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Wind Farm Noise Modelling
Preliminary Report
DRAFT

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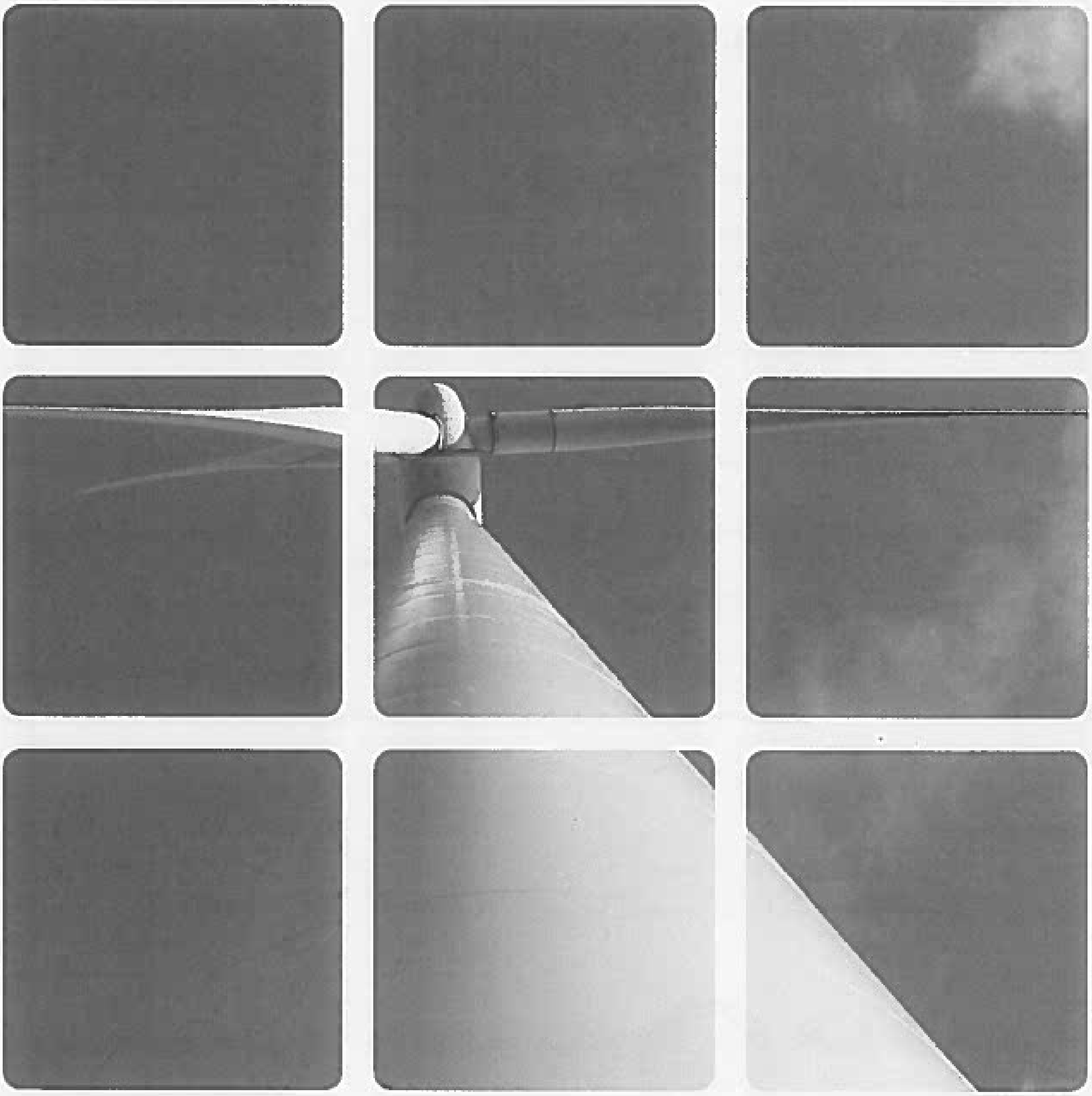

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SEAI

Report on Wind Turbine Noise Modelling

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EXECUTIVE SUMMARY

This report has been prepared in order to inform a decision on the impact of potential noise limits on the available wind energy capacity in Ireland. There are a number of simplifying assumptions that have been made in compiling this report, including the size of turbine chosen for the study. The turbine choice was determined from discussions with wind turbine manufacturers and wind farm developers as a 3-3.5 MW turbine with a tip height of 150-175m.

An acoustic model with the following iterations was prepared:

- Turbine type x 3
- Turbine hub height x 3
- Wind speed x 7
- Ground factor x 2
- Terrain contours x 7

Noise predictions were calculated in 10 metre steps out to a distance of 1 kilometre using the ISO 9613-2 methodology and following the Institute of Acoustics *"Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise"*. This yielded statistically robust distance/noise level data which was then analysed to determine appropriate separation distances for each 1 dBA band in the range 38 dBA to 45 dBA.

From the calculated separation distances a GIS model was prepared with the separation distance applied to:

- Sensitive Receptors listed in the GeoDirectory
- Ecological constraints
- Cultural Heritage sites
- Geological exclusion area
- Topographical and land cover constraints

Based on turbine tip height appropriate wind speed zones/areas were determined and a calculation of the available land and potential wind farm development capacity was determined.

The potential capacity for wind farm development is impacted significantly by the selection of a fixed noise limit level. The reduction from the current daytime limit of 45 dBA to the proposed limit of 40 dBA will result in a loss of capacity of 13,797 GWh or a 52% loss of capacity. Similarly a reduction from the current night time limit of 43 dBA will result in a 29% loss in capacity.

1 PROJECT BRIEF

The Department of Communications, Energy and Natural Resources (DCENR) is currently conducting a targeted review of the Wind Energy Development Guidelines 2006 (WEDG06). The review is a targeted review in relation to noise, proximity and shadow flicker.

RPS have been commissioned by the Sustainable Energy Authority of Ireland (SEAI) for the provision of a desk study to assess the impact of a range of noise limits on the location and scale of wind turbine development in Ireland. This desk study will inform the DCENR of the appropriateness of applying an absolute noise limit value in the range of 38 – 45 dB by assessing the potential impact of each of the 8 proposed absolute noise limits with respect to the identification of potential areas for future wind project development.

1.1 SCOPE OF WORK

A revised methodology was developed to meet the revised timeframe issued by SEAI to ensure that the desk study informs the DCENR of the potential impact and appropriateness of the absolute noise limit values prior to the development of the revised guidance. The scope of this acoustic modelling and GIS mapping exercise is to provide a preliminary desk analysis of noise emissions from large wind turbines in 'typical' conditions in Ireland.

This report is based on the specification in Appendix 1 of the SEAI Request for Tenders Document:

- Identification of potential areas available for future wind project development having regard to a given range (38 – 45dB) of noise limits;
- Delivery of a GIS application that will, take consideration of the location of dwellings & other noise sensitive properties, identify viable areas for wind turbine placement with a given set of inputs;
- A GIS application output, a map layer of the viable wind turbines sites under the range of noise limits (from 38 – 45dB).

The methodology to complete this work is outlined in Section 2 of this report.

2 MODEL METHODOLOGY

The acoustic models produced in this study are based on the identification of potential viable areas for wind turbine placement with regard to the use of an absolute noise limit (38 – 45 dB expressed as L_{A90}) as an appropriate means to control noise impact.

The process starts with a simplified acoustic model for a single candidate turbine in a generic setting. This turbine is modelled using an industry standard acoustic modelling software package to obtain the separation distances associated with different fixed limit noise levels. From this single turbine, parameters likely to influence noise emissions from turbines are modelled to determine a range of distances over which specific noise levels will occur.

This table is then used in combination with the geo-directory to prepare maps of the country. The geo-directory is used to identify all the exclusion zones set out in Section 4 of this report. From the distances determined from the acoustic model, an exclusion zone based on the required separation distance to achieve a particular noise limit value is plotted. This identifies the 'residual' areas where a wind turbine can be located without the noise level arising from the turbine exceeding the threshold value.

Using GIS, the maps are used to calculate the 'residual' areas which are in turn used to prepare a table of available area suitable for wind farm development, subject to the particular noise thresholds.

2.1 ACOUSTIC MODEL

The acoustic model is based on a single candidate turbine on different terrain types. The sound emission levels have been calculated to a distance of 1 kilometre, in accordance with ISO 9613-2, using the industry standard Cadna noise (Version 4.3) modelling software. The single candidate turbine was then factored up to a multiple turbine scenario. The parameters of the model are set out in Section 3 of this report.

An acoustic model was prepared using candidate turbine noise data for typical 2.3 to 4.5 MW turbines. The predicted noise level at any point was then calculated for terrain and meteorological factors to determine an estimated operating noise level from a theoretical wind farm. This provides a table of the required separation distances from a sensitive receptor location to a turbine.

2.2 GIS MODEL

ESRI ArcGIS 10.2 is used for data collation and building the GIS process model. The An Post GeoDirectory is used for identification of the sensitive receptors. The GeoDirectory classifies each building as being either residential, commercial, both (residential and commercial) or unknown. The data comes as point database where each building is located to within a metre with pinpoint accuracy. GeoDirectory also gives further breakdowns of information such as townland, electoral and county divisions. Euclidean distance raster is generated from the GeoDirectory points with the exclusion of commercial point locations. Other technical, environmental, cultural heritage and archaeological exclusions are also applied to the distance raster.

The output from the acoustic model and the matching wind speed thresholds are incorporated into the GIS model to calculate the available areas. A detailed parameters and process flow is given in Section 4 of this report.

3 ACOUSTIC MODEL

The scope of this acoustic model is to provide a preliminary analysis of noise emissions from large wind turbines in 'typical' conditions in Ireland. The study is designed to cater for the largest range of conditions possible while retaining realistic, rather than extreme modelling scenarios.

3.1 ACOUSTIC MODEL ASSUMPTIONS

Wind farm design and layout is a highly complex task requiring the consideration of shadow flicker, visual impact, setback distances, wind conditions, turbine clearance/separation and ecological requirements, in addition to acoustics. In order for this study to provide a realistic wind farm model scenario, a number of simplifying assumptions have been made regarding the type, layout and location of wind turbines:

1. Turbines will not be located on a water body (lake or river of more than 700m in extent),
2. There are no non-acoustic restrictions on turbine location,
3. All turbines are 'typical' turbines as set out in Section 3.2,
4. All turbines experience the same meteorological conditions, and
5. Cumulative impacts of multiple turbines equate to a 3 dB increase in received noise level (wind farm factor – see section 3.2.1).

3.2 ACOUSTIC MODEL CALCULATION PARAMETERS

The acoustic model has been prepared using the parameters set out in Section 4 of the *"Institute of Acoustics Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise"*, Cand et al (2013). These parameters represent current best practice for modelling wind farm noise. The main points set out in the methodology are as follows:

- Model calculations are carried out using *ISO 9613-2: Acoustics – Attenuation of sound during propagation outdoors – Part 2 General Method of Calculation for Propagation Modelling*,
- Wind turbine sound power (source) to be based on manufacturer warranted values or 'standard' values measured using IEC 614100-11 plus 2 dB to allow for measurement uncertainty,
- Reported wind speeds are normalised to a height of 10m,
- Ground factor, G = 0.5 or G = 0.0 (Hard ground or propagation over water).
- Wind turbine noise predictions are based on octave band data,
- L_{90} values are determined by subtracting 2 dB from L_{eq} levels,
- Receiver height of 4 metres, and
- Atmospheric conditions of 10°C and 70% humidity.

In addition to the noise model calculations, certain assumptions are made regarding the siting and configuration of wind turbines in wind farms.

3.2.1 Single Turbine Model v Wind Farm Model

The basis of the model is that of a single turbine. In order to cater for the likelihood that turbines will arise in clusters, a correction for the proximity of additional turbines is required.

Wind farm layouts are planned to optimise the electrical output when all the other constraints have been taken into consideration. In order to achieve maximum electrical output it is necessary to separate the turbines to avoid turbulence from one turbine interfering with another. The separation distance is normally measured in terms of rotor diameter and is generally site specific. The common range of separation distances is from 6 to 12 rotor diameters, which in the case of large turbines means something greater than 500m.

With a single turbine impacting on a sensitive location, the acoustic model predicts a noise level in dB. Due to turbine separation it is likely that the next nearest turbine will be at least 1.4 times the distance of the first turbine away, if the turbines are close to the sensitive receptor location. This would have the effect of adding 2 dB to the single turbine noise level. At greater separation distances the cumulative impact would be less than this at the sensitive location.

In order to estimate the potential of additional turbines (more than 2) a correction factor of 3 dB has been adopted for the purpose of the acoustic model.

3.2.2 Terrain

In order to provide a representative selection of terrain types, candidate turbines were modelled on the following terrain;

- Flat terrain with ground factors of 0.0 and 0.5
- 20 degree inclines with ground factors of 0.0 and 0.5 for cross-slope, up-slope and down-slope conditions
- 40 degree inclines with ground factors of 0.0 and 0.5 for cross-slope, up-slope and down-slope conditions

This range of terrain types provides a broad range of situations where turbines could be located in either undulating or flat terrain. The terrain slope is based on the terrain between the source and receiver positions in order to replicate propagation across complex terrain, in particular across valleys.

3.2.3 Turbine Hub Height/Tip Height

The acoustic model is based on the available information from three specimen turbines. From discussions with manufacturers' representatives and wind farm designers, the maximum hub height likely to be chosen in Ireland is in the order of 100m. Hub heights of 120m are possible in low wind sites on continental Europe but unlikely in Ireland. For the purpose of this study, noise models were prepared on the basis of three turbine hub heights; 75m, 92m and 110m. This covers the likely range of hub heights to be encountered in Ireland.

The current design of 3-3.5MW turbines has a range of rotor diameters from 100m to 140m, the larger diameter rotors being used on low wind sites. If we combine the highest possible hub height (120m) with the largest rotor diameter (140m); this yields a maximum tip height of 190m. In order to estimate the available land resource tip heights of 125m, 150m, 175m and 200m were used in the setback calculations. For practical purposes in Ireland, tip heights of 150m to 175m are likely to form the design envelope in the medium term. Turbine tip heights of 125m to 166m have been modelled acoustically for this report. This constraint was based on available sound power data.

3.3 TURBINE CHOICE

A review of 68 sample large wind farms that have been granted planning permission indicates that 43 sites are proposing wind turbines of less than 2.5 MW capacity, 18 sites are proposing turbines with a rated capacity of between 2.5 MW and 2.75 MW and 7 sites are proposing to use turbines of 3 MW capacity. This reflects international practice where the maximum turbine size appears to be stabilising at around 3 to 3.5 MW for onshore wind farms, with larger units being designed for offshore use.

In order to determine the type of turbines likely to be used on wind farms in Ireland, and the corresponding noise emissions, a desk study of candidate turbines was undertaken. This included turbines in the range 2.3 to 4.5 MW from the following manufacturers:

- Enercon
- Gamesa
- General Electric
- Nordex
- Siemens
- Vestas

Consultations took place with manufacturers, wind farm designers and developers to determine the likely scope of design briefs over the next 10 years. As some of the data was provided on a commercially sensitive basis, candidate turbines are not named in this report.

The consensus view is that the current generation of 3 to 3.5MW turbines is likely to be the largest common candidate turbine type in the medium term. This is based on manufacturers' development programmes and the tendency to locate larger wind turbines offshore. Noise emissions from turbines are the focus of considerable design effort on the part of manufacturers. The result is that the noise levels of current turbine designs have not increased in proportion to the increase in power output.

A report prepared for the Danish Energy Authority (Delta, 2008) provided sound power level data for 37 wind turbines from 75 kW to 2000 kW. This data was combined with manufacturers' data to produce **Error! Reference source not found.**. This figure demonstrates that while there has been a 60 fold increase in power output, the sound power output has increased by 16 dB, a 3 to 4 fold increase in relative terms.

A trend line has been constructed in Error! Reference source not found. and the three candidate turbines used for this study are at or above this trend line in terms of sound power.

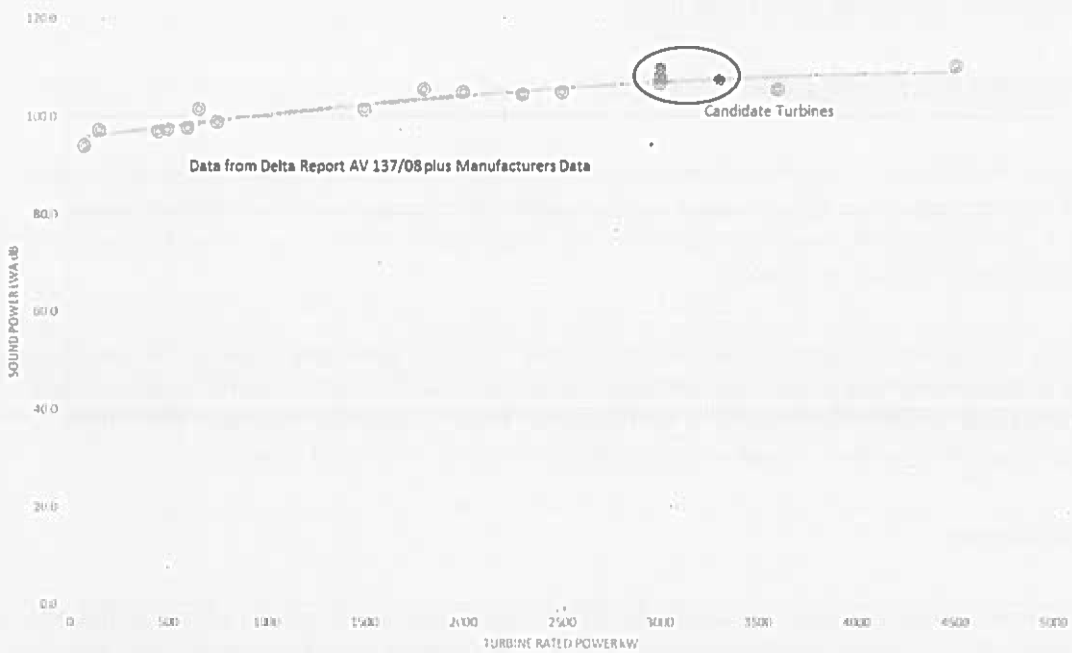


Figure 3.1: Turbine Sound Power vs Turbine Electrical Power Output

It is reasonable to assume that a range of capacities will continue to be used onshore as site specific considerations will limit turbine height and scale. For the purposes of this study, a 3 to 3.5 MW turbine size has been chosen. Three typical turbine configurations (A, B and C), based on manufacturers' specifications (+2 dB for measurement uncertainty), are shown in Table 3.1.

Table 3.1: Typical turbine configurations

	Rating (MW)	Blade Diameter (m)	L_{WA} (dB) @ 10m/s wind speed
Turbine A	3.0	112	108.7
Turbine B	3.0	101	110
Turbine C	3.3	100	107.6

The hub heights shown in Table 3.1 have been taken as the heights for typical sites. On higher wind speed sites the hub heights may decrease to 70m. The blade diameter is unlikely to get much larger as noise emissions are related to blade tip speed and rotor diameter is one of the primary limiting controls in this regard.

3.3.1 Wind Turbine Noise Data

Wind turbine noise emission data is now reported in accordance with IEC 61400-11 using 'standardised' wind speeds. DECLG (2013) proposes an absolute noise limit, which is independent of wind speed. At lower wind speeds, and lower power outputs, noise emissions from turbines are reduced. With modern pitch controlled turbines; as the wind speed increases, the noise level from the turbines increases until it reaches a plateau at around 8m/s. The modelling for this survey was based on octave band sound power output levels for a range of wind speeds from 4m/s to 10m/s in 1m/s intervals, i.e. 7 separate wind speed bands.

3.4 ISO 9613-2 MODEL PARAMETERS

The standard is designed to enable the calculation of L_{eq} values from sound power levels (L_w) under 'average' meteorological conditions which are favourable to propagation. The standard considers downwind and temperature inversion conditions as using these conditions as a baseline tends to predict worst-case (highest) noise levels.

In the case of a generic model for the whole country, it is not physically possible for sensitive locations to be downwind in worst-case conditions all of the time. One of the overall assumptions is that turbines are equally distributed in all directions from a sensitive location. The model is therefore conservative in that a downwind situation is unlikely to arise all of the time.

3.4.1 Directivity

Directivity arises in two contexts; the directivity of the source and the directivity of the model. For the purposes of this study wind turbine sources are considered omnidirectional. ISO 9613-2 however does introduce a significant directionality in noise levels as the standard is based on downwind propagation or inversion conditions. This is illustrated in Figure 3.2 and Figure 3.3 where ISO 9613-2 is considered as 'average conditions for downwind propagation'.

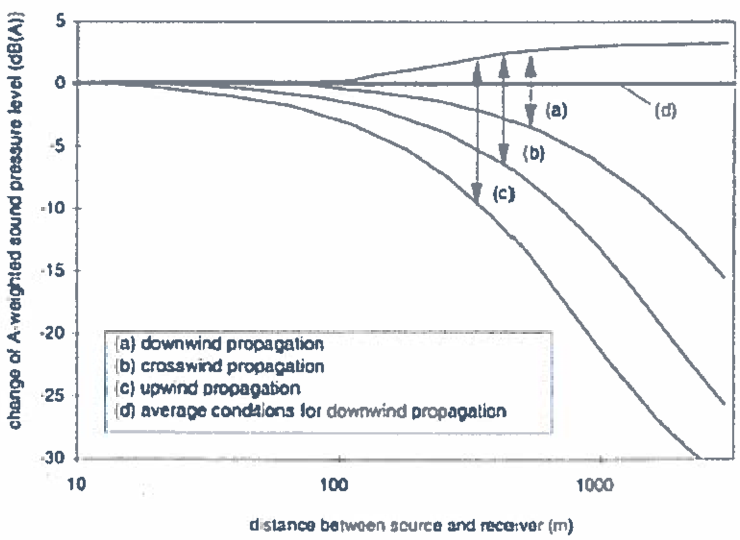


Figure 3.2: Weather Effects from Wagner et al (1996)

Figure 3.2 shows the possible change of A-weighted sound pressure level due to weather effects compared to propagation including only spherical spreading and air absorption. At 1,000m the difference between upwind and 'average' conditions is approximately 20 dB.

Figure 6 (b) of Cand et al (2013) also indicates that there is a significant difference between downwind, crosswind and upwind propagation. The difference between downwind and upwind propagation in complex terrain is indicated as being up to 8 dB.

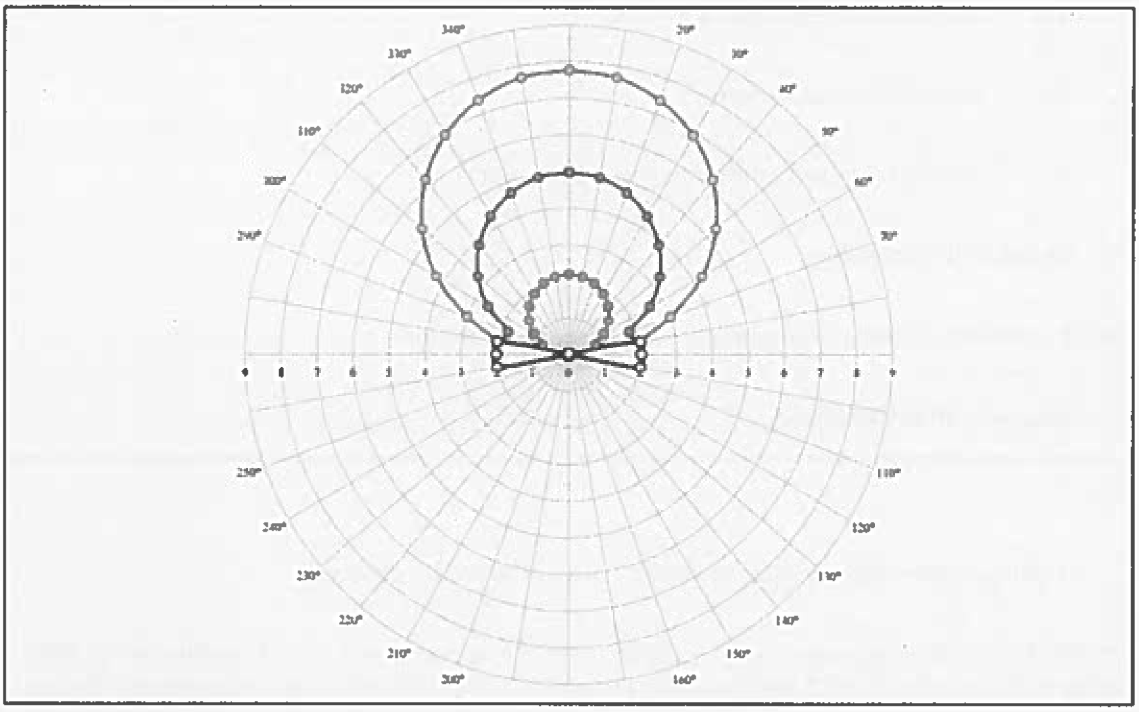


Figure 3.3: Weather Effects from Cand et al (2013)

Figure 3.3 shows the estimated change in noise levels with wind direction. 180° refers to a receptor downwind of the wind turbine in complex landscapes (refer to Figure 6(b), Cand et al (2013). Black corresponds to close to the source, expanding outward to Red which equals 18 times the tip height).

ISO 9613-2 does not have the capability of modelling specific wind directions. Figure 3.2 would indicate attenuation changes of up to 20 dB between upwind and downwind propagation, while Figure 3.3 is more conservative.

No wind direction correction is applied to the models for the purposes of this report. The separation distances are based on downwind propagation/inversion which is not the case on a continuous basis. This provides a conservative estimate of the separation distance required.

3.4.2 Attenuation

Attenuation usually refers to a decrease in intensity of sound as a result of the absorption of energy and scattering out of the path of a detector. Attenuation can arise from a number of factors and ISO 9613-2 sets out the total attenuation to be taken into consideration as follows:

$$\text{Attenuation} \quad A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \qquad (2)$$

Where:

A_{div} = attenuation due to geometrical spreading

A_{atm} = attenuation due to atmospheric absorption

A_{gr} = attenuation due to ground effect

A_{bar} = attenuation due to barriers

A_{misc} = attenuation due to miscellaneous other effects

3.4.3 Geometric Spreading

ISO 9613-2 calculates geometric spreading according to the formula:

$$A_{geometric} = 20 \log10 (d/d_o) + 11 \qquad (3)$$

Where:

d is the source-receiver distance and d_o = 1m is a reference distance.

There will be a certain ambiguity in the region near the source which is not evident in far field conditions. In the case of wind turbine noise at neighbouring properties, we are generally dealing with far field conditions. For any given site the variation in this parameter does not alter. Standard spherical propagation as set out in ISO 9613-2 is used.

3.4.4 Atmospheric Absorption

The atmospheric attenuation depends on the frequency of the sound and the ambient temperature and relative humidity of the air. Atmospheric pressure has a very weak influence and can be ignored. Cand et al (2013) suggests that for wind turbine noise prediction, the ambient temperature and the relative humidity should be standardised at 10°C and 70% respectively. This has the effect of reducing uncertainty due to atmospheric absorption to within the overall tolerance bands of ISO 9613-2.

There is no site specific correction required for atmospheric absorption. No additional correction is therefore proposed for atmospheric absorption.

3.4.5 Ground Factor Effects

The acoustic properties of ground attenuation are considered by applying an appropriate ground factor. A ground factor varies between 0 and 1, 0 being hard ground, paving, water or hard surfaces and 1 being soft ground, grassland, trees, vegetation or farm land. Cand et al (2013) and the *IOA Good Practice Guide* (IOA 2013) suggest that for wind farms, a ground factor of 0.5 should be used in all cases except large bodies of water or urban areas.

Given that we are considering large turbines (~3 MW), urban areas are not being considered. For the purpose of this study, the instance in which this would be a consideration comprises a relatively narrow body of water (up to 700m wide) with a wind turbine on one side and a sensitive location on the other. This is similar to a situation where noise propagates across a valley.

Significant research has been carried out on noise propagation over undulating ground. This can be a particular problem when wind turbines are located on elevated ground on one side of a valley and a sensitive location is on the other. The Ground Factor of 0.5 complies with the scenario recommended in the *IOA Good Practice Guide* (IOA 2013). All terrains are also calculated with a Ground Factor of 0.0 to replicate a worst case scenario where hard ground or transmission over water bodies is encountered.

3.4.6 Wind and Temperature Effects

The wind speed closer to the ground is lower than that at height. The temperature profile of the lower atmosphere depends on the time of day and the effect of solar heating. These factors combine to create a vertical gradient of sound speed. Sound will be refracted in the direction of higher sound speeds to lower sound speeds. This leads to sound being diffracted either upwards or downwards.

Under stable atmospheric conditions, downward propagation can occur during temperature inversions. This leads to increased sound levels at distance from the source. When the sound speed decreases with height, sound rays are bent upwards away from the ground, leading to reduced levels at distance from the source.

The modelling used in this report is based on downwind propagation or inversion conditions, i.e. worst case.

3.4.7 Atmospheric Turbulence Effects

The wind speed and temperature profile are not constant but generally tend to vary around mean values over relatively short periods (minutes). The effect of turbulence is to create variations in received sound level around a mean value. In extreme cases this can lead to changes in the order of 10 dB but this is relatively extreme and the typical variation is in the order of 5 dB.

No correction for atmospheric turbulence has been applied to the models in this report.

3.4.8 Barrier and Terrain Effects

Topographic screening effects are considered in section 7.4 of *ISO 9613-2 – Screening*. The standard includes for calculations, including significant screening. In the context of wind turbines in open countryside however, the effect of screening is limited. Cand et al (2013) recommend that the maximum screening effect should be limited to 2 dB "and then only if there is no direct line of sight between the highest point on the turbine rotor and the receiver location".

For the purpose of this study no additional correction for screening is applied.

3.5 ACOUSTIC MODELLING RESULTS

The acoustic model for the candidate turbines were created with variations in turbine hub heights, terrain contours, ground factor and wind speed. The noise level for each combination was calculated in 100m intervals out to a distance of 1km. This yielded over 113,000 individual model scenarios with each scenario representing one iteration of the outlined variables at different distances from the turbine.

The model scenarios were sorted into 1 dB 'bins', each of which had several thousand combinations that resulted in a received level in the range, cross referenced with the distance from the source at which it ocurred. The mean and standard deviation distance for each 1 dB bin were calculated using an Excel spreadsheet.

Plots of the data for each 1 dBA band are provided in Figure 3.4 to Figure 3.11.

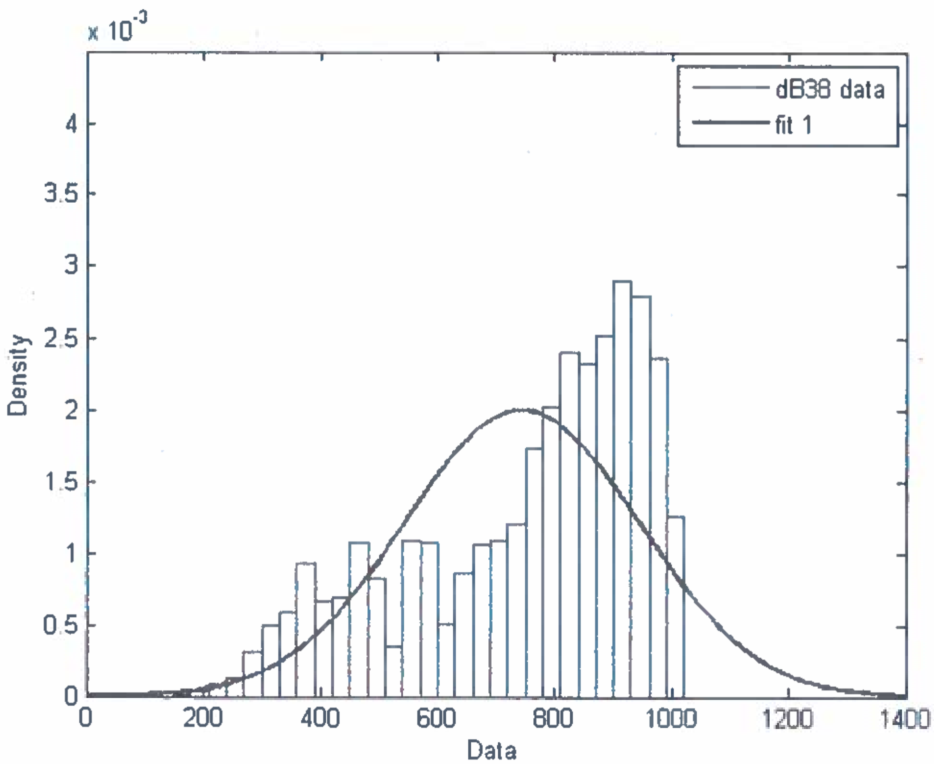


Figure 3.4: Probability Density Function for 38 dB (n=5592)

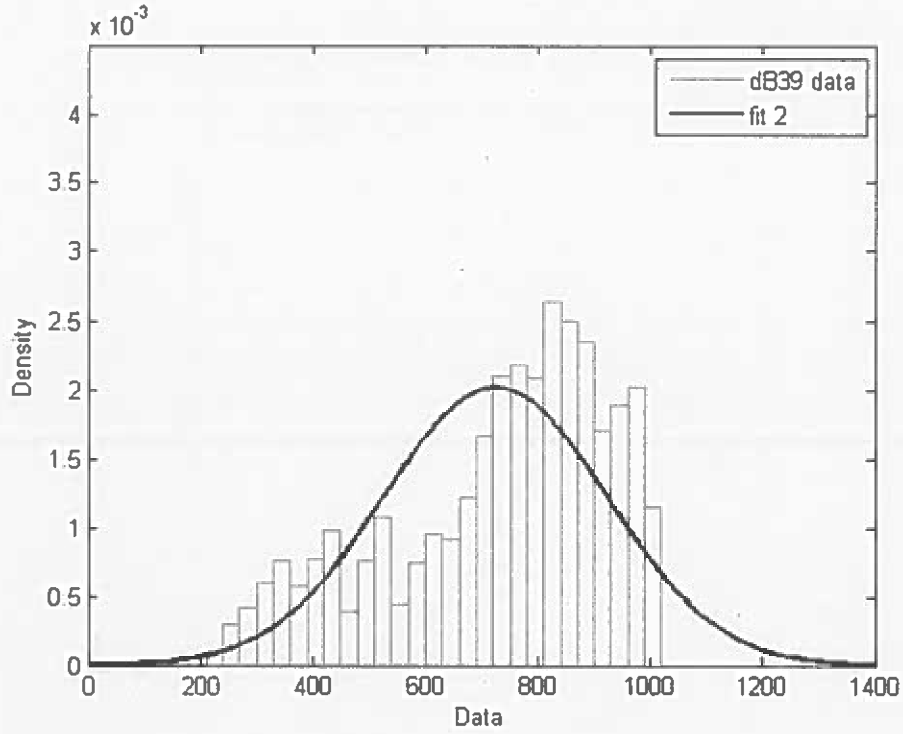


Figure 3.5: Probability Density Function for 39 dB (n=6186)

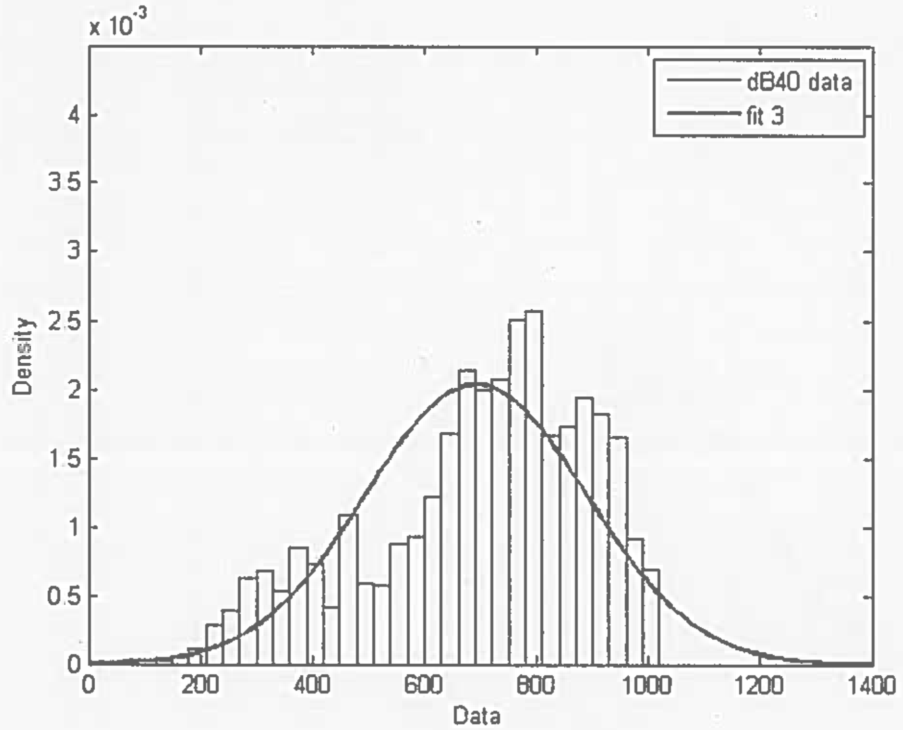


Figure 3.6: Probability Density Function for 40 dB (n=6431)

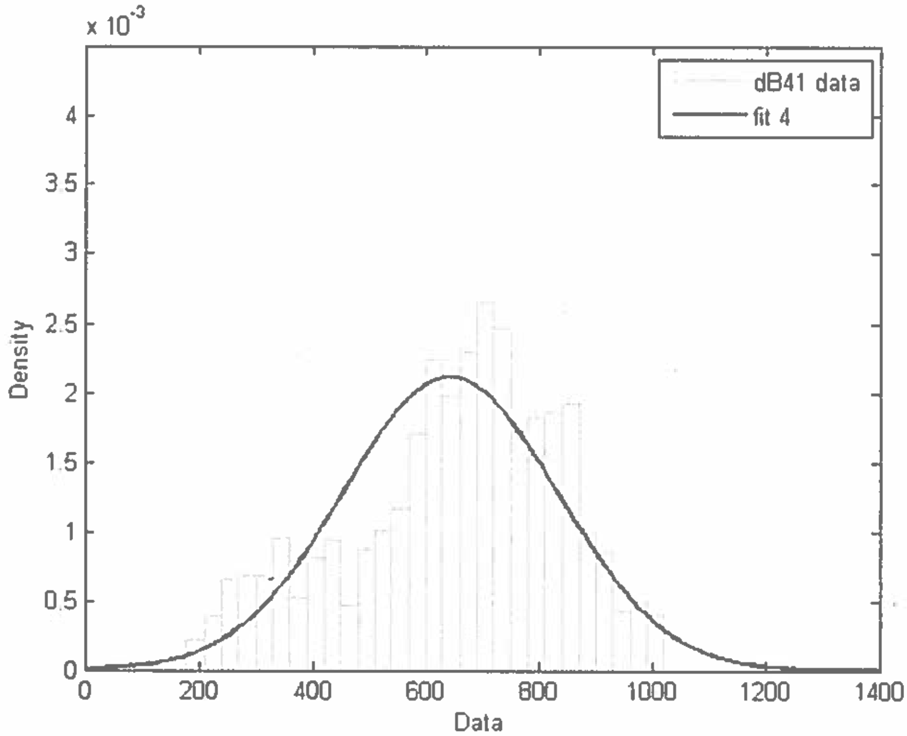


Figure 3.7: Probability Density Function for 41 dB (n=6272)

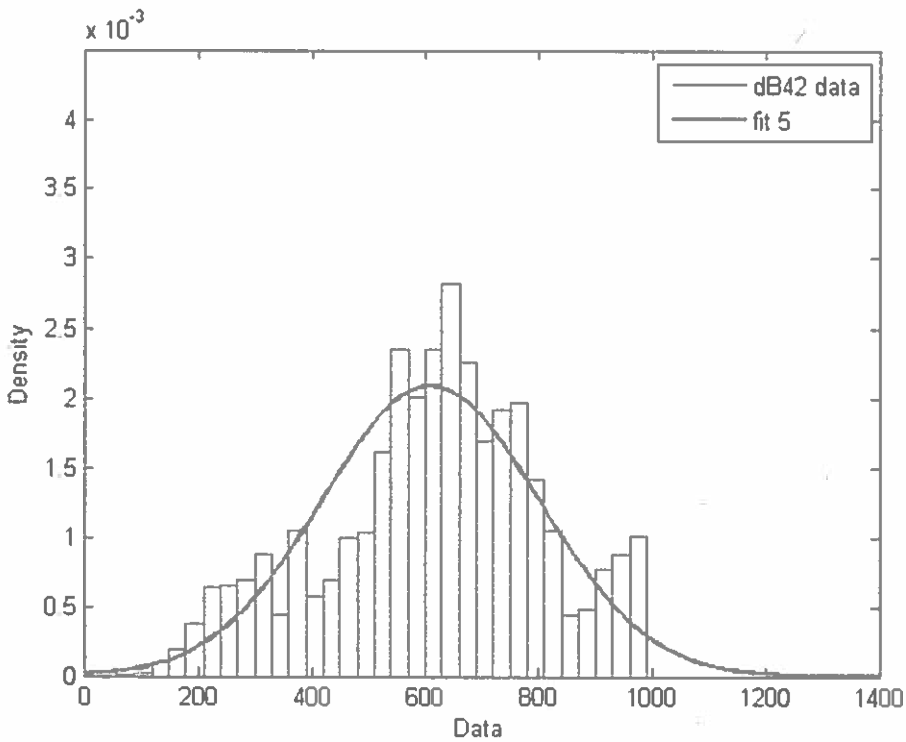


Figure 3.8: Probability Density Function for 42 dB (n=6133)

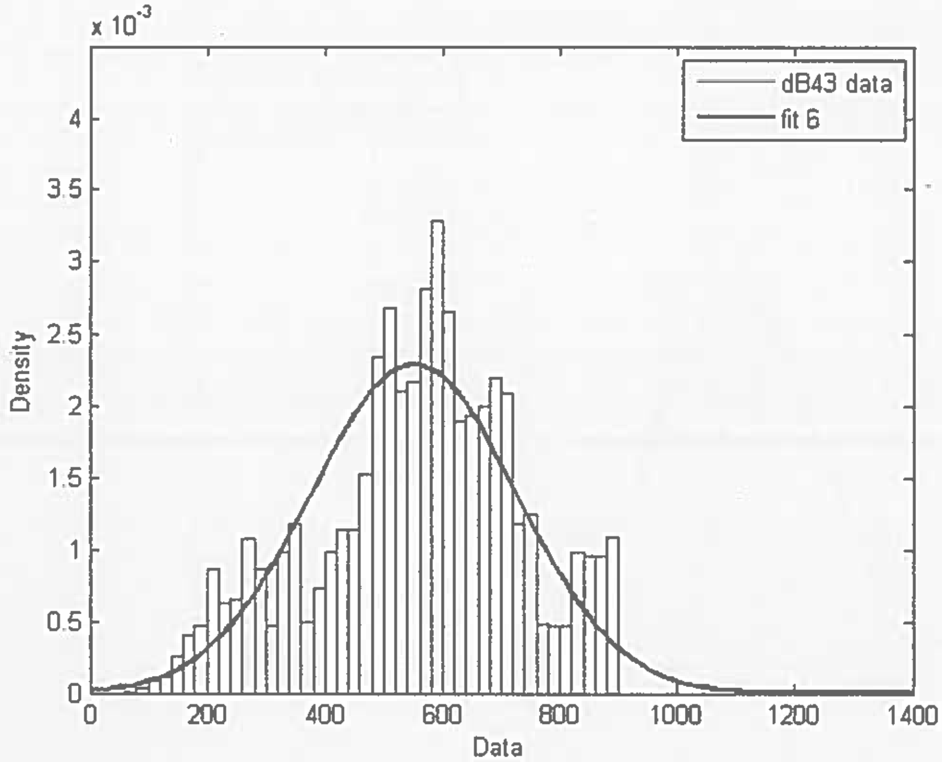


Figure 3.9: Probabillty Density Function for 43 dB (n=5645)

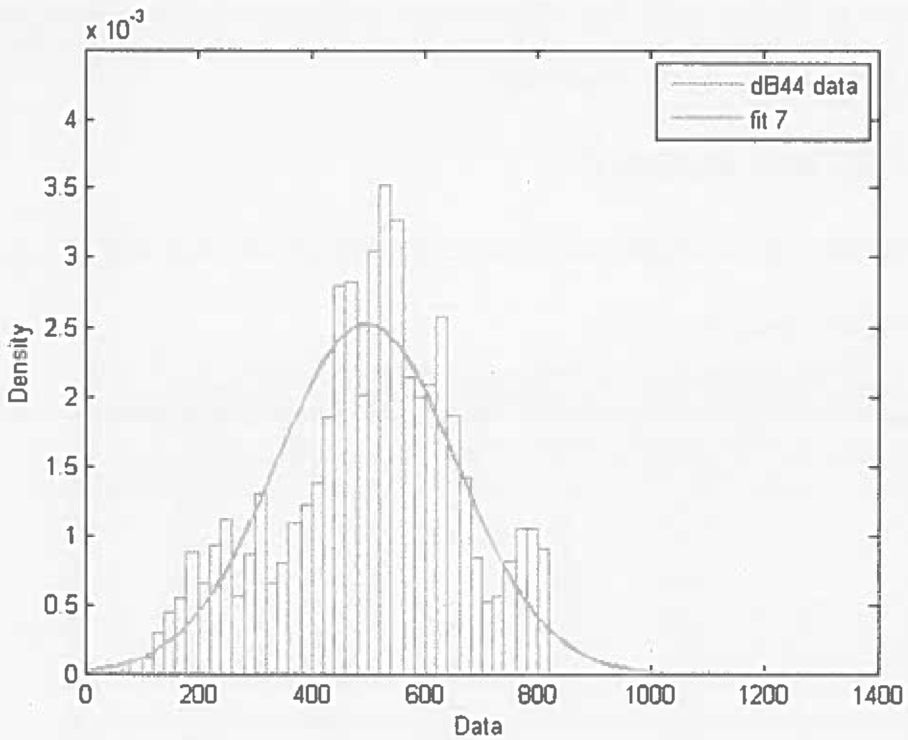


Figure 3.10: Probability Density Function for 44 dB (n=5197)

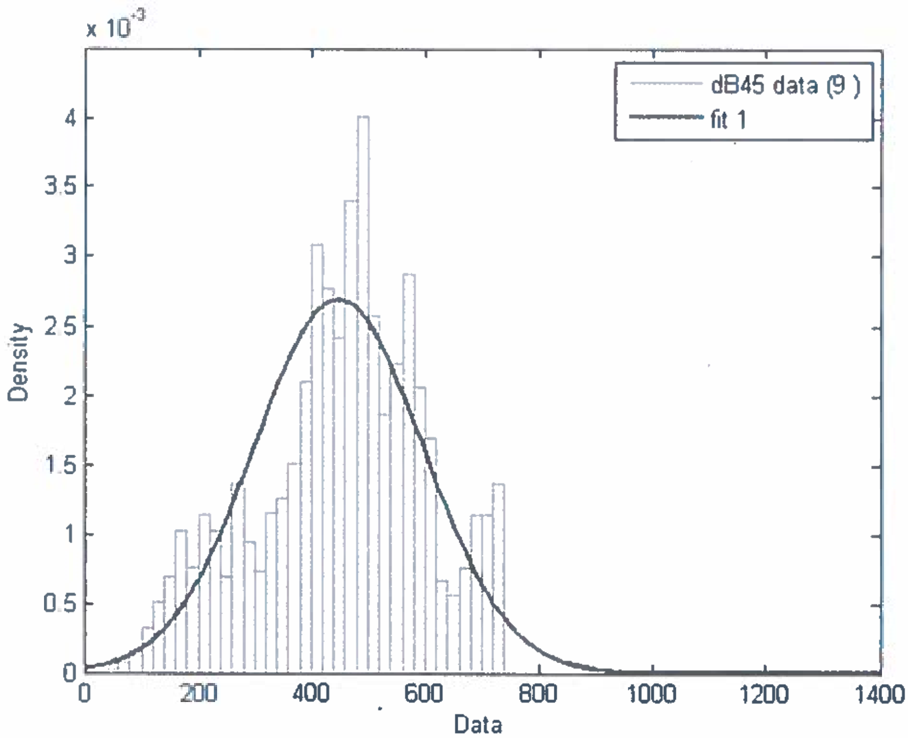


Figure 3.11: Probability Density Function for 45 dB (n=4757)

The mean and standard deviation distances were combined to provide a 99th percentile distance which was then input to the GIS model. The 99th percentile is based on the 'three-sigma' rule whereby Wheeler & Chambers (1992) demonstrated that 99% of data falls below mean plus three times the standard deviation, even for non-normal data.

3.6 ESTIMATED SETBACK DISTANCES

The estimated setback distances, as dervided from the acoustic model, are set out in Table 3.2.

Table 3.2: Acoustic Model Setback Distances

Absolute Noise Limit dBA	Statistical Mean Distance metres	Distance Standard deviation metres	99%ile Distance metres
38	725	198	1319
39	692	196	1280
40	643	189	1209
41	610	191	1183
42	551	175	1075
43	497	158	972
44	448	148	893
45	383	133	782

4 GIS MODEL

4.1 SENSITIVE RECEPTORS DATABASE

The GeoAddress Locator from the An Post's GeoDirectory is used for the identification of sensitive receptors. GeoDirectory provides a complete database of all of the buildings in the Republic of Ireland and their geolocation details. It is the only reliable and up-to-date information on address location based on the Ordnance Survey Ireland (OSI) large scale data and backed by An Post. The data is updated quarterly.

For this study the buildings data from the GeoDirectory which holds the grid coordinates in both Irish Grid and Irish Transvers Mercator, associated unique ID, building use and several other important attributes is used. The building use column classifies all points into residential (R), commercial (C), both residential and commercial (B) or unknown (U).

The GeoDirectory is a comprehensive Building and Address Point database and therefore it is assumed that all sensitive receptors are spatially represented as a point in the database. The following building use categories are used as sensitive receptors for this study.

- R - Residential
- B - Both Residential & Commercial
- U - Unknown

4.2 DISTANCE MODEL

Euclidean, or straight-line, distance raster is created using the sensitive receptors as source. The source identifies the location of the objects of interest which in this case are the residential, both residential and commercial and unknown point locations from the GeoDirectory. The source locations are transformed into a raster and assigned with 0 values.

The Euclidean distance output raster contains the measured distance from every cell to the nearest source. The distances are measured as the crow flies (Euclidean distance) in the projection units of the raster, in this case meters, and are computed from cell centre to cell centre.

The raster is created at cell size of 20m resolution and is used as the basis for all analysis in the GIS model.

4.3 EXCLUSION ZONES

The following datasets were used as exclusion zones and removed from the distance model created in the previous step.

4.3.1 Biodiversity and Ecology

- Special Areas of Conservation (SAC)
- Special Protection Areas (SPA)
- National Parks
- Ramsar Sites
- Lakes
- Fresh Water Pearl Mussel catchments (designated under si296 only)
- Annex 1 Habitats (extracted from CORINE 2006)*
- Shellfish Areas
- Natural Heritage Areas (NHA)
- Proposed Natural Heritage Areas (pNHA)
- Salmonid Rivers (Salmonid rivers are available as line features therefore total length of salmonid rivers within each setback and height scenario are calculated and presented in the matrix)
- Important Bird Areas (the data is available as point dataset therefore total counts within each setback and height scenario are presented in the matrix.

*The following CORINE 2006 codes are used to extract areas of un-confirmed Annex 1 habitats.

Table 4.1: CORINE 2006 Classes considered for Annex 1 habitats

CORINE Level 3 Code	Level 3 Description
311	Broad-leaved forests
321	Natural grassland
322	Moors and heathlands
331	Beaches, dunes, sand
412	Peat bogs
421	Salt marshes
423	Intertidal flats
521	Coastal lagoons
522	Estuaries

4.3.2 Population

- Settlements and Built-up areas (CSO Dataset)
- Zoned Land (MyPlan.ie Data)
    - Current Development Plans
    - Current Local Area Plans
    - Other Current Plans
- Airports/Aerodromes (1km buffer applied for this study)

4.3.3 Cultural Heritage and Architectural Conservation

- World Heritage Sites (UNESCO Sites)
- Record of Monuments and Places
- National Inventory of Architectural Heritage

The cultural heritage and architectural conservation datasets are available as point layer. Therefore the counts per setback areas are presented in the matrix.

4.3.4 Soils, Geological and Hydrogeology Exclusion Areas

- Geological Heritage Areas
- Landslide Susceptibility Areas [not excluded as per GSI advise)
- Quaternary Data 2014 (not excluded as per GSI advise)

4.3.5 Topography, Landcover and Landuse Exclusion Areas

- Military Lands
- Slopes greater than 10 degrees (17.6%)
- Walking and Cycling Trails (polyline dataset therefore are represented as total length within the setback and height scenarios).

4.4 MINIMUM AREA REQUIREMENT

Minimum area is calculated on assumption of single turbine and based on the manufacturers' models of the various tip heights. The clearance distance from boundary of a wind farm is assumed at 2.5 x rotor diameter. The circle area is calculated using the following formula.

$$A=\pi r^2$$

Table 4.2 shows the minimum area requires per height scenario.

Table 4.2: Minimum Area Calculation

Tip Height	Rotor Diameter	Clearance Distance (2.5 x rotor diameter)	Minimum Area Required in m²	Minimum Area Required in km²
125m	90m	225m	159043	0.159
150m	105m	262.5m	216475	0.216
175m	112m	280m	246300	0.246
200m	126m	315m	311724	0.311

4.5 WIND SPEED AREA CALCULATIONS

The wind speed areas are calculated from the Wind Atlas 2013 data. The Wind Atlas 2013 displays wind speeds at 20, 30, 40, 50, 75, 100, 125 and 150 metres above ground level (agl), at a horizontal resolution of 100m, SEAI(2013).

The data from the Wind Atlas 2013 was made available in the GIS format as rasters with 100m cell size and in the Irish Transverse Mercator (ITM) coordinate system. Figure 4.1 is an example from the Wind Atlas Report.

Figure 4.1: Mean wind speed averaged over 2001 – 2010 at 100m agl (Wind Atlas 2013)

For each area, the wind speed rasters were classified into the following classes and the areas were calculated using each set of setback distance polygons created in the earlier steps.

Areas that have windspeeds lower than those shown in the Table 4.3 are excluded. The tip height alongside each 'minimum' wind speed is aligned with the typical wind turbine size required to make sites with that average wind speed viable.

Table 4.3: Matching Wind Speed

Tip Height of Interest	Matching Minimum Wind Speed at Tip Height (m/s) 100m
200m	7.50
175m	7.60
150m	7.75
125m	8.00

4.6 ARCGIS MODEL

All spatial datasets are collated, harmonised into one coordinate system (Irish Transverse Mercator) and added to the project's File GeoDatabase in ESRI ArcCatalog. For the spatial analysis a series of models were built in the ArcMap Model Builder. Figure 4.2 shows the process flow of the ArcGIS model.

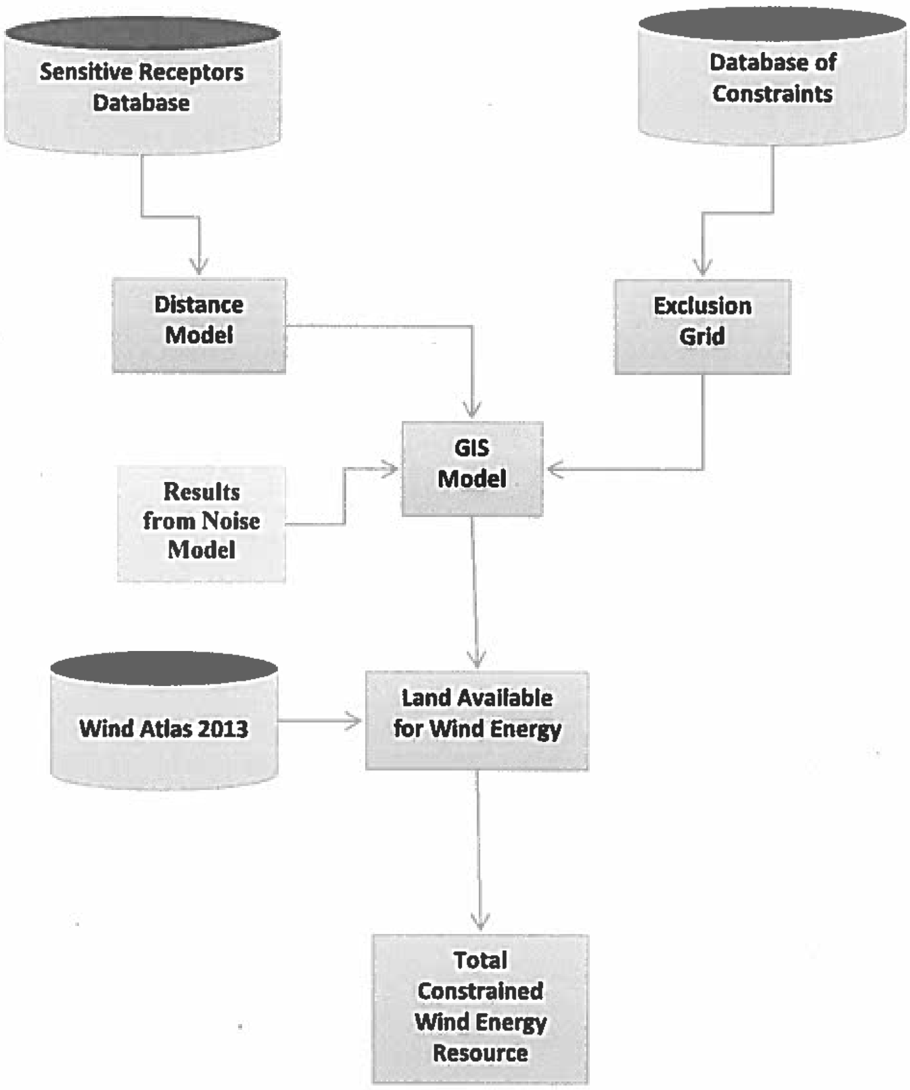


Figure 4.2: Process Model of the spatial analysis

5 OVERVIEW OF MODELLING RESULTS

The estimated set back distances, as outlined in Table 3.2, provide details on the statistical propagation from a wind farm to a sensitive receptor which provides a representative statistical distance within which noise limits could be reached. The separation distance is based on a 99th percentile, i.e. three sigma distance from the source, as set out in Section 3.5. The estimated set back distances which were derived from the acoustic model were inputted into the GIS Software package (ArcGIS) for post processing and mapping.

Table 5.1 represents the potential area available for wind development in Ireland resulting from a number of putative noise limit scenarios. These scenarios are based on an absolute noise limit value in the range of 38 - 45dB (expressed as L_{A90}). Each zone is based on a potential dB noise level and a range of assumed tip heights (defining the minimum parcel of land required for a single turbine, and removing parcels below this size).

An available capacity was developed to determine the potential turbine output for the available land. Table 5.1 outlines the Capacity Output Potential for each noise level limit.

Table 5.1: Potential area available for wind development in Ireland

Absolute Noise Limit	Tip Height (m)	Rotor Diameter (m)	Clearance Distance (m)	Min Area Required (sq m)	Available Area (sq km)	Percent of ROI land area
38 dB	200	126	315	311	411	0.585%
	175	112	280	246	398	0.567%
	150	105	262.5	216	325	0.463%
	125	90	225	159	164	0.234%
39 dB	200	126	315	311	432	0.615%
	175	112	280	246	418	0.595%
	150	105	262.5	216	340	0.483%
	125	90	225	159	172	0.244%
40 dB	200	126	315	311	477	0.679%
	175	112	280	246	459	0.653%
	150	105	262.5	216	370	0.527%
	125	90	225	159	185	0.263%
41 dB	200	126	315	311	494	0.702%
	175	112	280	246	475	0.676%
	150	105	262.5	216	382	0.543%
	125	90	225	159	189	0.269%
42 dB	200	126	315	311	574	0.817%
	175	112	280	246	554	0.789%
	150	105	262.5	216	439	0.624%
	125	90	225	159	210	0.299%
43 dB	200	126	315	311	679	0.967%
	175	112	280	246	649	0.923%
	150	105	262.5	216	502	0.714%
	125	90	225	159	234	0.332%
44 dB	200	126	315	311	789	1.123%
	175	112	280	246	753	1.071%
	150	105	262.5	216	570	0.811%
	125	90	225	159	254	0.362%
45 dB	200	126	315	311	1,018	1.449%
	175	112	280	246	964	1.372%
	150	105	262.5	216	708	1.008%
	125	90	225	159	288	0.410%

5.1.1 Caveats

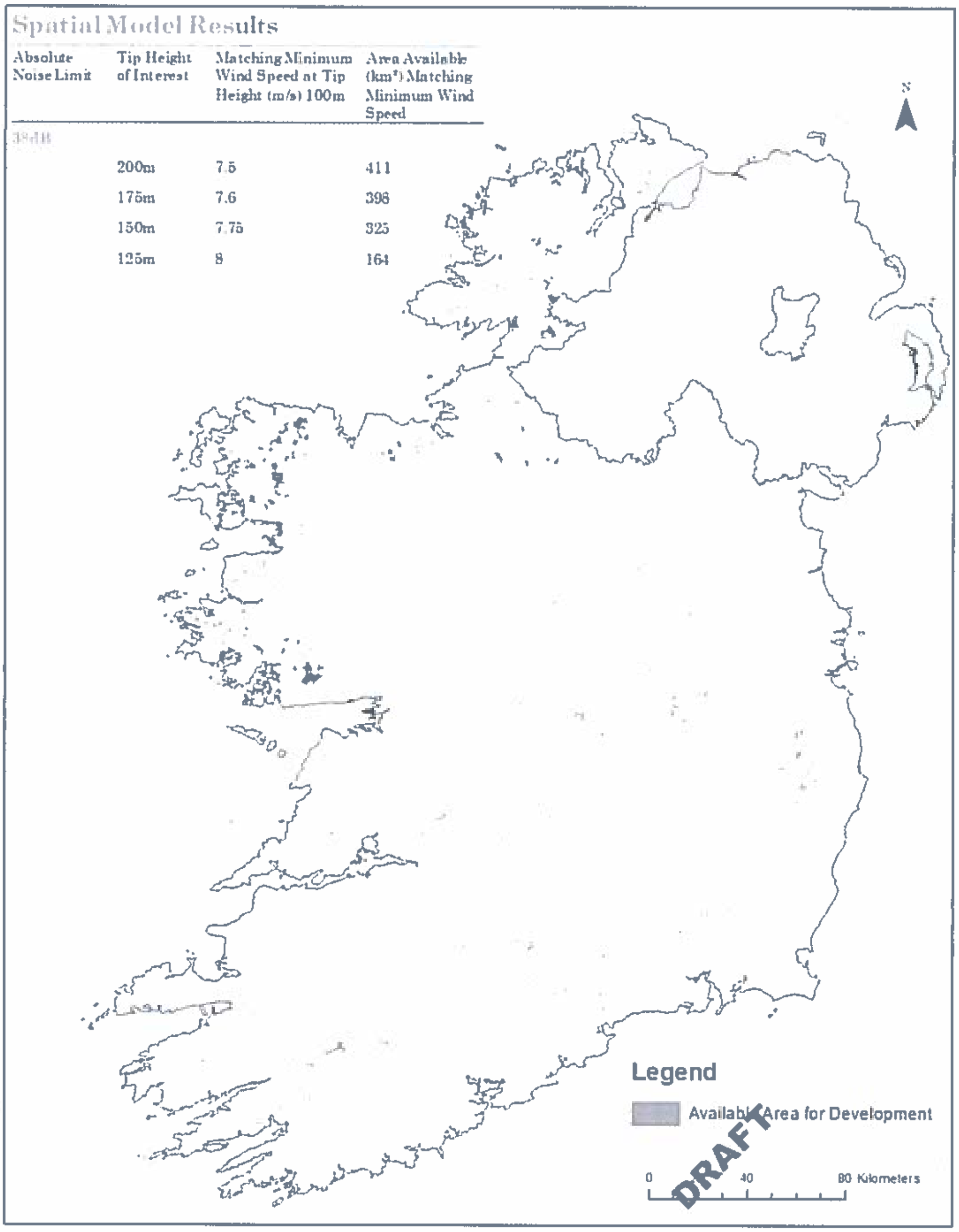
Given the high level nature of the exercise, a number of core assumptions were used to develop a basic model in order to complete these calculations. These assumptions were as follows:

- Setbacks are taken from the An Post GeoDirectory dataset, using datapoint locations identified as residential and commercial.
- Turbine output capacity was assumed to be 3-3.5 MW, given current trends in the industry. Three turbines, from the most popular wind turbine manufacturers represented in Ireland, were taken from within this range and the model was based on the manufacturers' noise data for these turbines.
- A wind farm factor was applied to the separation distances to replicate multi-turbine emissions. Tip heights and assumed rotor diameter were used to exclude unconstrained land parcels of a size below which a single turbine could not be erected. Exclusion zones were also used including geographical features such as lakes and certain designated areas, given the likelihood of planning being applied for and granted in these areas. These areas include SAC's, SPA's, National Parks, Ramsar sites, certain Freshwater Pearl Mussel catchments designated under SI296, Annex 1 Habitats, Military Areas and Natural and Geological Heritage Areas.

The following key points have also been considered, given that they would further reduce the amount of viable sites from the capacity figures produced in this high level analysis:

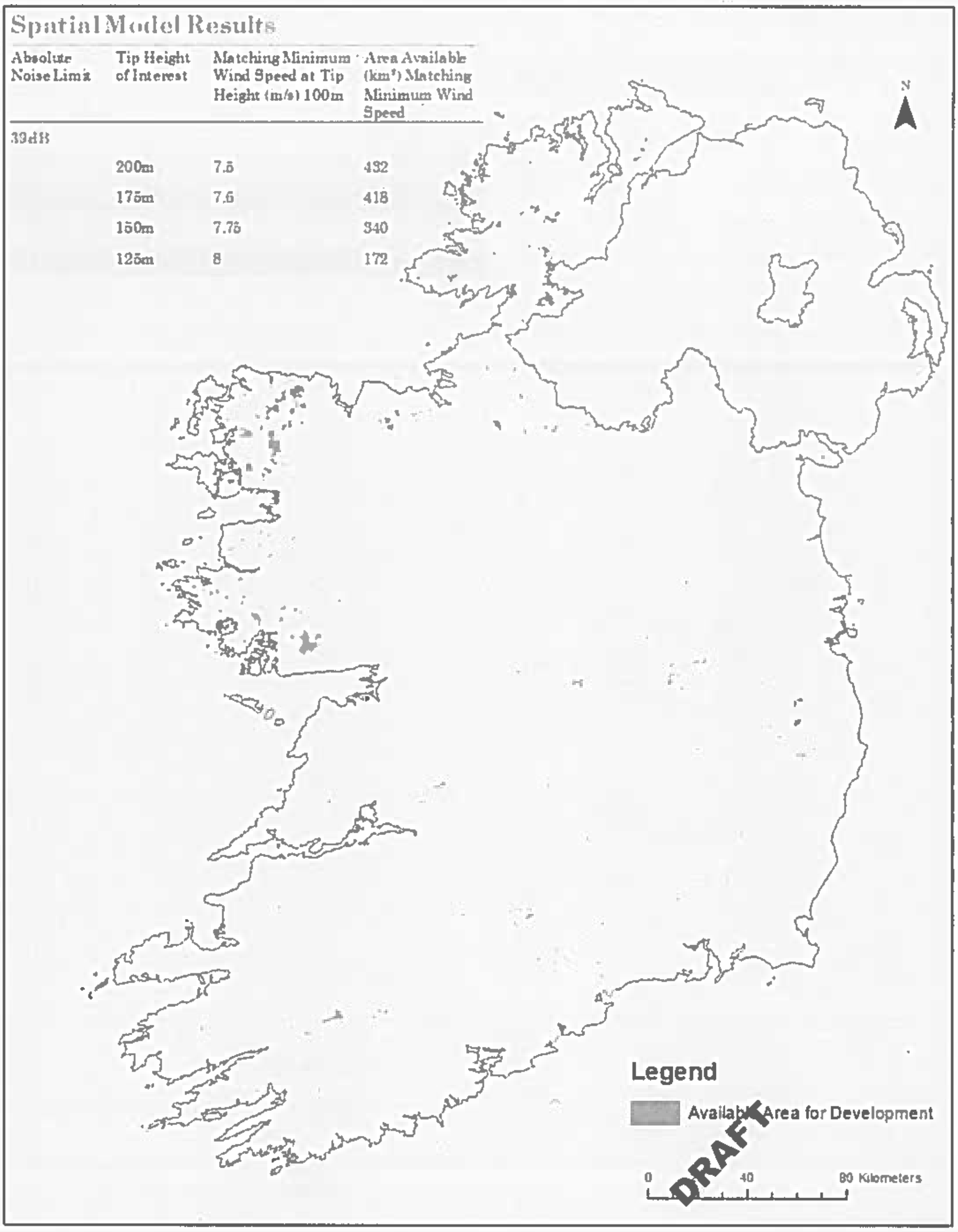
- The analysis considered a range of scenarios for the turbines relating to wind speed, noise attenuation, atmospheric and other effects to provide a representative statistical distance within which noise limits could be reached.
- The analysis completed, defined a zone where the separation between turbine and receptor is statistically (99th percentile) greater than the cumulative correction setback distance and within which turbines are likely to operate without acoustic restrictions.
- The model, by its nature, cannot take account of site-specific engineering and other technical constraints, including site specific wind quality. It is probable that a proportion of the available land, and capacity indicated would prove not to be technically or economically viable due to site specific constraints.
- The model cannot take account of site specific environmental designations, nor can it assume the cumulative effects of wind being concentrated into a significantly reduced national landbank. It is probable that a proportion of the available land and capacity indicated would not be successful within a planning process, given these local factors.

The potential viable areas for wind turbine placement with regard to the use of an absolute noise limit (expressed as L_{A90}) as an appropriate means to control noise impact are presented in Figure 5.1 to Figure 5.8.



Absolute Noise Limit	Tip Height of Interest	Matching Minimum Wind Speed at Tip Height (m/s) 100m	Area Available (km²) Matching Minimum Wind Speed
38dB			
	200m	7.5	411
	175m	7.6	398
	150m	7.75	325
	125m	8	164

Figure 5.1: Absolute Noise Limit 38dB



Absolute Noise Limit	Tip Height of Interest	Matching Minimum Wind Speed at Tip Height (m/s) 100m	Area Available (km²) Matching Minimum Wind Speed
39dB			
	200m	7.5	432
	175m	7.6	418
	150m	7.75	340
	125m	8	172

Figure 5.2: Absolute Noise Limit 39dB

Spatial Model Results

Absolute Noise Limit	Tip Height of Interest	Matching Minimum Wind Speed at Tip Height (m/s) 100m	Area Available (km²) Matching Minimum Wind Speed
40dB			
	200m	7.5	477
	175m	7.6	459
	150m	7.75	370
	125m	8	165

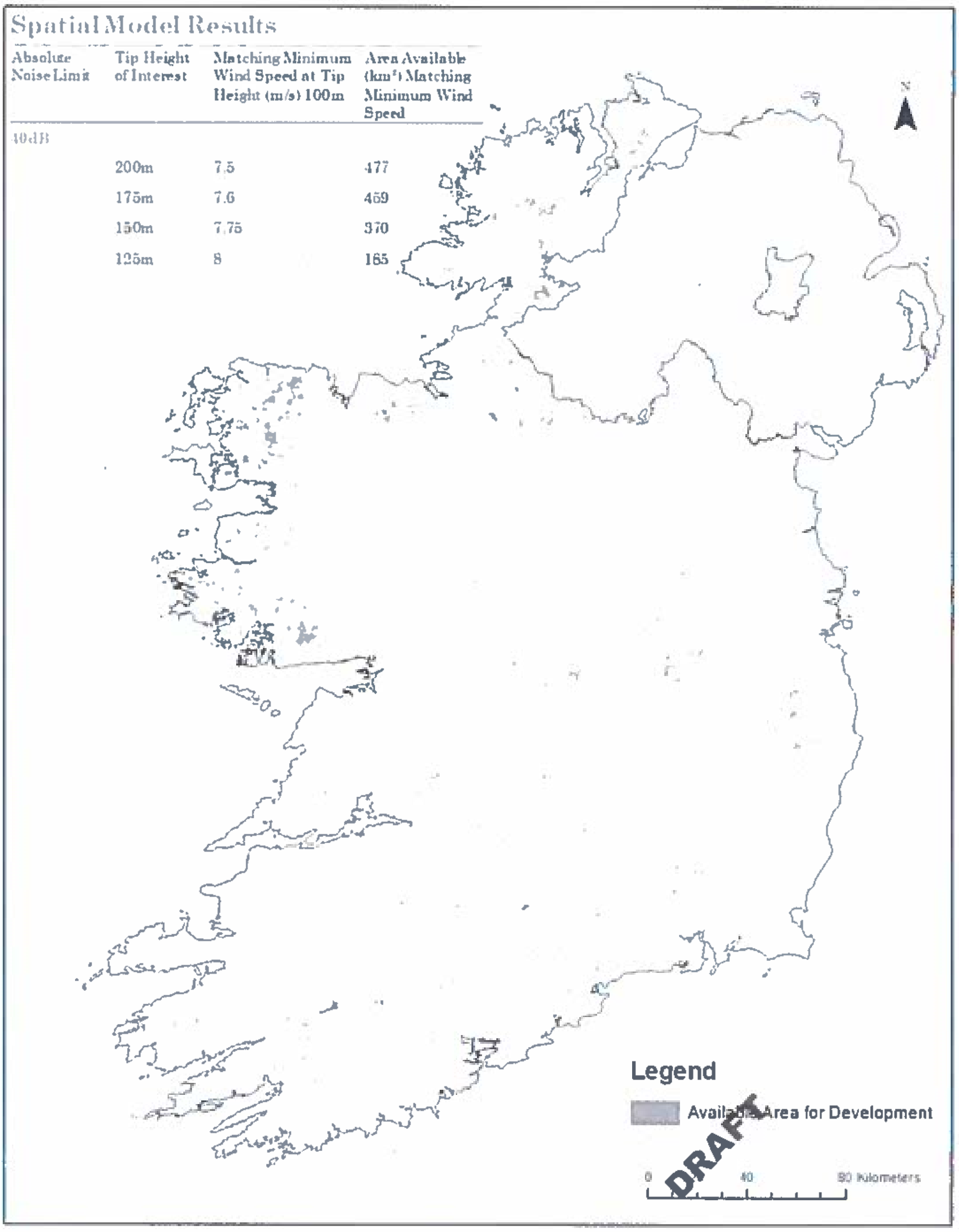


Figure 5.3: Absolute Noise Limit 40dB

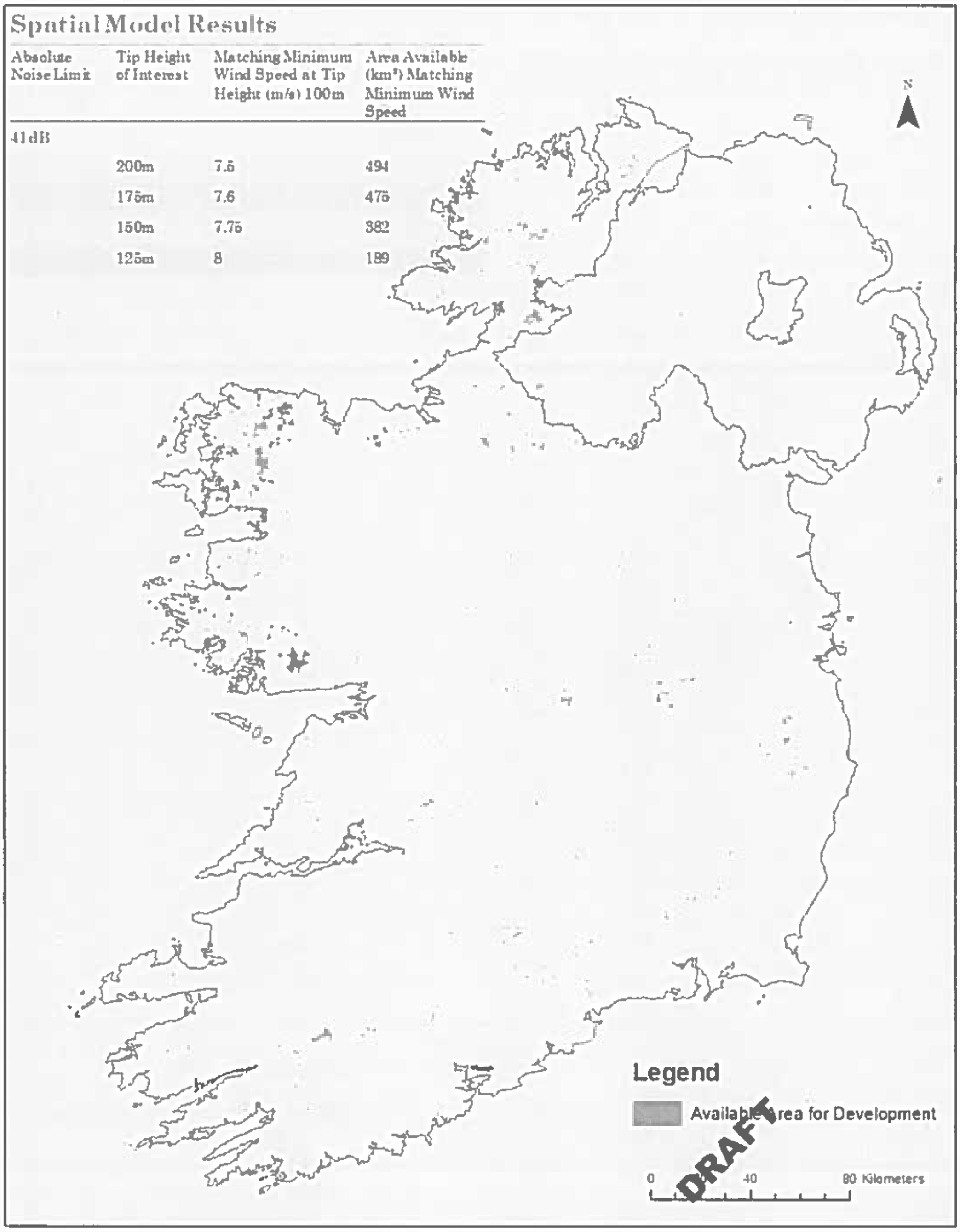
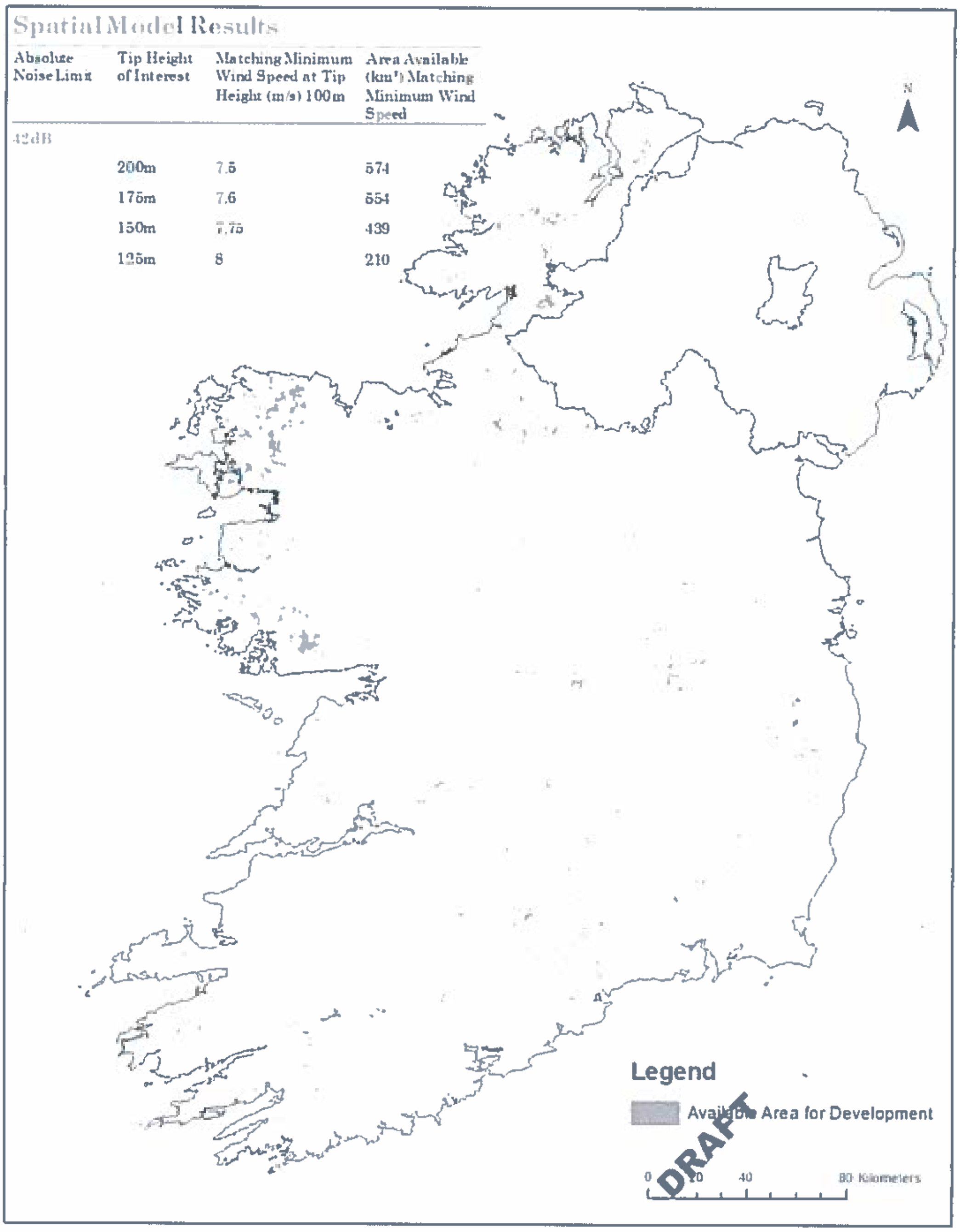


Figure 5.4: Absolute Noise Limit 41dB



Absolute Noise Limit	Tip Height of Interest	Matching Minimum Wind Speed at Tip Height (m/s) 100m	Area Available (km²) Matching Minimum Wind Speed
42dB			
	200m	7.5	574
	175m	7.6	554
	150m	7.75	439
	125m	8	210

Figure 5.5: Absolute Noise Limit 42dB

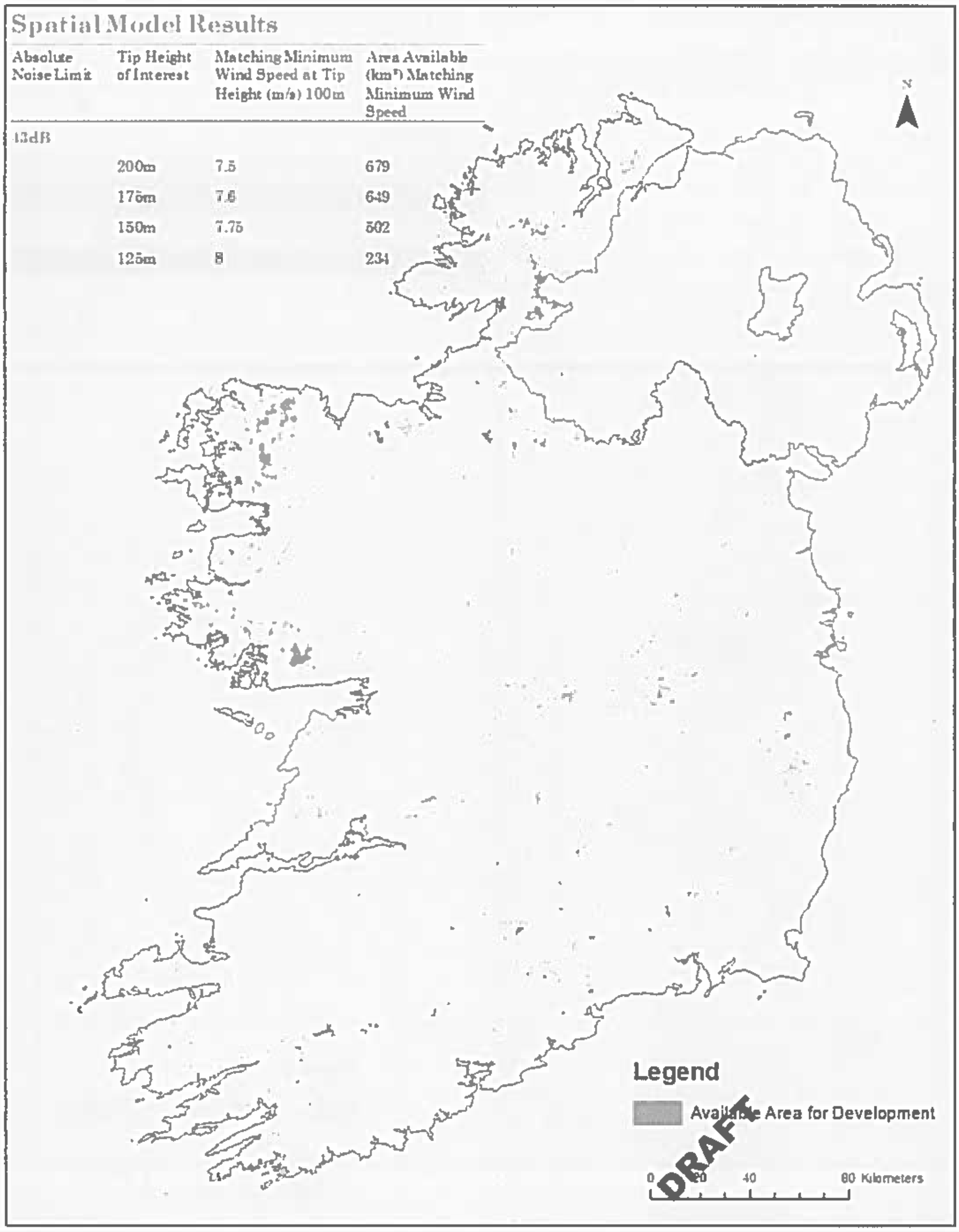


Figure 5.6: Absolute Noise Limit 43dB

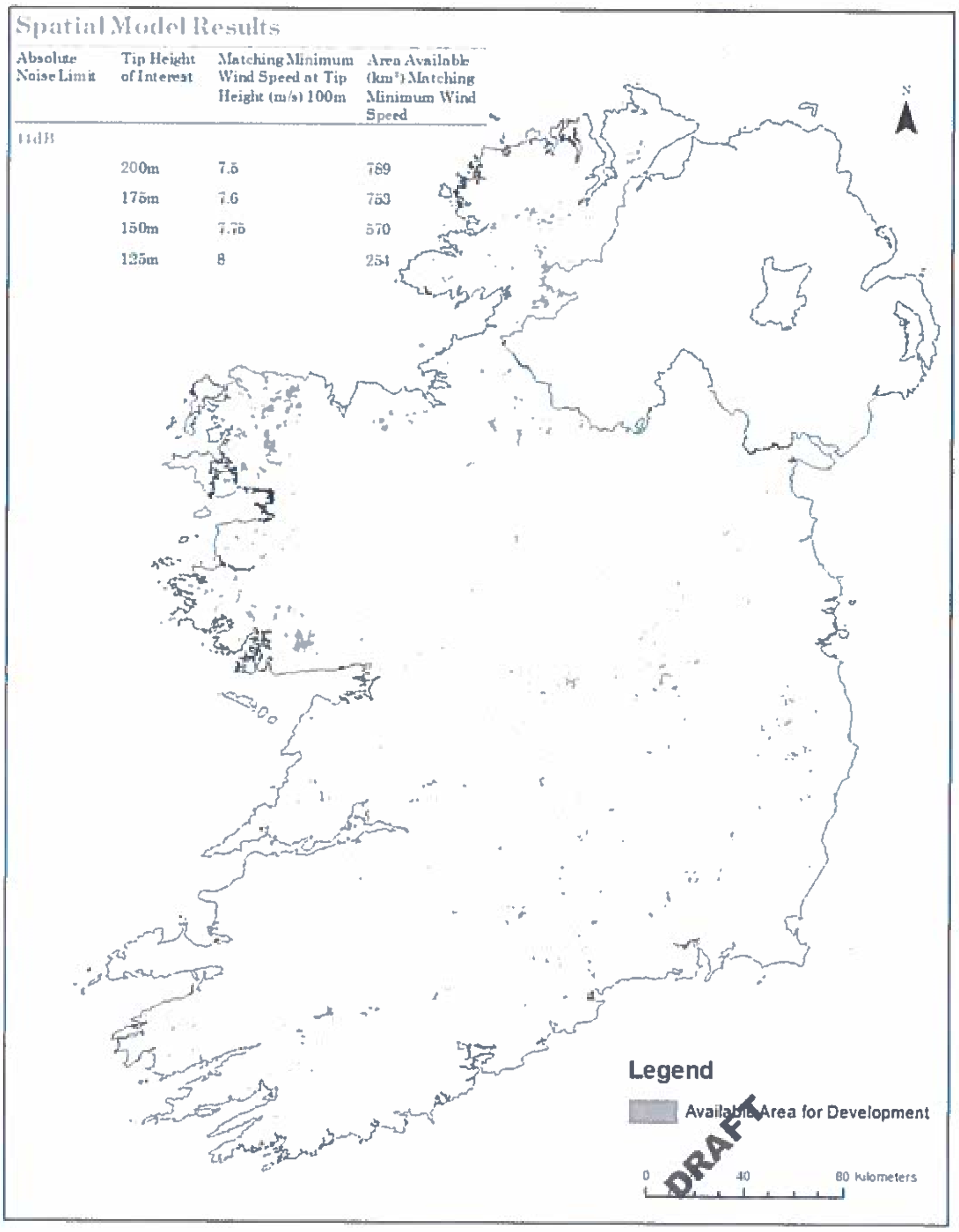
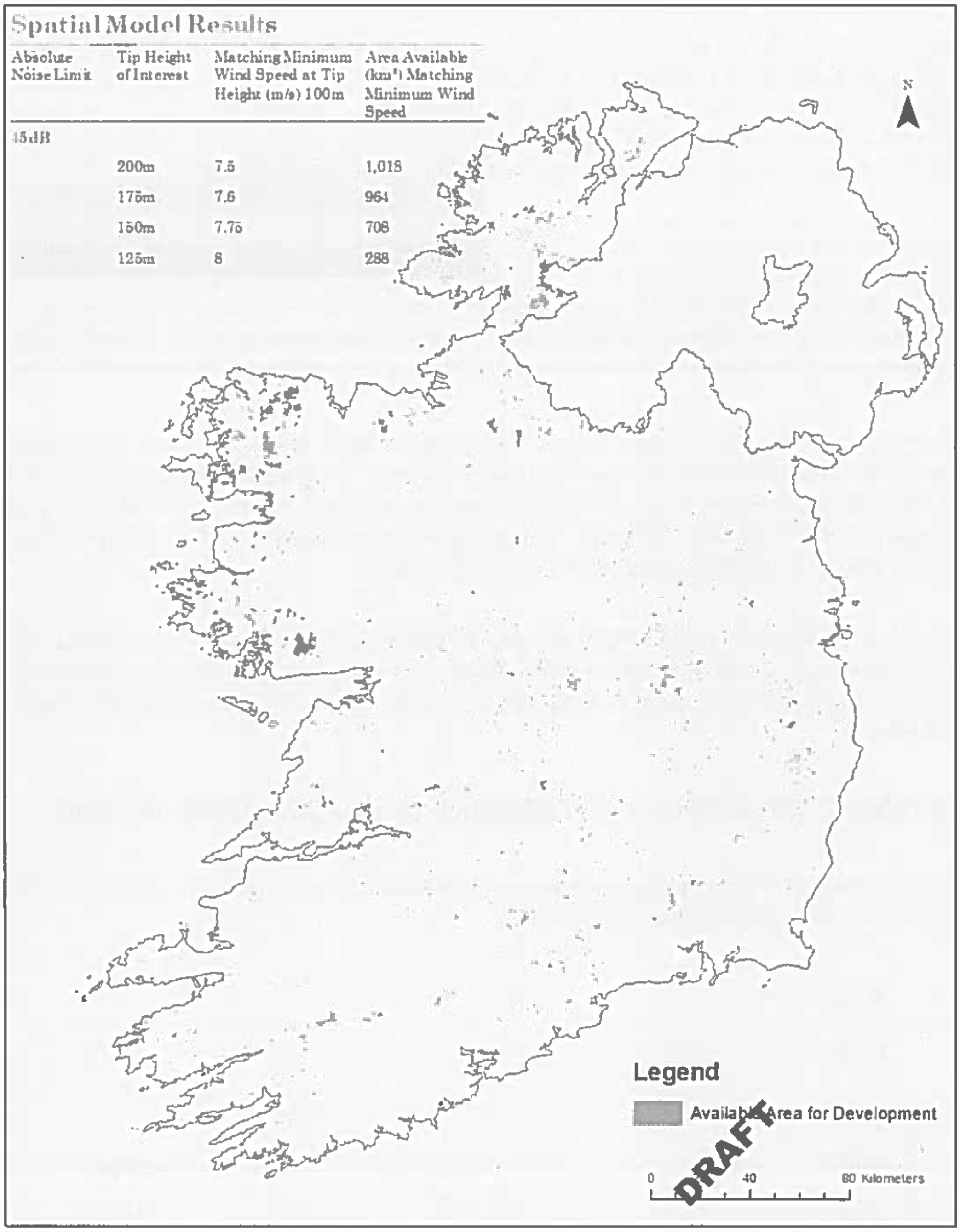


Figure 5.7: Absolute Noise Limit 44dB



Absolute Noise Limit	Tip Height of Interest	Matching Minimum Wind Speed at Tip Height (m/s) 100m	Area Available (km²) Matching Minimum Wind Speed
45dB			
	200m	7.5	1,018
	175m	7.6	964
	150m	7.75	708
	125m	8	288

Figure 5.8: Absolute Noise Limit 45dB

6 DISCUSSION

The acoustic model results are presented in Section 3.5. The modelling results which resulted in each 1 dB noise limit band were collated and a Probability Distribution Function plot of the data is presented. The plots show that for lower noise levels (38 dBA to 40 dBA) the data is not normally distributed. The data is shewed to the higher end of the distance spectrum. For noise levels of 41 dBA to 45 dBA the data shows a reasonable approximation to a normal distribution.

The acoustic model provided data for over 113,000 individual 'models' comprising of a combination of the parameters outlined in Sections 3.2 to 3.4. The number of individual 'models' in each of the 1 dBA 'bins' ranged from 4757 to 6431, giving a robust statistical basis to the calculated result. The bands show that the proposed noise limit is inversely proportional to the acoustic setback distance as expected.

The GIS model provides the context where increasing setback distances result in significant reductions in available land area and potential wind capacity in Ireland. Table 5.1 sets out the available capacity which has a range of 248% from a low potential noise limit of 38 dBA to the existing daytime level of 45 dBA. With the site specific factors outlined in Section 5.1.1, this could result in a three to one reduction in potential capacity if adopted.

The potential viable areas for wind turbine placement with regard to the use of an absolute noise limit (expressed as L_{A90}) as an appropriate means to control noise impact have been presented in Figures 5.1 to 5.8. The potential capacity is directly related to the maximum tip height and absolute noise limit level.

6.1 POTENTIAL AREA AVAILABLE FOR WIND DEVELOPMENT IN IRELAND

The potential capacity for wind energy development in Ireland for the range of proposed noise limit levels and turbine tip height is shown in Figure 6.1.

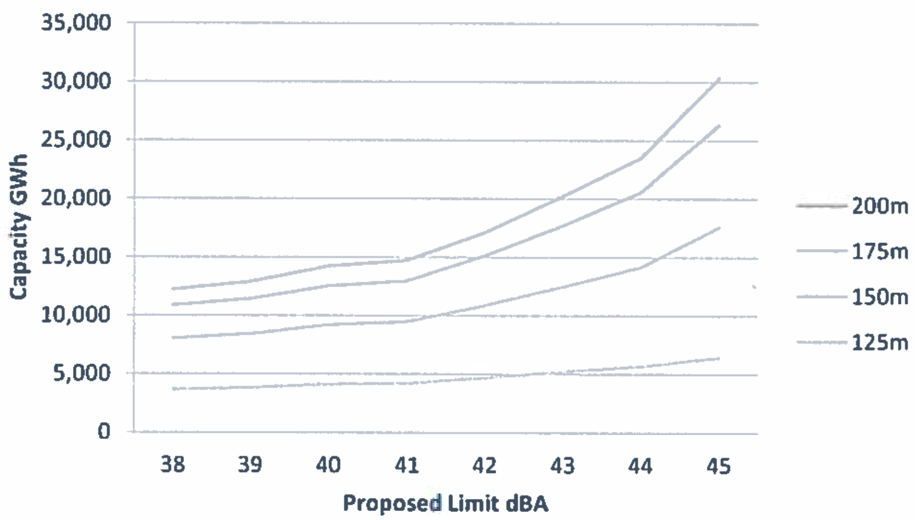


Figure 6.1: Wind Energy Capacity v Absolute Noise Level

Future large scale wind farm development is likely to use tip heights in the range 150m to 175m. 200m hub heights may be a requirement on some low wind sites but not the norm. Focussing on the impact of proposed fixed noise limit values in this band indicates that a wind energy output of 10,000 GWh is feasible with 175m tip heights but a challenge with a limit of 150m on tip heights.

Taking the 175m curve, the output decreases from 26,311 GWh at the current daytime limit of 45 dBA to 10,872 GWh at a potential limit of 38 dBA. The 175m data is shown in Table 6.1.

Table 6.1: Potential Capacity GWhr for wind development in Ireland

Capacity GWhr at 175m tip height							
38 dBA	39 dBA	40 dBA	41 dBA	42 dBA	43 dBA	44 dBA	45 dBA
10,872	11,415	12,530	12,963	15,128	17,713	20,551	26,311

7 CONCLUSIONS

The potential capacity for wind farm development is impacted significantly by the selection of a fixed noise limit level. The reduction from the current daytime limit of 4S dBA to the proposed limit of 40 dBA will result in a loss of capacity of 13,797 GWh or a S2% loss of capacity. Similarly a reduction from the current night time limit of 43 dBA will result in a 29% loss in capacity.

Changing the noise limit to a fixed level 3 or S dBA below the currently permitted levels will result in a significant loss in potential wind energy capacity.

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APPENDIX A

GLOSSARY OF TERMINOLOGY

Ambient / Background Noise	The ambient noise level is the noise level measured in the absence of the intrusive noise or the noise requiring control. The $L_{A90,\ 10min}$ is the parameter that is used to define the background noise level in this instance. L_{A90} is the sound level that is exceeded for 90% of the sample period. It is typically used as a descriptor for background noise.
A-weighting	The A-weighting approximates the response of the human ear, particularly for sounds of moderate and low levels
C-weighting	The C-weighting approximates the response of the human ear, particularly for sounds at high noise levels (typically greater than 100 dB).
dB	Decibel. The unit of sound level. A measurement of sound level expressed as a logarithmic ratio of sound pressure P relative to a reference pressure of Pr =20 µPa i.e. $dB = 20 \times \log(P/P_r)$
dB(A)	An 'A-weighted decibel' – a measure of the overall noise level of sound across the audible frequency range (20 Hz – 20 kHz) with A-frequency weighting (i.e. A-weighting) to compensate for the varying sensitivity of the human ear to sound at different frequencies.
HH	Hub Height.
Hertz (Hz)	Hertz is the unit of frequency. One hertz is one cycle per second. One thousand hertz is a kilohertz (kHz).
L_{Aeq}	The equivalent continuous (time-averaged) A-weighted sound level. This is commonly referred to as the average noise level.
L_{A90}	The A-weighted noise level equalled or exceeded for 90% of the measurement period. This is commonly referred to as the background noise level.
MW	1×10^6 Watts
Octave Band	Sound, which can occur over a range of frequencies, may be divided into octave bands for analysis. For environmental noise assessments, sound is commonly divided into 8 octave bands. The octave band frequencies are 63Hz, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz, 4kHz and 8kHz.
Sound Pressure Level (L_P)	A logarithmic ratio of a sound pressure measured at distance, relative to the threshold of hearing (20 µPa RMS) and expressed in decibels
Sound Power Level (L_W)	The level of total sound power radiated by a sound source. A logarithmic ratio of the acoustic power output of a source relative to 10^{-12} Watts and expressed in decibels.