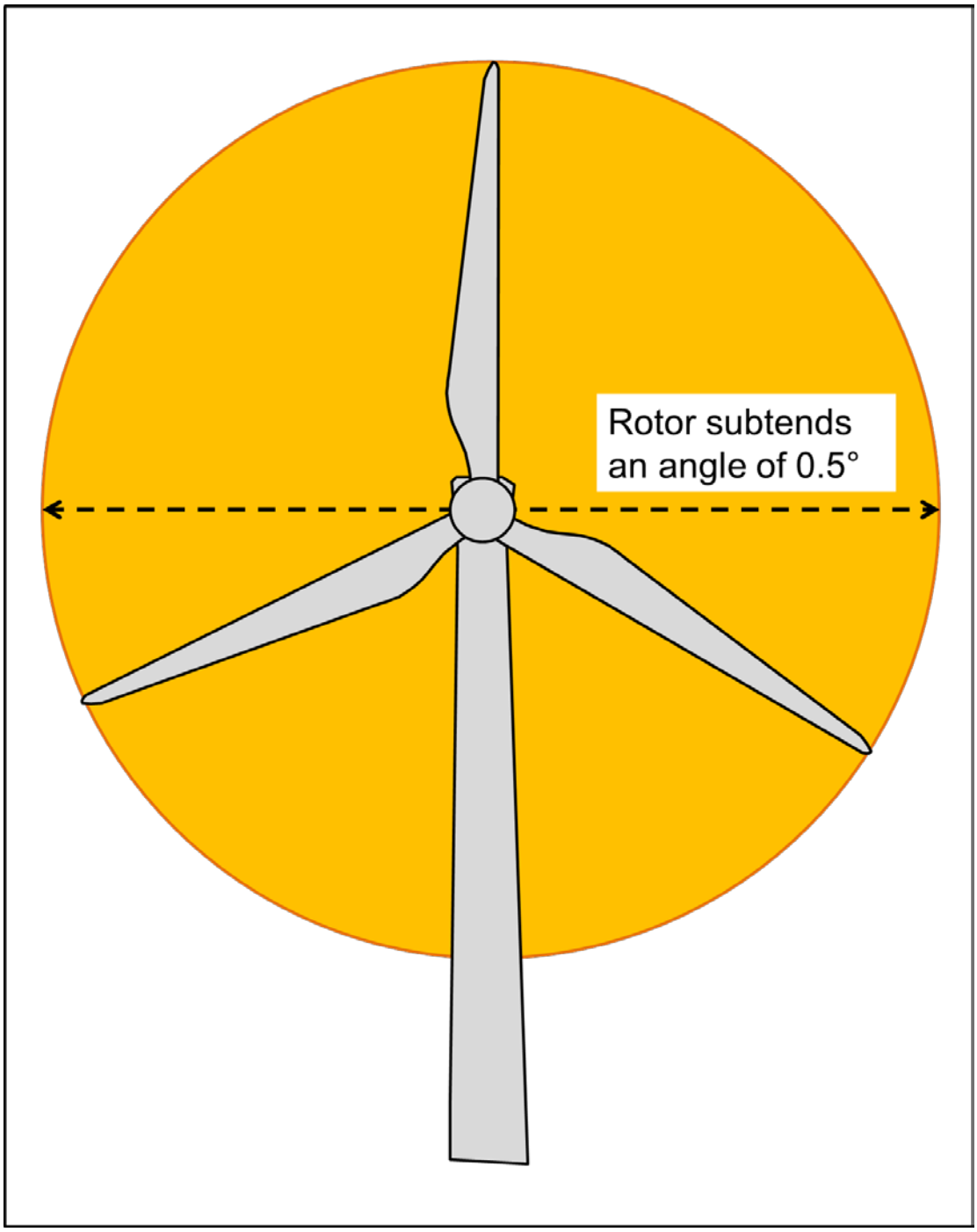

Figure 2: Rotor diameter with the same angular size as the sun

The scenario illustrated in Figure 2, above, would be unlikely to cause significant shadow flicker effects. In this scenario the turbine blades would only obscure part of the sun from view. Furthermore, the total amount of obscuration would remain constant as the blade rotates, such that changes in observed intensity would be relatively subtle.

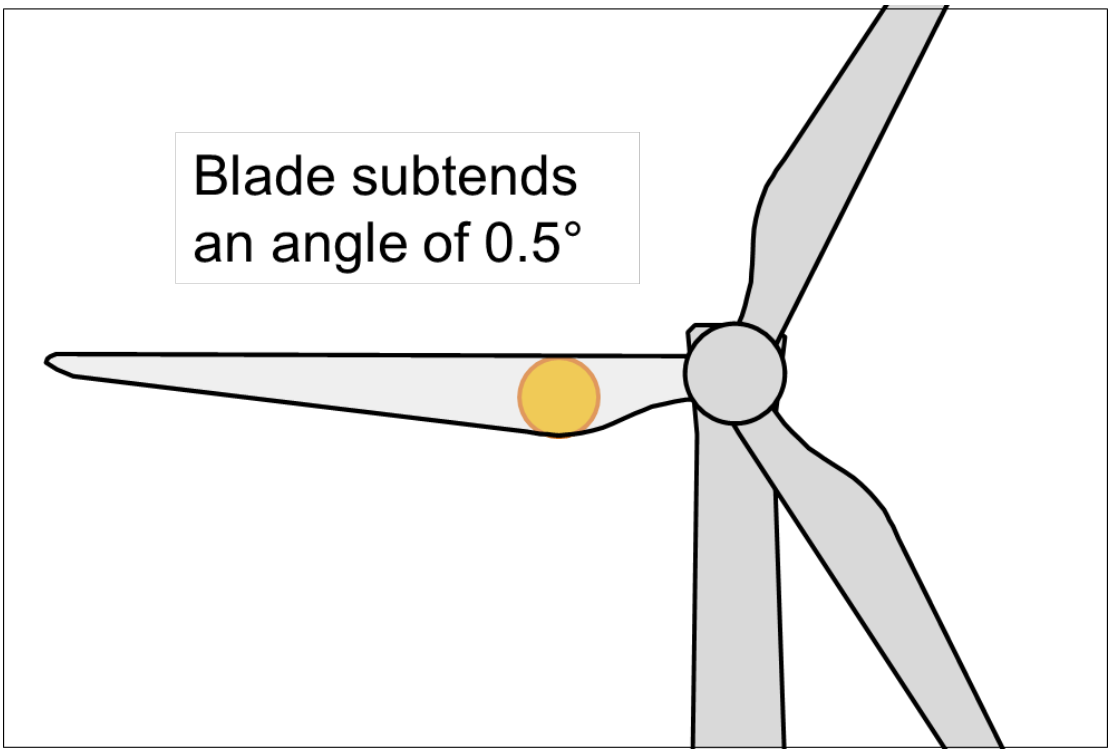

Figure 3: Turbine blade with the same angular size as the sun

The scenario illustrated in Figure 3 above is likely to cause significant shadow flicker.

This is because:

- The sun would be entirely obscured intermittently as the rotor spins.
- Paragraph 75 of the withdrawn companion guide to PPS22 supported the view that obscuration of the sun by the widest portion of the blade was the principle mechanism for shadow flicker [69].
- A popular rule of thumb for shadow flicker effects is to consider receptors within 10 rotor diameters. While the precise derivation of this buffer is unclear, it is more in keeping with the scenario in Figure 3 than the scenario in Figure 2.

The situation shown in Figure 3 is the worst-case scenario because the turbine is facing the observer with the widest portion of the blade obstructing the view of the sun. It also shows a case where the sun is entirely obscured by the blade.

The actual geometry is variable, based on the relative location and height of the observer and the turbine. The intervening terrain, sun position and orientation of the turbine will also affect the geometric relationship.

Cases where there is partial obscuration of the sun would also result in shadow flicker – because the light intensity at an observer's location would fluctuate. Figure 4, on the next page, illustrates such a case.

[69] "*At distance, the blades do not cover the sun but only partly mask it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines.*" – Planning for Renewable Energy, A Companion Guide to PPS22, Office of the Deputy Prime Minister, July 2013

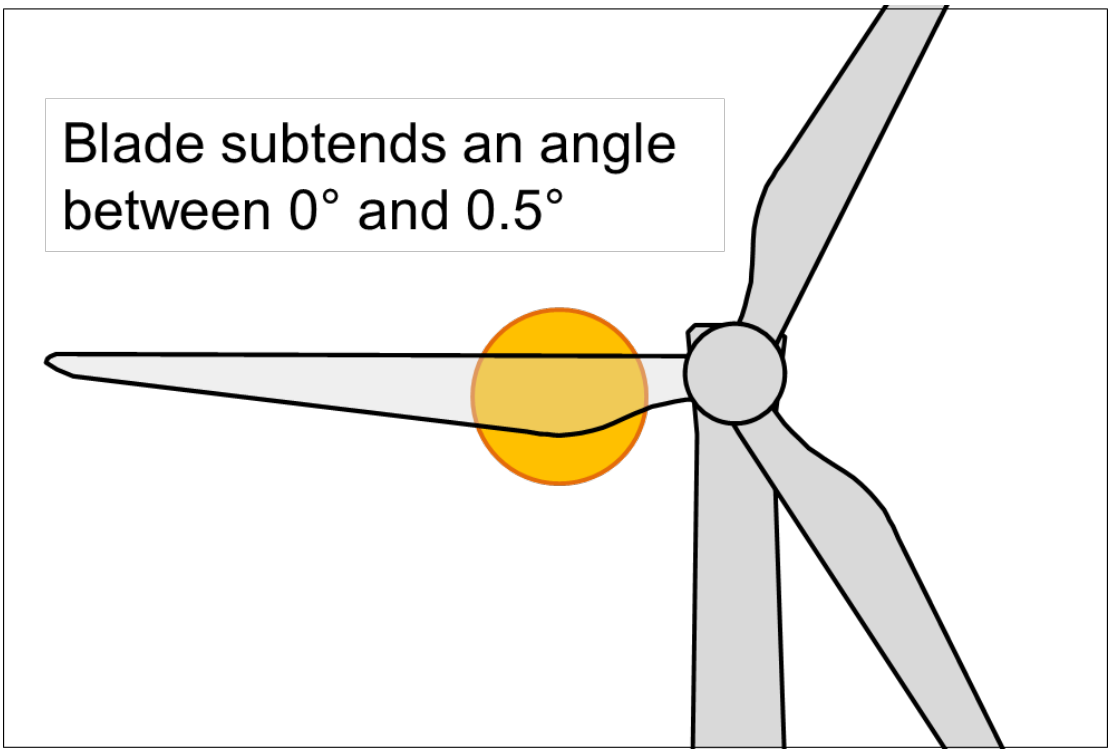

Figure 4: Turbine blade with a smaller angular size than the sun

Key parameters

Shadow flicker effects are dependent on:

- The location of the wind development – the turbine latitude dictates the observed path of the sun in the sky.
- The time of year.
- The terrain elevation at each turbine and observer.
- The effect of intervening terrain and/or obstructions such as hedgerows.
- The location, size and orientation of the receptor (window or other restricted opening).
- The distance between each turbine and receptor.
- The wind direction.
- The turbine hub height.
- The turbine rotor diameter.
- The turbine blade width.
- Cloud cover.

Factors such as cloud cover and wind direction are relevant when assessing the overall expected impact throughout the year. In terms of determining whether or not there will ever be an effect, an ideal approach would consider both:

- A worst-case scenario i.e. sunny conditions with the widest aspect of the blade facing the sun.
- An expected scenario based on likely weather conditions (wind and cloud cover) in the area.

Further considerations

From a technical perspective, there are three possible outcomes for a given receptor:

1. No shadow flicker effects are possible under any circumstances.
2. Shadow flicker effects are possible and the sun will be intermittently obscured entirely by the rotating blades.
3. Shadow flicker effects are possible and the sun will be intermittently obscured partially by the rotating blades.

Comprehensive formal guidance on shadow flicker effects is likely to define:

- Requirements for an assessment process.
- A quantified definition of an 'acceptable' impact.

The definition of an acceptable impact may be related to one or more of the following:

- Number of hours per day.
- Number of hours per year.
- Severity of impact.

In order to evaluate the number of hours within a given time period that effects could be experienced, the model must be able to assess worst-case scenarios based on the geometric locations of the sun, the turbines and the receptors.

In order to evaluate the severity of the impact, the change in observed intensity must be quantified in some way. A reasonable approach would be to define this in terms of percentage of sun obscuration e.g. if the widest part of the blade obscures less than 50% of the sun under worst-case conditions, the impact is considered negligible[70].

[70] The value of 50% is for explanation purposes only, there is no recommendation within this report with regard to acceptable limits.

Available tools

Overview

There are various commercial software packages that allow developers to model the potential shadow flicker. This review has sought to identify the most popular and most technically advanced models.

Identification of Models

Potential models were identified based on:

- A review of the literature referenced in Table 1 on page 9 of this report.
- A review of planning applications for the following large Scottish wind farms:
    - Clyde (extension).
    - Black Law (extension).
    - Fallago Rig.
    - Whitelee.
- A web search for other options – this was primarily a cross-check to support the above.

The assessed models are listed below. These are the software packages referenced in *Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011*. No other modelling options were identified[71] for assessment:

- WindFarm.
- Gerrard Hassan (GH) WindFarmer.
- WindPRO.

[71] Where specific reference was made to modelling software, it was one of the options that has been listed. In many cases there was no mention of the specific modelling details, or the need for modelling was dismissed altogether based on separation distances and/or turbine visibility.

Comparison of tools

Process

The available information for each modelling software package was reviewed. This was largely based on information from the companies directly, supported by external reviews within the previously cited literature.

It is understood that each tool takes as inputs the coordinates of the turbines and receptors. It is also understood that the path of the sun through the sky is accounted for in each of the models.

The following questions were investigated for each tool:

- Which of the following technical parameters are entered for the turbine:
  - Hub height.
  - Rotor diameter.
  - Blade thickness.
- Which of the following technical parameters are entered for the receptor:
  - Dimensions – effects for a window that is 2 metres by 1 metre could be different than for a window that is 0.5 metres by 0.5 metres.
  - Azimuth angle – a window that directly faces a turbine could be affected differently than a window that is directed towards one side of a turbine.
  - Vertical tilt angle – most windows are at 90 degrees to the ground, however some windows can be set at an angle and this could affect the results.
- Which of the following is accounted for within the terrain model:
  - Earth curvature.
  - Elevation above mean sea level (i.e. DTM[72]).
  - Obstructions above ground level (DSM[73]).
  - Intervening terrain and/or screening that would obstruct the turbines from a receptors' view[74].
  - The effect of terrain and/or screening on the horizon?
  - Interpolation algorithm – terrain data is typically comprised of a database of known land heights at regularly spaced points. Ordnance Survey Panorama data, for example, provides terrain heights above mean sea level every 50 metres. If a turbine or a receptor is located at some arbitrary location between these defined points, the terrain height must be extrapolated based on the known heights surrounding the location. There are various ways of doing this, with different levels of accuracy and conservatism.
- Can the effect of the prevailing wind direction be accounted for in any way?
- Can the effect of cloud cover be accounted for in any way?
- Are the precise days and times for predicted effects given?
- Are sunrise and sunset times incorporated (i.e. could the model erroneously predict effects at time when the sun would not be up)?

Assessment – Wind Farm

Table 2 below summarises the assessment of the shadow flicker capabilities within WindFarm by ReSoft. Note that WindFarm is a software package designed to aid in multiple areas of wind development. At the time of writing, version 4 of the software was available and version 5 was available on pre-release. The data was sourced from:

- The ReSoft website – which gives an overview of their Shadow Flicker Software.
- Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011.
- Direct enquiries to ReSoft (via email – See Appendix 2).

[72] Digital Terrain Model

[73] Digital Surface Model

[74] Note that a model could incorporate terrain data to calculate the relative heights of turbines and receptors, but not account for terrain that intercepts an observer's view of the turbines. This is why a separate category is listed for intervening terrain specifically.

Table 2: WindFarm review

Category	Question	Answer	Remarks
Turbine Data	Is hub height incorporated?	Yes	-
	Is rotor diameter incorporated?	Yes	-
	Is blade thickness incorporated?	No	The average chord width can be used to limit the assessment distance but nothing else.
Receptor Data	Are dimensions incorporated?	Yes	-
	Is azimuth angle incorporated?	Yes	-
	Is vertical tilt angle incorporated?	Yes	-
Terrain Model	Is earth curvature incorporated?	Yes	-
	Is elevation above mean sea level incorporated?	Yes	Terrain data can be imported.
	Are structures above ground incorporated?	No	The terrain data could be modified to account for known obstructions.
	Is intervening terrain / screening accounted for?	Potentially	It is understood that intervening terrain can be incorporated as part of the ZVI assessment within WindFarm. It may be possible to include this data as part of the shadow flicker assessment.
Terrain Model	Is the effect of terrain / screening on the horizon accounted for?	Yes	A minimum elevation angle for the sun can be entered.
	What interpolation algorithm is used?	Bilinear interpolation	-
Wind Direction	Can the prevailing wind direction be incorporated in any way?	No	-

Category	Question	Answer	Remarks
Cloud Cover	Can the likely cloud cover be incorporated in any way?	No	Results could be exported and manipulated further thereafter.
Sunrise / Sunset	Are the sunrise and sunset times incorporated?	Yes	This may be restricted to setting a minimum angle for the model to consider.
Model Output	Are the hours per day and hours per year that effects can occur quantified?	Yes	-

Assessment – GH WindFarmer

Table 3 below summarises the assessment of the shadow flicker module of GH WindFarmer. The data was sourced from:

- The Garrad Hassan website, which provides an overview of the module.
- Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011.
- Direct contact with Gerrard Hassan (via email, see Appendix 2).

Table 3: GH WindFarmer review

Category	Question	Answer	Remarks
Turbine Data	Is hub height incorporated?	Yes	-
	Is rotor diameter incorporated?	Yes	-
	Is blade thickness incorporated?	No	-
Receptor Data	Are dimensions incorporated?	No	Receptors are modelled as a single point.
	Is azimuth angle incorporated?	Yes	-
	Is vertical tilt angle incorporated?	Yes	-
Terrain Model	Is earth curvature incorporated?	Yes	-
	Is elevation above mean sea level incorporated?	Yes	-
	Are structures above ground incorporated?	No	
	Is intervening terrain / screening accounted for?	No	The terrain data could be modified to account for known obstructions.
Terrain Model	Is the effect of terrain / screening on the horizon accounted for?	Yes	There are three options: Assuming that turbines and the sun are always visible - reduces calculation time for sites in flat terrain Checking if turbine visibility is obstructed by terrain Checking if turbine and sun visibility is obstructed by terrain

Category	Question	Answer	Remarks
	What interpolation algorithm is used?	Bilinear interpolation	-
Wind Direction	Can the prevailing wind direction be incorporated in any way?	Yes	There are different rotor models in WindFarmer: rotor modelled as a sphere, rotor modelled as a plane following the sun's azimuth or with a fixed orientation. This could go some way to incorporating the prevailing wind direction, although some further data interpretation would most likely be required[75].
Cloud Cover	Can the likely cloud cover be incorporated in any way?	No	-
Sunrise / Sunset	Are the sunrise and sunset times incorporated?	Yes	This is restricted to setting a minimum angle for the model to consider.
Model Output	Are the hours per day and hours per year that effects can occur quantified?	Yes	-

[75] Because assuming a fixed orientation is not entirely realistic, the prevailing wind direction will not occur 100% of the time

Assessment – WindPRO

Table 4 below summarises the assessment of GH WindFarmer. The data was sourced from:

- The WindPRO website, which provides an overview of the module and an example output report.
- Update of UK Shadow Flicker Evidence Base, Parsons Brinckerhoff, March 2011.
- Direct contact with Gerrard Hassan (via email, see Appendix 2).

Table 4: WindPRO review

Category	Question	Answer	Remarks
Turbine Data	Is hub height incorporated?	Yes	-
	Is rotor diameter incorporated?	Yes	-
	Is blade thickness incorporated?	Yes	The example report made available by WindPRO shows that calculations are only made when more than 20% of the sun is covered by the blade.
Receptor Data	Are dimensions incorporated?	Yes	-
	Is azimuth angle incorporated?	Yes	-
	Is vertical tilt angle incorporated?	Yes	-
Terrain Model	Is earth curvature incorporated?	Yes	-
	Is elevation above mean sea level incorporated?	Yes	-
	Are structures above ground incorporated?	Yes	-
	Is intervening terrain / screening accounted for?	Yes	-
	Is the effect of terrain / screening on the horizon accounted for?	Yes	-

Category	Question	Answer	Remarks
Terrain Model	What interpolation algorithm is used?	Triangular Irregular Network	-
Wind Direction	Can the prevailing wind direction be incorporated in any way?	Yes	Real expected values can be produced based on wind direction.
Cloud Cover	Can the likely cloud cover be incorporated in any way?	Yes	Real expected values can be produced based on assumptions regarding solar statistics.
Sunrise / Sunset	Are the sunrise and sunset times incorporated?	Yes	-
Model Output	Are the hours per day and hours per year that effects can occur quantified?	Yes	-

Comparison of models

It can be seen that there are some differences between the models – these are summarised in Table 5 below. Note that there are different ways of defining a realistic 'worst case scenario' and a 'likely scenario'. The judgement has been made based on first principles and the author's professional opinion.

Table 5: Model comparison

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
Turbine Data	Incorporation of hub height	✓	✓	✓	✓	✓
	Incorporation of rotor diameter	✓	✓	✓	✓	✓
	Incorporation of blade thickness	✗	✗	✓	✗	✓
Receptor Data	Incorporation of window dimensions	✓	✗	✓	✓	✓
	Incorporation of azimuth angle	✓	✓	✓	✗	✓
	Incorporation of vertical tilt angle	✓	✓	✓	✗	✓
Terrain Model	Incorporation of earth curvature	✓	✓	✓	✗	✓
	Incorporation of a terrain model	✓	✓	✓	✗	✓
	Incorporation of structures above ground	✗	✗	✓	✗	✓

Category	Feature	WindFarm (ReSoft)	GH WindFarmer	WindPRO	Input required for worst case scenario?	Input required for likely scenario?
	Incorporation of intervening terrain	*Possibly*	✘	✓	✘	✓
Terrain Model	Incorporation of terrain / screening on the horizon	✓	✓	✓	✘	✓
	Sophisticated terrain data interpolation algorithm	✓	✓	✓	✘	✓
Wind Direction	Incorporation of wind direction	✘	✓	✓	✘	✓
Cloud Cover	Incorporation of likely cloud cover	✘	✘	✓	✘	✓
Sunrise / Sunset	Incorporation of sunrise and sunset times	✓	✓	✓	✘	✓
Model Output	Quantification of hours per day / per year that effects could occur	✓	✓	✓	✓	✓

Differences

It can be seen that there are some differences between the available modelling tools. The potential implications of these differences are presented below.

Blade Width

Incorporation of blade width is required to maximise the accuracy of the assessment. This is because obscuration of the sun by the blade is the primary mechanism that leads to the shadow flicker effects – see Section 2 of this report.

If blade width is not incorporated, the modelling would determine that any obscuration of the sun results in shadow flicker effects[76]. Whilst this is not the most accurate approach, it is the most conservative.

Window Dimensions

Modelling the window as a point rather than considering its true dimensions is an approximation that limits the accuracy of the assessment. It could also make the assessment less conservative in a scenario where the shadow partially covers a window. This is illustrated in Figure 5 below.

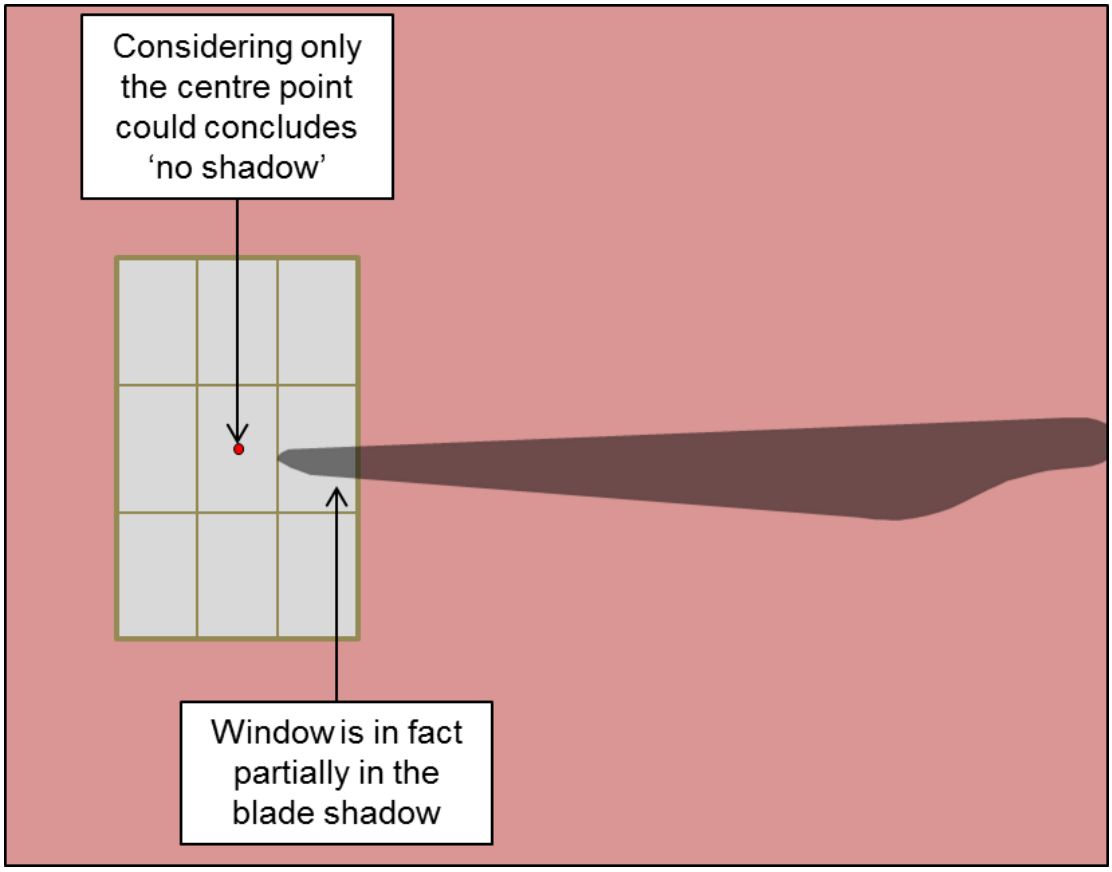

Figure 5: Importance of window dimensions

[76] In reality, partial obscuration of the sun may not result in significant effects.

Incorporation of structures above ground and/or intervening terrain

Structures or terrain that obstructs the path between a receptor and a turbine could reduce potential effects. If a hedgerow removes a turbine rotor from view, there can be no shadow flicker effects.

Assuming that the path between a receptor and a turbine is clear presents a worst-case scenario, which ensures a conservative assessment. However, it is not the most accurate approach and could potentially identify impacts that would not materialise in practice.

Incorporation of wind direction and/or cloud cover

Wind direction affects the orientation of the turbine rotor. This has implications for the likely extent of shadow flicker effects. Modelling the prevailing wind direction, and the associated 'profile' of the turbine rotor, would facilitate the most accurate results.

The same is true for cloud cover – if the intensity of the sunlight is low due to obscuration by clouds, the magnitude of the shadow flicker effects could reduce.

Assuming the rotor is always 'facing' a receptor and that there is no cloud cover presents a worst-case scenario. However, the real-world effects could be less than predicted.

Prevailing wind direction and predicted could cover are particularly relevant in the context of shadow flicker hours per year – because the likely effect over a protracted period of time is more reliable than for any given day in isolation.

Appendix 2 Consultation Responses to the review of tools and methods

WindFarm

From: support <support@resoft.co.uk>
Sent: 26 May 2016 12:05
To: Kai Frolic
Subject: Shadow Flicker

Follow Up Flag: Flag for follow up
Flag Status: Completed

Hi Kai

Please use support@... for support questions - info for licences and upgrades.

Please read the ShadowFlicker.pdf tutorial for info.

1 average chord width can be used for limit distance but nothing else
2 bilinear interpolation
3 no
4 no - you need to export the results and manipulate them in a spreadsheet
5 yes - see the tutorial

Regards
Alan Harris

Hi there,

I have a couple of questions a or the Shadow Flicker modelling capabilities within WindFarm which are not in the FAQs.

Could you please advise me regarding the below:

- Is the blade width incorporated in the shadow flicker modelling?

- How is the terrain data interpolated at specific points (e.g nearest neighbour, weighted average, other)?

- Can the prevailing wind direction be accounted for within the shadow flicker calculation?

- Can cloud cover be accounted for within the shadow flicker calculation - and if so how is this estimated?

- Are sunrise and sunset times accounted for within the shadow flicker calculation (I.e to avoid predicting effects before the sun is up)?

Many thanks in advance,

Kai Frolic

Pager Power
New Mill
Bakers Court
Great Cornard
Sudbury
Suffolk

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GH WindFarmer

From: GH - WindFarmer <windfarmer@dnvgl.com>
Sent: 26 May 2016 08:38
To: Kai Frolic
Subject: RE: GL WindFarmer Shadow Flicker Module

Follow Up Flag: Flag for follow up
Flag Status: Flagged

Dear Kai

Please find the answers below:

- Does the model incorporate hub height, rotor diameter and blade thickness?

The model uses turbine hub height and rotor diameter and optionally the offset between the rotor and the tower.
Blade thickness is not considered but this can be covered by a maximum distance where flicker can occur set by the user.

- Does the model incorporate the dimensions and of the window?

Receptor locations are modelled as a single point so for modelling larger windows you would need to use multiple receptors.

- Does the model incorporate the azimuth and vertical tilt of the window?

Yes, receptors have settings for bearing and tilt so you can model windows or greenhouse cases where flicker can be seen from all directions.

- Does the model include Earth Curvature?

Yes (optional).

- Can screening obstructions be incorporated into the analysis?

Screening uses the digital terrain model as input so if the data include obstacles they are considered.
It is not possible to define obstructions like walls, hedges or trees on top of the digital terrain data.

- Is the effect of intervening terrain on visibility and the horizon accounted for within the results?

Yes, there are 3 options:
- assuming that turbines and the sun are always visible - reduces calculation time for sites in flat terrain
- checking if turbine visibility is obstructed by terrain
- checking if turbine and sun visibility is obstructed by terrain

- How are terrain data values at particular locations interpolated (e.g. Nearest neighbour, weighted average etc)

Terrain height at turbines and receptors uses a bilinear interpolation of the gridded terrain data.

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- Are the prevailing wind direction and cloud cover accounted for within the model - if so how are these determined?

There are different rotor models in WindFarmer: rotor modelled as a sphere, rotor modelled as a plane following the sun's azimuth or with a fixed orientation.
The option with fixed orientation can be used to model shadow flicker for the prevailing wind direction.
Cloud cover is not considered (worst case calculation only).

- Are the sunrise and sunset times considered (e.g to avoid predicting effects when the sun isn't up)?

Yes, there is no flicker if the sun's elevation is less than a minimum elevation angle set by the user.
To consider sunrise and sunset this can be set to 0 deg.
However, this minimum angle is often set to 3 deg to encounter for low light intensity when the sun is close to the horizon and obstructions by nearby obstacles.

Please don't hesitate to contact us again if you have any further questions.

Regards,

Anja Neubert

Best regards
for GL GH Deutschland GmbH

Dipl.-Met. Anja Neubert
Senior WindFarmer Specialist, Software Tools and Products Renewables Advisory DNV GL - Energy

For WindFarmer technical support write to windfarmer@dnvgl.com Marie-Curie-Str. 1, 26129 Oldenburg, Germany www.dnvgl.com

DNV and GL have merged to form DNV GL - Read more here: www.dnvgl.com/merger

-----Original Message-----
From: Kai Frolic [mailto:kai@pagerpower.co.uk]
Sent: 25 May 2016 15:49
To: GH - WindFarmer
Subject: GL WindFarmer Shadow Flicker Module

**********-Important message from DNV GL - GSS IT-**********
- PLEASE NOTE! This Message has been sent to your Legacy domain address which will soon be OBSOLETE! You need to notify the sender to use your DNVGL.COM address for the future.
As announced, the legacy domain address will be REMOVED after 01.01.2015, thus such messages as this will NOT reach you anymore. More information will be found here:
<http://inside.dnv.com/intra/news/matters/2014/gss/termination_of_legacy_email_domains_per_01012015.asp>

****

Good afternoon,

I am looking into the capabilities of the Shadow Flicker module within GL WindFarmer.

I have some technical questions, listed below, I hope that someone can advise me on these queries.

- Does the model incorporate hub height, rotor diameter and blade thickness?

- Does the model incorporate the dimensions and of the window?

- Does the model incorporate the azimuth and vertical tilt of the window?

- Does the model include Earth Curvature?

- Can screening obstructions be incorporated into the analysis?

- Is the effect of intervening terrain on visibility and the horizon accounted for within the results?

- How are terrain data values at particular locations interpolated (e.g. Nearest neighbour, weighted average etc)

- Are the prevailing wind direction and cloud cover accounted for within the model - if so how are these determined?

- Are the sunrise and sunset times considered (e.g to avoid predicting effects when the sun isn't up)?

Thank you in advance,

Kai Frolic

Pager Power
New Mill
Bakers Court
Great Cornard
Sudbury
Suffolk
CO10 0GG

01787 319001

WindPRO

From: EMD International A/S <support@emd.dk>
Sent: 25 May 2016 15:59
To: Kai Frolic
Subject: Re: [Ticket#1010575] Shadow Flicker Modelling in WindPRO

Follow Up Flag: Follow up
Flag Status: Completed

Hello Kai,
- Does the model include Earth Curvature?
Yes. However, since the calculation runs only for distances of max 2,5 km, Earth curvature is irrelevant.
- How are terrain heights at particular points interpolated (e.g. Nearest neighbour, weighted average, other)?
We use the Triangular Irregular Network method.

Cheers

Maurizio
WindPRO Support Team

Maurizio Motta

--
EMD International A/S
Niels Jernes Vej 10
9220 Aalborg Ø
Tel: +45 96 35 44 44
Email: support@emd.dk - Web: http://www.emd.dk/
--

25/05/2016 16:50 - Kai Frolic wrote:

> Good afternoon,
>
> I am looking into the capabilities of the Shadow Flicker module within WindPRO.
>
> The website and the example report answered most of my questions, I just have two points I'd like to clarify.
>
> I have some technical questions, listed below, I hope that someone can advise me on these queries.
>
> - Does the model include Earth Curvature?
>
> - How are terrain heights at particular points interpolated (e.g. Nearest neighbour, weighted average, other)?
>
> Thank you in advance,
>
> Kai Frolic
>
> Pager Power
> New Mill
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> Sudbury

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