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How Does Noise Influence the Design of a Wind Farm?

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Summary

The primary purpose of a wind farm is to produce electricity and it is the objective of a developer to design a wind farm which optimizes the potential yield and maximizes the financial return. However, site restrictions and planning constraints, one of which is noise, affect the total installed capacity and layout of a wind farm, and needs to be considered carefully.

This paper introduces the subject of wind farm design from a developer's perspective, from finding suitable land, to submitting a planning application. Initially a suitable location is assessed for favourable conditions such as wind resource, adequate grid infrastructure, and access for abnormal loads, then the wind farm is designed in accordance with constraints which include: archaeology; ecology; landscape and visual impact; local residences and other technical constraints.

Operational noise from a wind farm is only one factor affecting the constraints due to local residences, but it has a strong influence in determining the capacity and layout of a wind farm. The assessment of wind farm noise is completed following relevant guidance in accordance with planning policy. Another factor that is discussed is the influence of cumulative wind farms on the design of a wind farm in relation to noise, depending on their status in the planning process.

1. Introduction

RES are a renewable energy company that not only develop wind farms but also other forms of renewable energy technology (solar photovoltaic, solar thermal and biomass) for the provision of heat and power. RES has a portfolio of more than 6 GW constructed and several thousand megawatts under construction and in development. Given this experience, the purpose of this paper is to provide information to the acoustics community on how wind farms are developed and where noise fits into the development process. Something which can be misunderstood by those not involved in the area is that noise is not the primary driver in wind farm design. This paper outlines what the key design drivers actually are and why a wind farm is designed the way it is.

The paper commences by looking into the location of a wind farm through site selection by providing details of the environmental and technical areas, such as wind

resource, proximity to grid, proximity to exclusion zones, location in relation to habitations etc, that need to be considered.

Following site prospecting/selection is a discussion on the design of a wind farm with regards to site specific development which covers all the necessary constraints that feed into the environmental assessment, including: visual and landscape assessment; ecology; archaeology; agriculture; electromagnetic links; highways and noise.

Further information in relation to noise is continued with reference to the appropriate assessment methodology, how this influences the design of the wind farm, and the affect other wind farms have in the design of a new wind farm.

2. Site Selection

Site selection typically comprises a desk based study carried out against key site criteria, for example the wind resource; proximity to the electrical grid; proximity to airport exclusions; proximity to habitations etc. Sites are identified by site prospecting and determining which the best candidates for development are.

For example, the outcome of an England & Wales site selection process is shown in Figure 1.

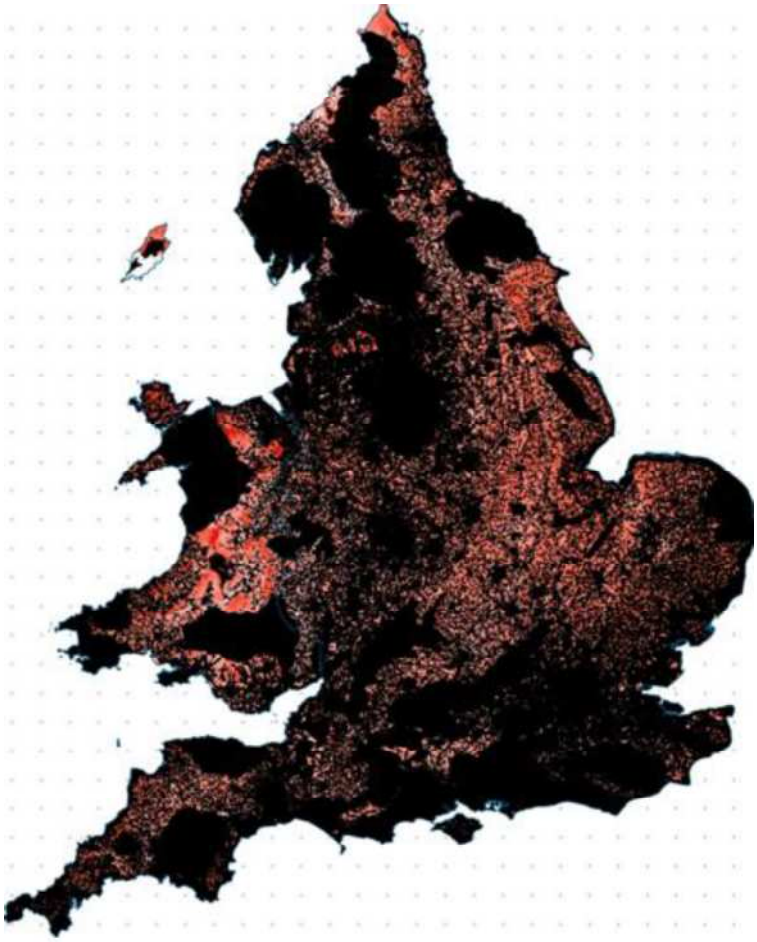

Figure 1 England & Wales Site Selection

Once a number of potential sites have been identified, the sites are assessed and ranked in order of priority based on environmental, technical and policy considerations. The most promising of the sites require a site visit and preliminary discussion with both the landowner and the planning authorities.

There are a number of environmental considerations which include visibility from surrounding areas, the proximity to habitation, shadow flicker, electromagnetic effects, TV interference, flora and fauna, impact upon land use and land use designated areas, for example Sites of Special Scientific Interest (SSSI's) in the UK.

Technical considerations include wind resource which is used to refer to the amount of useful wind available at a site. The economic viability of a wind project is dictated by the resource assessment and hence it is critically important. As wind farm economics are dominated by mean wind speed and the wind turbine layout is dominated by wind direction. To obtain this resource information, in order to aid the wind farm development activities high resolution wind maps are produced using mesoscale modelling. A mesoscale model can provide estimated long-term mean wind speeds with good accuracy and simulate the long-term wind climatology effectively. An example of predicted wind maps are shown in Figure 2.

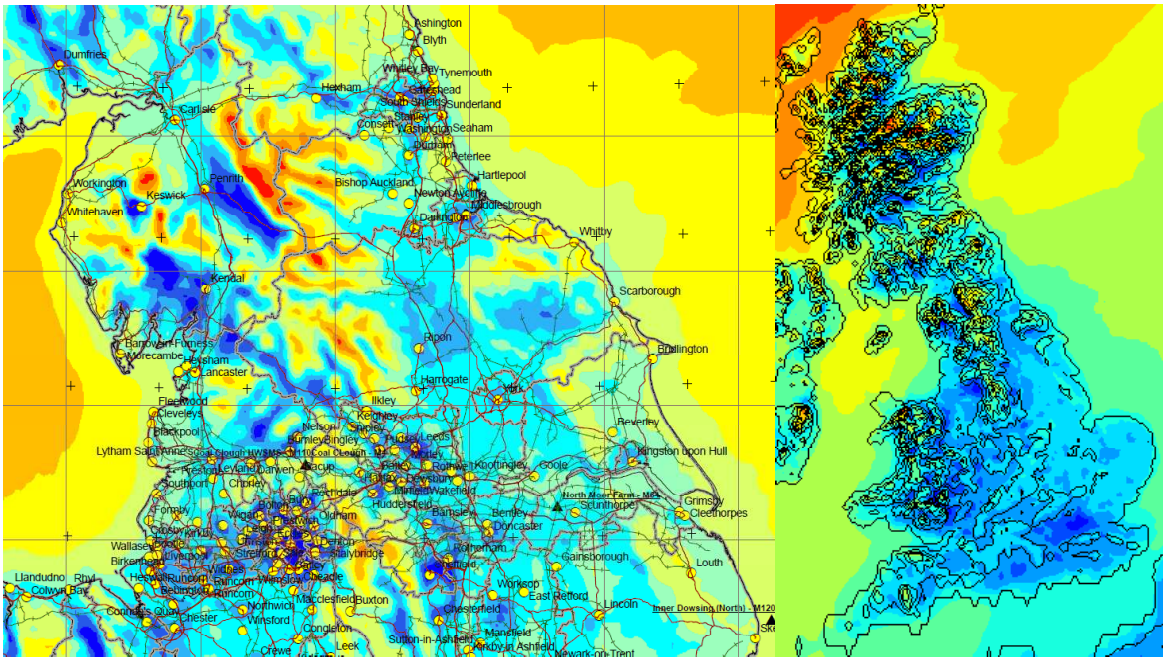

Figure 2 Mesoscale model for UK

Availability of suitable land is another technical consideration, as a large, open land area is required, given typical turbine spacing's of 100 - 400 m). The location needs to be well exposed and not too steep, and ground conditions need to be suitable, for constructing foundations etc.

Good access is required since long site access tracks are expensive, and corners, buildings etc. can cause problems for lorries carrying blades. Also grid connection needs to be considered taking into account the proximity of an existing grid network and sufficient capacity to accommodate generation.

Policy considerations include knowledge of the consenting process, the timescales involved in consenting wind farms in different regions and assessing the impact of policy on technical and environmental considerations.

After considering all relevant environmental and technical considerations a developer will make a decision as to which sites to develop further. The selected sites begin the core part of the development process which consists of resource & energy yield assessment, environmental assessment, and planning. Concurrent to the site development is a continuous process of public consultation through public meetings, information leaflets and websites.

3. Wind Farm Design

An initial site layout for the turbines is designed to optimise the energy yield from the site by maximising the beneficial topographical effects and minimising wake effects while staying within the various constraints, and consequently layout design is an iterative process.

The complexity of the optimisation process is indicated by the wind rose. Modelling wind flow across the site takes into account site conditions to create a suitably spaced layout. Depending on the wind rose the required spacing between turbines within rows and between the rows varies, due to wake effects between turbines with regard to loss of energy and turbulence created in the wakes. For omni-directional winds, layout optimisation algorithms are required, a typical layout and wind rose is shown in Figure 3. For a unidirectional wind rose (shown in Figure 4) the turbines will be positioned in rows; within the rows turbines are positioned reasonably close (3 rotor diameters) while the rows are spaced farther apart (>5 rotor diameters).

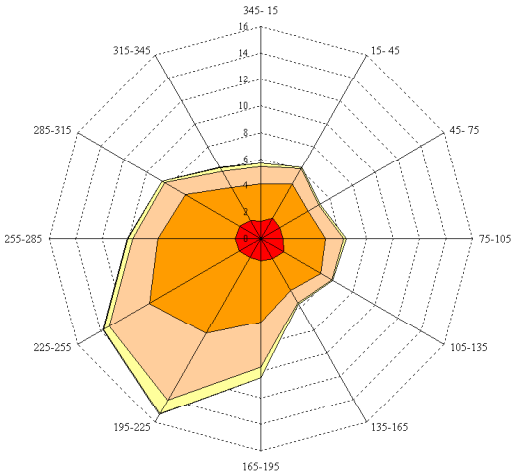

Figure 3 Wind rose and optimum layout for a site with an omni-directional wind rose

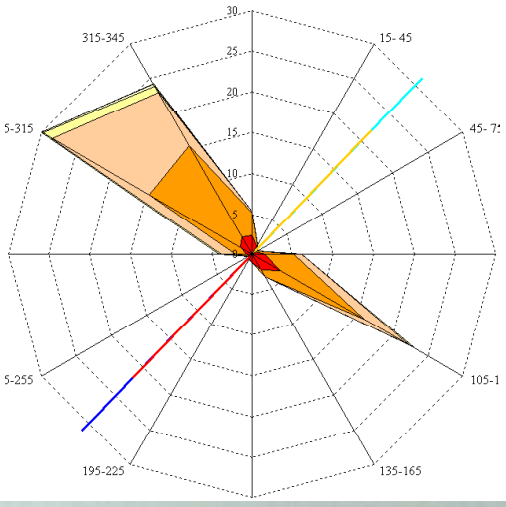

Figure 4 Wind rose and optimum layout for a site with a unidirectional wind rose

3.1 Wind Resource

Wind speeds on site are typically measured for at least 12 months to observe seasonal variation. However in order to determine the wind speed over the life time of the wind farm a technique is employed called Measure-Correlate-Predict (MCP) to predict long term wind resource (RES, 2004).

3.2 Energy Yield

A wind farm's energy yield is calculated from the power curve (& thrust curve for wake losses), wind distribution, wind shear, air density (power linearly proportional to density), and turbulence (impact on wake losses and power curve). Energy losses are calculated from wake losses, topographical effects, availability of turbines and electrical grid, electrical line losses, and turbine control losses. Additional losses like wake sector management, noise curtailment, and icing related shutdowns may be required on site by site basis. An uncertainty assessment is the done to quantify and highlight the various risks affecting the energy yield.

3.3 Environmental Assessment

For larger wind power projects, usually over 5 MW, the wind farm developer is legally required to produce an Environmental Impact Assessment (EIA). This environmental assessment evaluates the effect of the proposed wind farm on the landscape and environment, and it also allows the developer to design suitable mitigation measures to mitigate any impacts the wind farm might have.

One of the main environmental considerations is the Landscape and Visual Impact Assessment (LVIA) which describes and evaluates the landscape character and visual amenity of an area and assesses the potential impact of the wind farm on the

physical landscape characteristics and visual amenity of the study area. Figure 5 shows a wireframe and photomontage visual and landscape assessment.

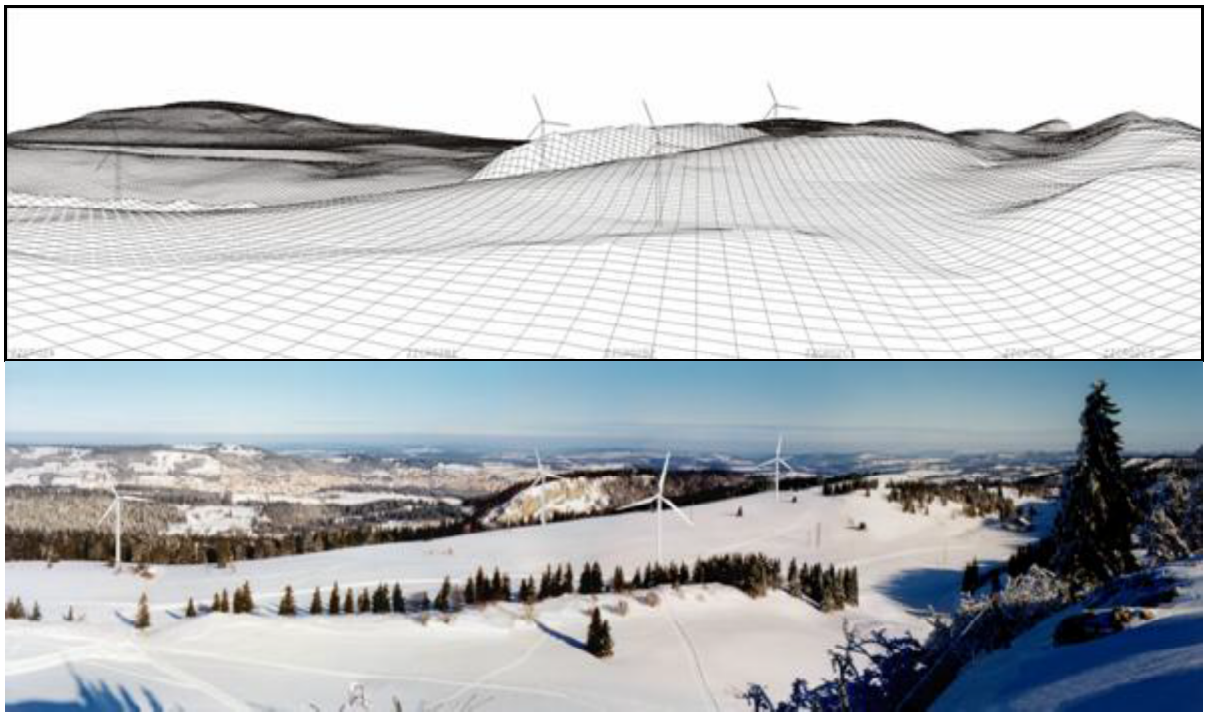

Figure 5 Visual and landscape assessment: Wireframe & Photomontage

The visual context of the site is described using a Zone of Visual Influence (ZVI) established to indicate where the site and proposed turbines are likely to be visible (coloured areas define turbine visibility) from. An example of a ZVI is shown in Figure 6.

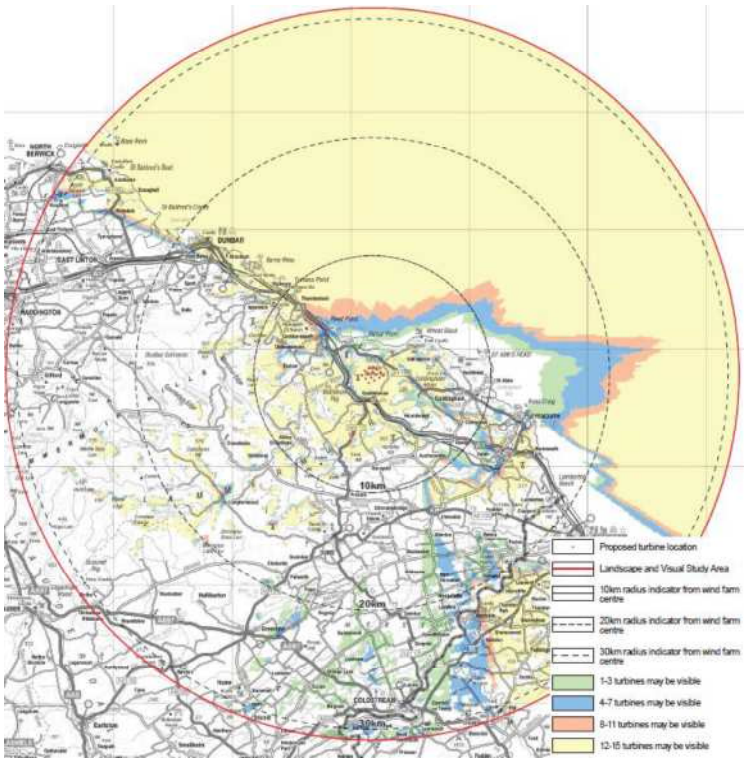

Figure 6 An example for Zone of Visual Influence (ZVI)

An ecology study of flora and fauna addresses the potential impacts of the wind farm on the habitats and species in the study area. Areas of national or local interest are identified, along with protected species, breeding and migrating birds.

An archaeological and cultural heritage assessment is undertaken in advance of submitting a planning application for the proposed wind farm. This assessment examines the known archaeology and built heritage and an assessment is made of the likely significant effects of the wind farm development upon archaeology and cultural heritage.

An electromagnetic links assessment is carried out for the likely impacts of the wind farm on communication systems that use electromagnetic waves as the transmission medium (e.g. television, radio or microwave links).

An aviation assessment is carried out for the likely impacts of the wind farm on the operational requirements of various aviation or weather related stakeholders which make extensive use of radar systems.

The Highways and Rights of Way assessment deals with effects arising from the predicted levels of traffic movements associated with the wind farm including public rights of way. The main transport effects are associated with the movements of commercial Heavy Goods Vehicles (HGVs) and abnormal loads to and from the site during the construction phase of the wind farm.

Assessment of the potential impacts of the wind farm on existing baseline conditions which include geology, geomorphology, soils, minerals, ground contaminants and hydrogeology are also completed. The potential hydrological (i.e. surface water) effects of the construction, operation and decommissioning of the wind farm development is also assessed. The assessment techniques used are aimed at identifying hydrological constraints on the layout of the wind farm, including areas in which development should be avoided and areas in which hydrological mitigation measures are required.

Under certain combinations of geographical position, time of day, time of year & meteorological conditions, the sun may pass behind the turbine rotor and cast a shadow over neighbouring buildings' openings (i.e. windows and doors) where the contrast between light and shade is most noticeable. To a person within that room the shadow, depending on its intensity, may appear to flick on and off, giving rise to an effect referred to as 'shadow flicker'. The wind farm is designed so that the distance to nearest properties is adequate so there is minimal impact from shadow flicker in accordance with appropriate guidance.

Noise can have an effect on the environment and on the quality of life enjoyed by individuals and communities. The effect of noise is therefore a material consideration in the determination of planning applications. An assessment of the acoustic impact of the wind farm is completed according to the recommendations & guidelines detailed in the 'The Assessment and Rating of Noise from Wind Farms' (ETSU, 1996) in the UK. The aim of these guidelines is to ensure noise levels will offer a reasonable degree of protection to the acoustic amenity of residents who are in proximity to the proposed wind farm.

3.4 Constraints Map

Through the process of different constraints and adverse impacts being identified and evaluated there is an iterative approach to the design of the wind farm. The wind farm is designed to avoid environmental constraints and typical separation distances are as follows:

- Bridleways – 200m
- Gas Pipe lines – 1.5 x hub height
- Overhead High Voltage Power Lines-3 x Rotor Diameters.
- Footpaths – 50m
- Roads – toppling distance
- Bats ~1 x rotor diameter + 50m
- Scheduled Ancient Monuments – typically toppling distance
- Blanket Bog – avoid
- Habitations – approx 10D
- Electromagnetic Interference (EMI) – depends on constraint
- Hydrology – 70m (30m for ditches)

Figure 7 shows the results of such constraints and consequently the limitation to the locations of turbines for the wind farm.

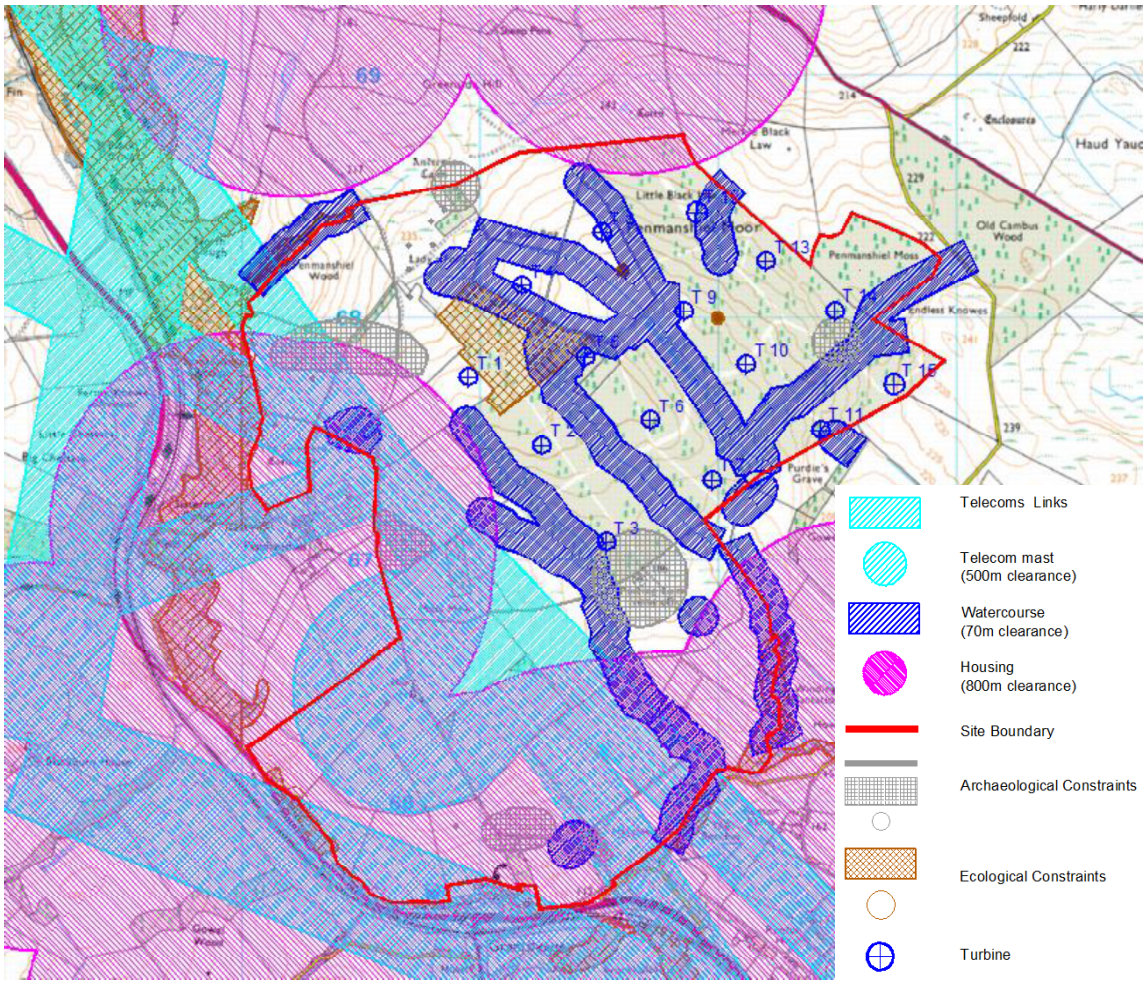

Figure 7 Combined Constraints Map

4. Noise

Following completion of designing a layout based on all the constraints defined by distance as shown in Figure 7, this normally results in a layout which does not have any noise issues, and consequently the design of a wind farm does not typically depend on noise. However the proposed wind farm layout is checked for noise in accordance with appropriate guidance on assessing wind farm noise, which in the UK is ETSU-R-97.

The ETSU-R-97 guidance makes it clear from the outset that any noise restrictions placed on a wind farm must balance the environmental impact of the wind farm against the national and global benefits that arise through the development of renewable energy resources. The principle of balancing development needs against protection of amenity may be considered common to any type of noise control guidance.

The basic aim of ETSU-R-97, in arriving at the recommendations contained within the report, is the intention to provide:

"Indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities."

ETSU-R-97 provides a robust basis for assessing the noise impact of a wind farm and has been applied at the vast majority of wind farms currently operating in the UK An article published in the Institute of Acoustics Bulletin Vol. 34 No. 2, March/April 2009 (Institute of Acoustics, 2009), recommends a methodology for addressing issues not made explicit by, or outside the scope of, ETSU-R-97 – such as in relation to wind shear or noise propagation modelling. This article was authored by a group of independent acousticians experienced in wind farm noise issues working for both wind farm developers, local planning authorities and third parties.

More recently the Institute of Acoustics has brought out a Good Practice Guidance (IoA GPG, 2013). The Good Practice Guide provides guidance on all aspects of the use of ETSU-R-97 and, effectively, reaffirms the recommendations of the Acoustics Bulletin article with regard to propagation modelling and wind shear.

4.1 Assessment Methodology

To ensure adequate assessment of the potential impacts of the operational noise from the proposed wind farm the following steps are undertaken in accordance with relevant guidance.

The baseline noise conditions at each of the nearest neighbours to the wind farm are established by way of representative background noise surveys. The assessment of background noise levels at potentially sensitive neighbouring locations requires the measurement of not only noise levels, but concurrent wind conditions, covering a representative range of wind speeds. These wind measurements are made at the wind turbine site rather than at the properties, since it is this wind speed that will subsequently govern the wind farm's noise generation. To establish the baseline conditions, sound level meters and associated apparatus are set-up to record the

required acoustic information at a selection of the most noise sensitive dwellings geographically spread around the proposed site and are likely to be representative of other houses in the area.

The noise levels incident at the nearest neighbours due to the combined operation of all the wind turbines for the proposed wind farm using a sound propagation model are estimated giving due regard to: the locations of the wind turbines; the locations of the nearest, or most noise sensitive neighbours; the intervening terrain; & the likely noise emission characteristics of the wind turbines. The ISO 9613 Part 2 model is used (ISO, 1996), this being identified as most appropriate for use in such rural sites (ETSU, 2000), and recommended for use in the Institute of Acoustics Good Practice Guidance. The specific interpretation of the ISO 9613 Part 2 propagation methodology has been employed as in the Institute of Acoustics Bulletin article (Institute of Acoustics, 2009). An example of the predicted noise levels at nearby properties is typically presented as shown in Figure 9.

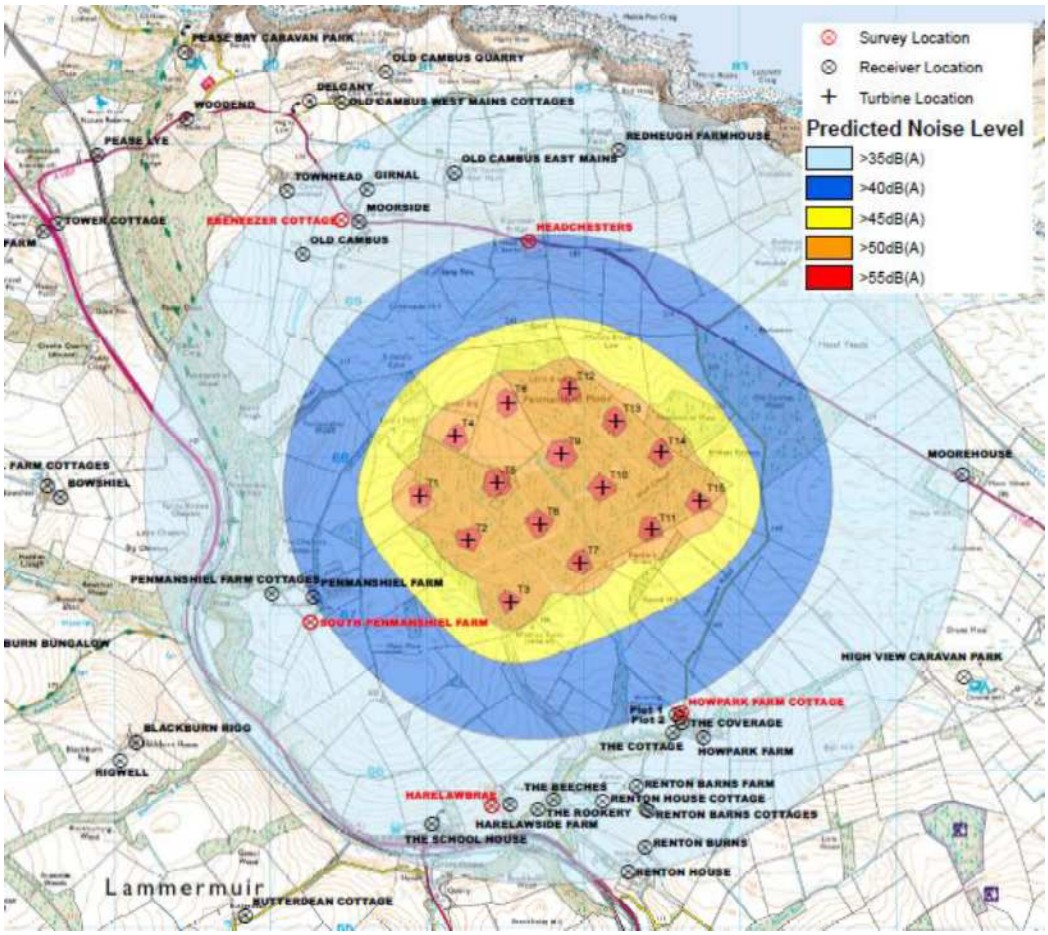

Figure 9 Example of a Predicted Noise Footprint

With due regard to relevant guidance or regulations the acoustic assessment criteria is derived. ETSU-R-97 states that different limits should be applied during quiet waking and night-time hours. The quiet waking hour's limits are intended to preserve outdoor amenity, while the night-time limits are intended to prevent sleep disturbance. The general principle is that the noise limits should be based on existing background noise levels, except for very low background noise levels, in which case a fixed limit may be applied.

The evaluation of the acoustic impact is undertaken by comparing the estimated noise levels with the assessment criteria. An example of the comparison of predicted noise levels with limits is shown in Figure 9.

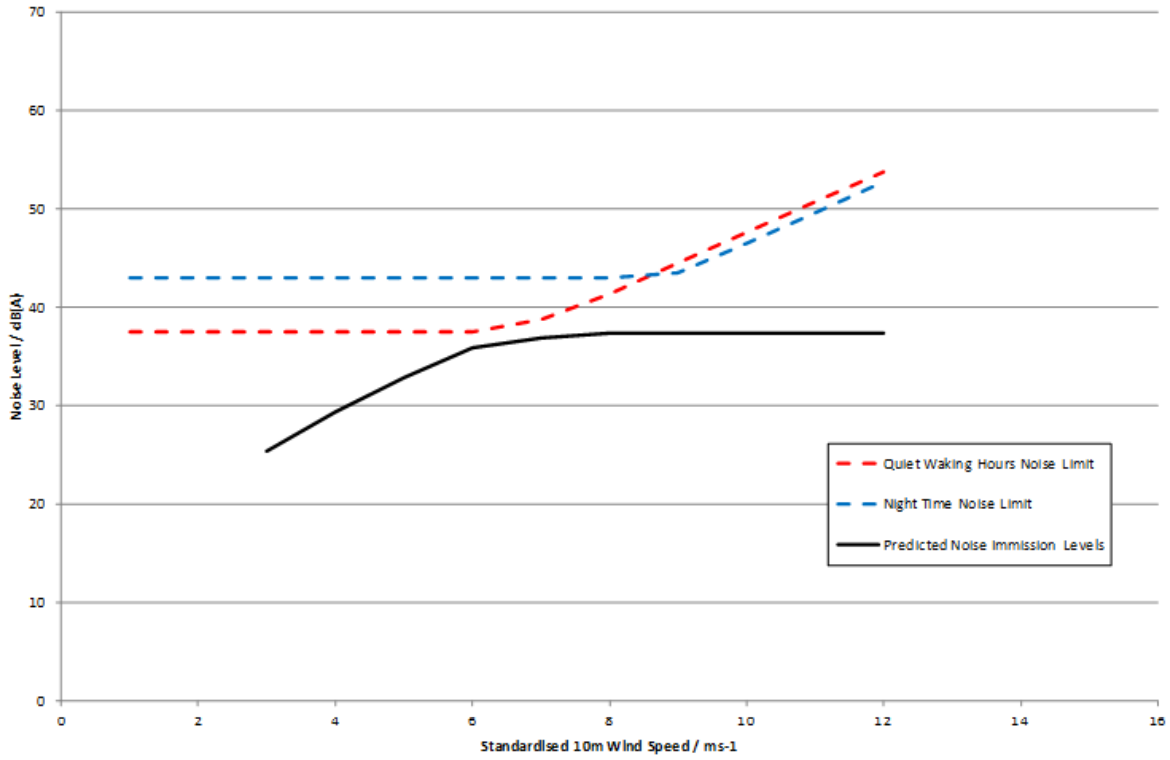

Figure 9 Comparison of predicted noise levels against limits

If the noise limits were exceeded then noise becomes a critical constraint and the proposed wind farm layout, or turbine type, needs re-evaluated so that the wind farm is designed to comply with appropriate guidance on wind farm noise.

4.2 Cumulative Consideration

In acoustic practice it is generally accepted that where a difference in noise immission levels due to each noise source is greater than 10 dB(A) there is negligible cumulative effect and the smaller source can be ignored. Therefore, conversely, a cumulative impact of any magnitude can only be possible if both wind farms produce predicted noise levels within 10 dB of each other at the assessed property.

ETSU-R-97 recommends that the derived noise limits applicable at nearest house locations shall relate to the cumulative effects of noise from all wind turbines that may affect a particular location.

Depending on the status of the cumulative wind farm, this will determine how it is to be assessed. These include whether or not the proposed wind farm has had a planning application submitted and is waiting to be determined, or if it has been consented. If the wind farm is at a preplanning stage it would not be considered because an application may never be submitted or the layout may change before going to planning. Existing wind farms would be considered in the same way as consented wind farms.

For wind farms not yet determined, but with a planning application submitted, the method to assess these wind farms would be to predict noise immission levels at the assessed properties due to the third party wind farm, and then complete a cumulative noise assessment by combining predicted noise levels due to the proposed wind farm and the third party wind farm, and compare these cumulative predictions to the appropriate noise limits.

If a wind farm has been granted planning consent, as a worst case assumption, it may be postulated that this wind farm could produce higher noise levels than predicted for that site, i.e. produce noise levels that are at maximum equal to the consented noise limits. For this situation the critical property is identified and this will be the property that can have noise levels at the limits which the third party wind farm has been conditioned to. Consequently all other properties would have lower noise levels otherwise the critical property would be in breach of noise limits, therefore the noise levels at the other properties are predicted by inferring the predicted noise levels from the most critical property.

The process as of assessing cumulative noise impact is overly conservative at ensuring that the ETSU-R-97 derived limits at each nearby house are adhered to, as some houses cannot be downwind of all wind farms at the same time. As such a directional assessment is typically completed to show more realistic noise levels at the most critical properties.

The issue with attempting to design a wind farm to account for cumulative wind farms is that the status of these wind farms could change unless they are already consented or exist, in which case the wind farm must be designed so that noise limits are not exceeded considering worst case assumptions.

5. Conclusions

A developer is responsible for designing a wind farm considering all constraints, of which noise is only one factor. This paper provides an insight into the process of wind farm design and how noise only plays a small part of the design process.

Key design constraints that feed into the environmental assessment include visual and landscape, ecology, archaeology, agriculture, electromagnetic links and highways, and from the different constraints and adverse impacts a wind farm is designed.

Noise is evaluated according to the appropriate guidance and legislation, and the wind farm redesigned where necessary to account for noise. Consideration also needs to be given for the status of cumulative wind farms, and how these affect the design of the wind farm in relation to noise.

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