SEAI RD&D Project Report

Wind Autoproduction Micro-siting Guidelines

Rev 1.0

07/12/2016

1.0 Background

The transition from fossil fuel based economy to renewable energy based economies is a key goal of many countries. With this interest has been growing in how homes, businesses, communities and citizens use energy with the growth of smart city initiatives. According to the energy white paper Ireland's Transition to a Low Carbon Energy Future 2015-2030 [1] consumers and industry will be encouraged to become proactive energy users (prosumers) reducing energy demand and enabled and incentivised to participate actively in the electricity market via a range of local/onsite energy generation technologies (including wind). Large energy uses have the potential to generate onsite electricity to offset imports from the grid and to participate in electricity markets with electricity exports i.e. autoproduction.

Wind autoproduction is the generation of electricity by a wind turbine(s) for onsite consumption. The wind turbine is connected to the customer side of the electricity meter thereby offsetting the purchase of retail electricity from the grid i.e. reducing electricity bills. It is sometimes referred to as "behind the meter" generation. The economic advantage of wind autoproduction it that the unit of electricity (kWh) generated by the wind turbine that is consumed onsite is of a high value to the consumer. Due to the power (kW) mismatch with time of consumer demand and onsite generation there will be times (on a second by second basis) when a turbine may produce too much power, in which case the resulting excess energy is exported to the grid, usually at a lower price. At other times the wind turbine may not produce enough power in which case the power deficit is supplied by the grid resulting in the import of electrical energy at the retail rate. The energy performance of wind turbines is sensitive to a number of atmospheric parameters such wind speed, wind direction, wind shear, wind veer, turbulence and air density. These factors are influence by local and regional features around the site such as terrain, obstacles, general surface roughness and thermal effects [2]. Unlike typical onshore wind farm sites wind autoproducers tend to be single turbines at lower elevations in rural areas (e.g. near agricultural farm buildings) or in peri-urban areas (e.g. industrial estates) with a higher likelihood of being in vicinity of manmade obstacles (e.g. buildings) and trees. In addition, parts of regional terrain within 10s of km of the site may likely be at higher elevations than the turbine site itself. In relation to the wind resource this presents extra challenges in wind turbine siting for autoproduction in that many wind autoproduction sites may have complex wind flows that are heavily influenced by local obstacles resulting in lower average annual wind average speeds, unique wind speed distributions, high turbulence, high wind shear, and highly directional wind flows (both horizontally and vertically). Wind autoproducers are also likely to be in areas closer to people and planning constraints may be more stringent in terms of setback distances from nearest neighbours/boundaries, shadow flicker and noise. To achieve best energy and economic performance from any wind project careful attention must be given to siting and sizing a wind turbine at the given site. In addition to the wind resource, the power performance characteristics of a given turbine, consumer load profile, electricity costs and local planning constraints are significant factors.

(Fields et al 2016) [3] carried out a study on the current state of the industry in the USA regarding distributed wind resource assessment (DWRA). It was based information gained through direct engagement with industry from 1kW single turbines to multi MW community owned windfarms connected to electrical distribution systems. It reports that due to the diversity of project sites and turbine sizes there is little agreement on the accuracy of DWRA methods with up to 250% error and that current DWRA processes largely exclude consideration of site-specific winds and turbine loading/suitability. It identified that *"the distributed wind industry lacks representative atmospheric and turbine performance data to validate and benchmark existing methodologies for predicting project performance and site suitability".* It also stressed the need of *"access to critical site information to facilitate* *atmospheric modelling, such as terrain, surface roughness, 3D buildings, and other surface features in a way that is affordable for the scale of distributed wind projects."* A study (van Kuik et al 2016 [4]) on the long term research challenges of wind energy carried by the European Association of Wind Academics (EWEA) identified "*as wind turbines are being installed more and more in complex terrain and offshore, the question is how to generalise an inflow classifications scheme so that many kinds of different locations can be well characterised"*

The study also stated that from a wind flow point of view.

"The inherent nonlinearity and chaos of fluid dynamics occur at all scales, from weather patterns relevant to wind power grid integration, to turbulence essential to dynamics turbine loads. The inability to calculate flows from first principles has made continued interaction between modelling and measurements indispensable. Although powerful computers now enable simulating turbulent wind conditions with increasing detail, precise results are not guaranteed."

These issues are directly relevant to wind autoproduction applications

1.1.Overview of wind resource

The wind resource varies over a wide range of time scales from inter-annual to sub-second and spatial scale from 1000s km to sub-metre. A general over view is shown Figure 1.

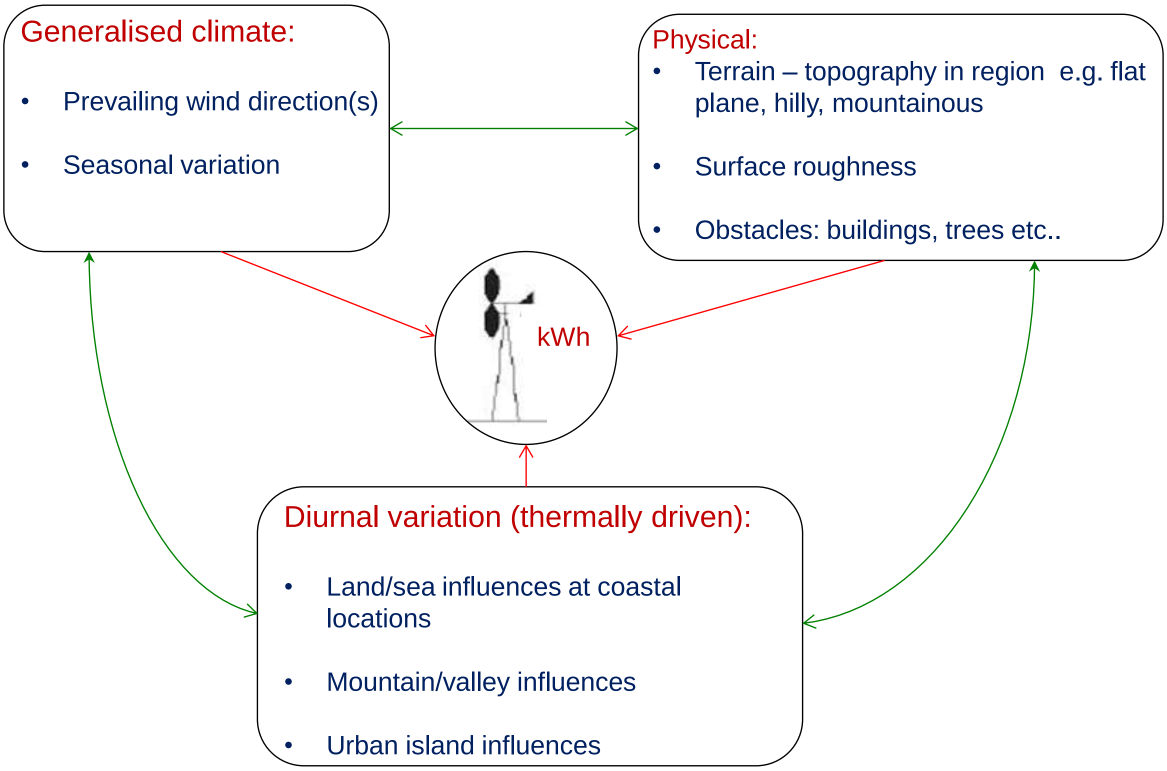


Figure 1.1

2.0 Project Introduction

This RD&D project consists of multiple wind resource measurements at 4 different locations in Ireland ranging from rural to peri-urban so as to assess the characteristics of the wind resource in terms of speed, direction and turbulence intensity. It aims to draw conclusions on site specific factors that have the most significant impacts when considering the installation a wind autoproducer. The measurement time periods range from months, carried out within the timeframe of the project, to longer multi-annual data measuring periods from prior measurement campaigns. The data consists of 2D measurement from traditional cup anemometers and wind vanes, short term LiDAR profiling and multi-annual SCADA data from an operating large scale wind autoproducer. Three case studies are presented that explore the mesoscale and microscale factors that need to be considered when siting a wind autoproducer. It is hoped that further work in this relatively complex area will continue through further measurements, analysis and refinements and through collaboration with IEA Wind Task 27.

3.0 Measurement Sites

1) Rural elevated

Two met masts installed 6.8km apart in a hilly upland region of Co. Wicklow. Both sites are relatively free of local obstacles and the focus of this case study is on mesoscale impacts of regional topography on the measured wind characteristics. Measurements were at taken 13m at one site and at 40m at the other. These height were chosen to represent tower heights that an individual farm might use for a single small to medium scale turbine in an on-farm auto production application.

2) Rural low elevation

One met mast installed at Louth County Council animal compound representing a rural small business energy user. Measurements were taken a 13m to assess the viability of installing a small wind turbine on a 13m tower.

3) Peri-Urban Area

Wind and energy performance measurements of a large scale wind autproducer with 60m hub height, wind measurements from 10m mast and LiDAR measured wind shear profiles in a suburban garden. This case study represents industrial and small business users who wish to deploy wind autproduction. Preliminary LiDAR wind shear profiling from an the urban back garden of a domestic to assess small wind turbine tower heights that may be required for meaningful energy output in these cases

4.0 Case Studies

4.1 Case study 1 – Two mast comparison at elevated rural sites 6.8km apart

Figure 1 show the location of two met masts M1 and M2 in a rural upland hilly area. Both sites are approximately 20km from east coast. The masts are 6.8km apart (as the crow flies). M1 is a 13m mast located on top of a hill with an elevation of 258m above sea level. M2 is a 60m mast located on top of another hill elevated at 410m and has multiple measurement heights. A 40m measurement height at M2 was used in this study.

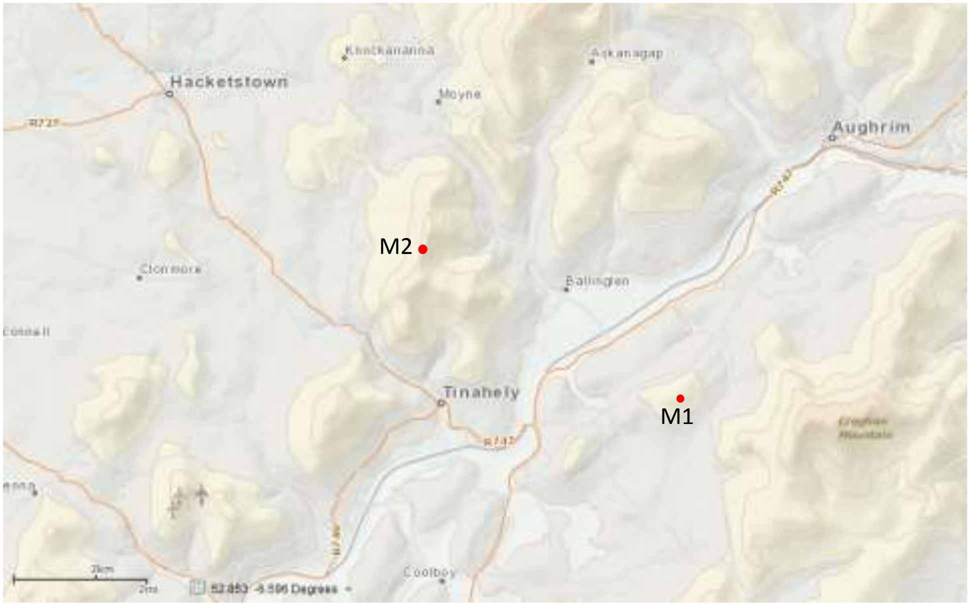


Figure 4.1

Measuring equipment

Parameter	M1	M2
Wind Speed	2D cup anemometer: NRG 40C	2D cup anemometer: NRG 40C
Wind Direction	Wind vane: NRG 200P	Wind vane: NRG 200P

Data logger	Second Wind Nomad	Second Wind Nomad
Sampling rate	1 s	1 s
Logging interval	1 minute	10 minute

Table 4.1

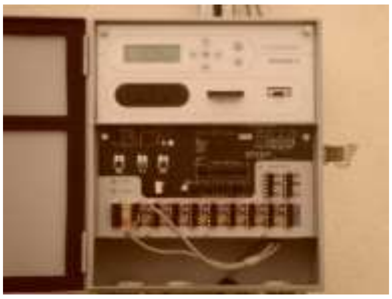


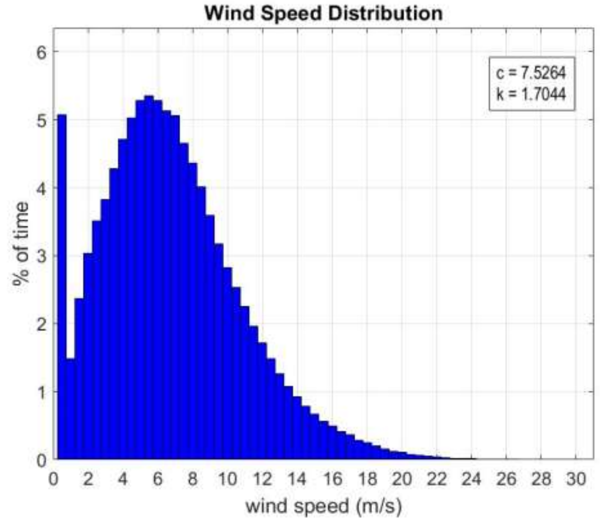
Figure 4.2: Data logger

Site M1

Figure 4.3

Site M1 is a relatively has a relatively low surface roughness with no significant local obstacles.

Results of data analysis for M1



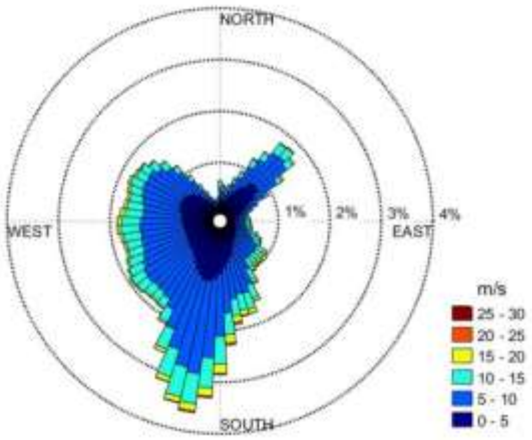
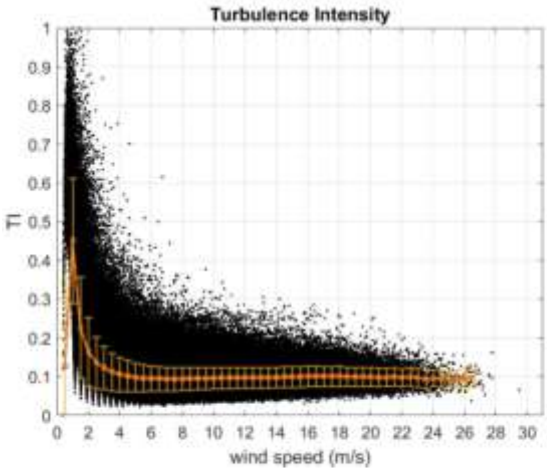


Figure 4.4 ***Figure 4.5***



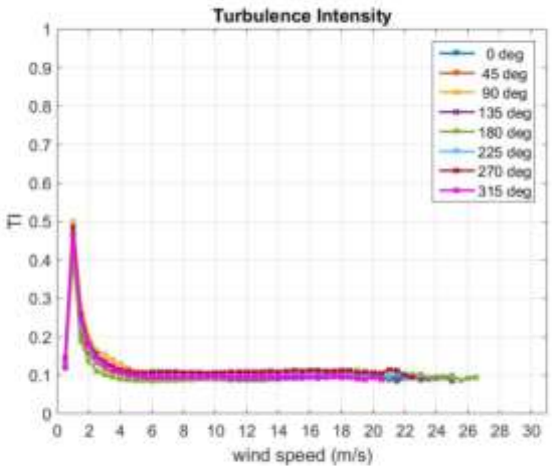


Figure 4.6 ***Figure 4.7***

Measurement height (m) a.g.l	Mean wind speed (m/s)	1-second max Wind speed (m/s)	Turbulence Intensity @ 15 m/s
13	6.7	34.5	0.1

Table 4.2

Table 4.2 show that this site is a good wind site with a high mean wind speed and low turbulence intensity (@ 15m/s) for the given measurement height of 13m. There are no specific increases in turbulence intensity with direction which can be an expected result as the site is relatively free of local obstacles. The distinctive features of the results appear in the wind rose shown in figure 4.5 where winds appear to come from distinct directions. Specifically the best winds come from the south southwest direction, with a distinct lack of wind from the north and easterly sectors. When regional topography (mesoscale) features are examined in figure 4.1 it can be seen that there are distinct features in excess of a 10km radius around the mast location. Figures 4.8 and 4.9 shows the north westerly views from M1 where the elevated regional topography can be seen.

Figure 4.8

Figure 4.9

Figure 4.10

Figure 4.11

Figure 4.10 shows the M1 mast location from north west of the site looking towards the east. The ~600m high mountain in the background which is ~ 3km east of M1 mast is responsible for the significant lack of winds in the easterly sector. Figure 4.11 show the best wind sector as displayed on the wind rose i.e. south southwest direction looking from M1 mast which shows ~ 35km to 40km fetch in this direction

Site M2

Site M2 at an elevation of 410m has a relatively low surface roughness to the west with some low forestry trees to the east and north resulting in the surface roughness being higher than at M1. Measurements at mast M2 here are taken at a height of 40m above ground level.

Figure 4.12

Results of data analysis for M1

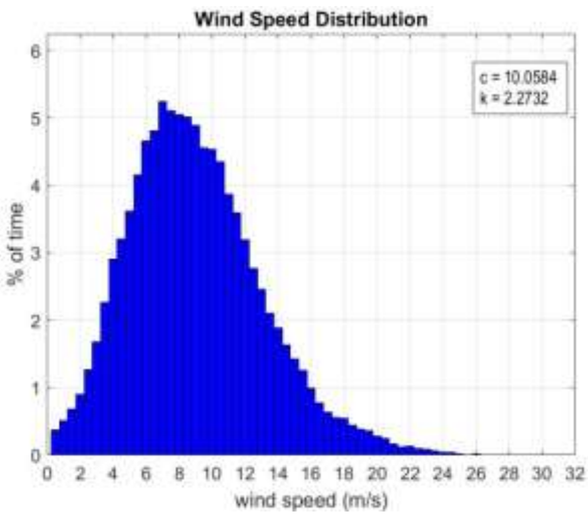


Figure 4.13

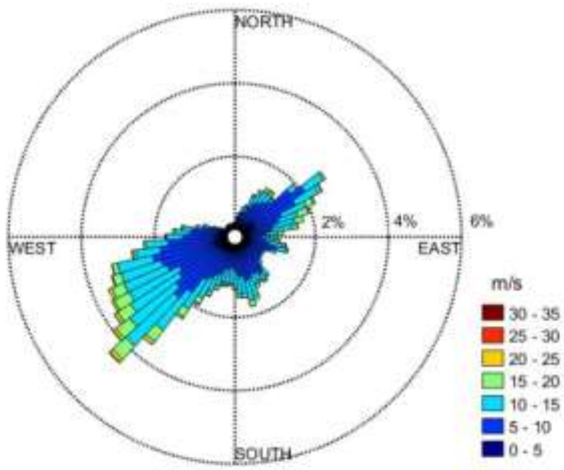


Figure 4.14

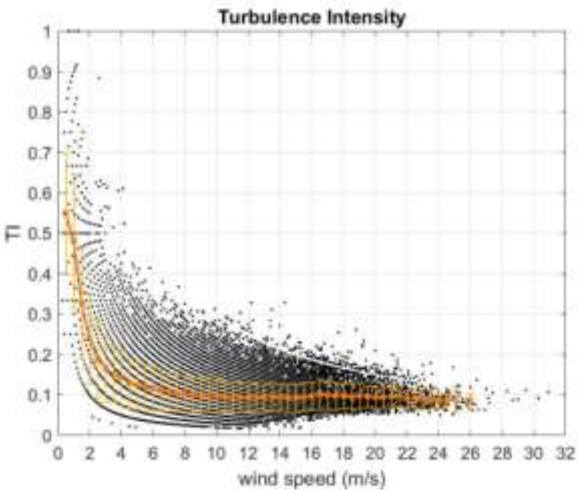


Figure 4.15

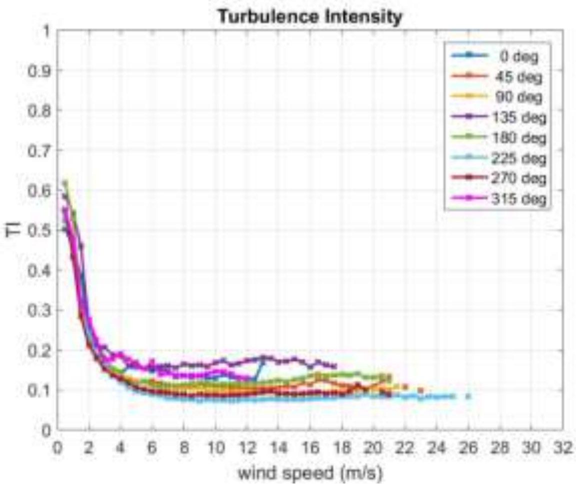


Figure 4.16

Measurement height (m) a.g.l	Mean wind speed (m/s)	1-second max Wind speed (m/s)	Turbulence Intensity @ 15 m/s
40	9	38.3	0.1

Table 4.3

Table 4.3 shows that this site is a very good wind site with a high mean wind speed and low turbulence intensity (@ 15m/s) for the given measurement height of 40m. Differences in turbulence intensity with direction can be seen in figure 16 with higher turbulence in the north to east to south sectors which is a reflection of the forested areas in these directions. However turbulence intensity remains below 20% @ 15m/s in all cases. The wind rose also shows distinct south west and north east dominant wind directions. These are not exactly the same as for M1 despite it being only 6.9km away. This show that regional (mesoscale) topography many km from a given mast location can have influence over short distances (few km) from the mast.

Figure 4.17

Figure 4.18

Figure 4.19

Figure 4.17 show the south westerly views from M2 which has a fetch in the region of 40km. The northwest to northerly view in Figure 4.18 is looking into a higher elevated topography (covered in cloud) resulting in reduced winds from that direction. Figure 4.18 show the south easterly sector which has also reduced winds. This appears to due to the mesoscale blocking effect of the same 600m high mountain that reduced winds in the easterly sector for mast M1. (It is ~ 10km from M2).

A comparison of the wind roses M1 and M2 of overlaid on a topographic is show in figure 4.20. Here the mesoscale directional influences are more evident. Both locations are affected from the north and east. The hills to the west of M1 have result in the more southerly prevailing wind at M1. Because both location are ~ 20km from east coast both have north easterly components likely from easterly onshore wind steered through the gaps/valleys to the north east of both mast locations.

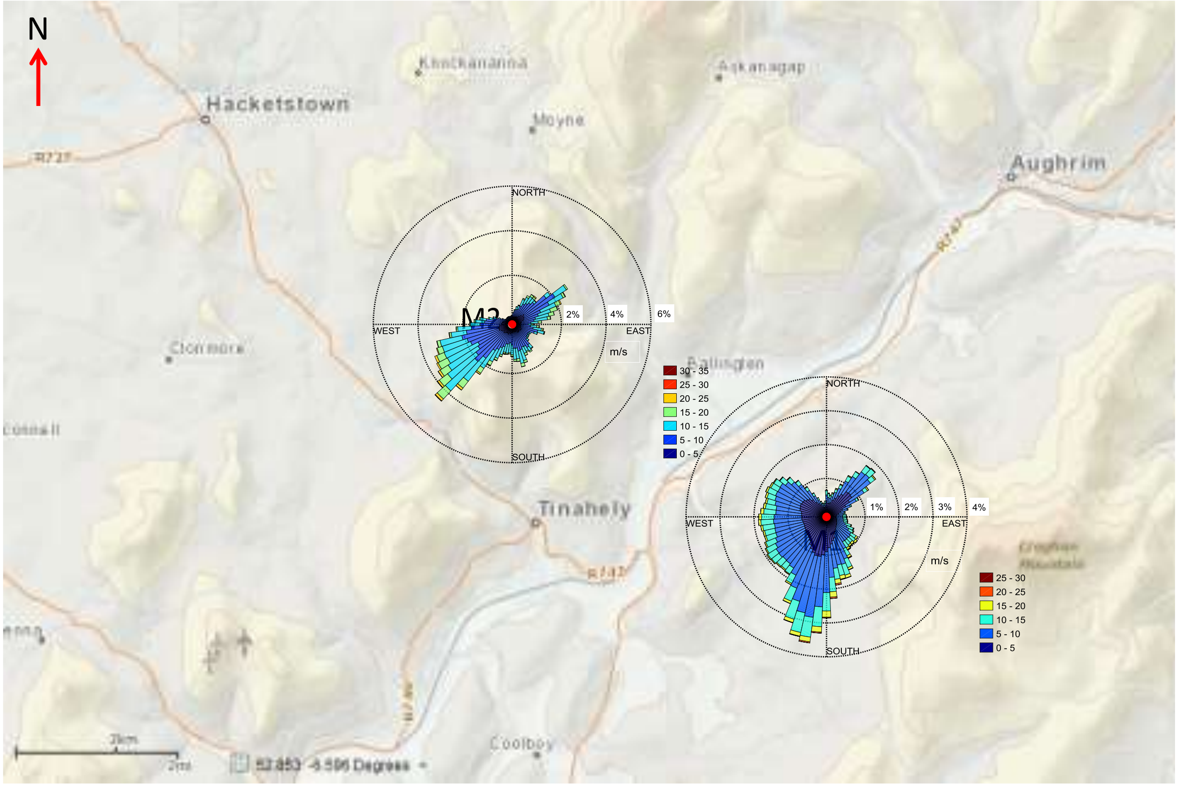


Figure 4.20

Key learning from case study 1

- When siting a wind turbine in any location the potential of mesoscale influences within a 20km radius of the site should be taken into account. This is particularly important when there is higher elevated topography within 20km, in what would be considered the general prevailing wind direction, that could result in blocking or direction steering of wind. Similarly a site within 20km of the coast may have extra energy to be gained from onshore winds due to land/sea influences and topography between the site and coast should be considered.

4.2 Case Study 2-Rural at low elevation

Figure 4.21 show the location a 13m met mast at the Louth Co. Co dog pound located a at low elevation of 10m in a rural location ~ 5km from the east coast. The mast is surrounded by nearby obstacles such as the building itself and neighbouring houses and motor way service stations. Figures 4.22 and 4.23 shows a plan view of the site at defend scales showing the mast location and Table 4.4 gives approximate distances and heights of local obstacles from the mast location

Figure 4.21

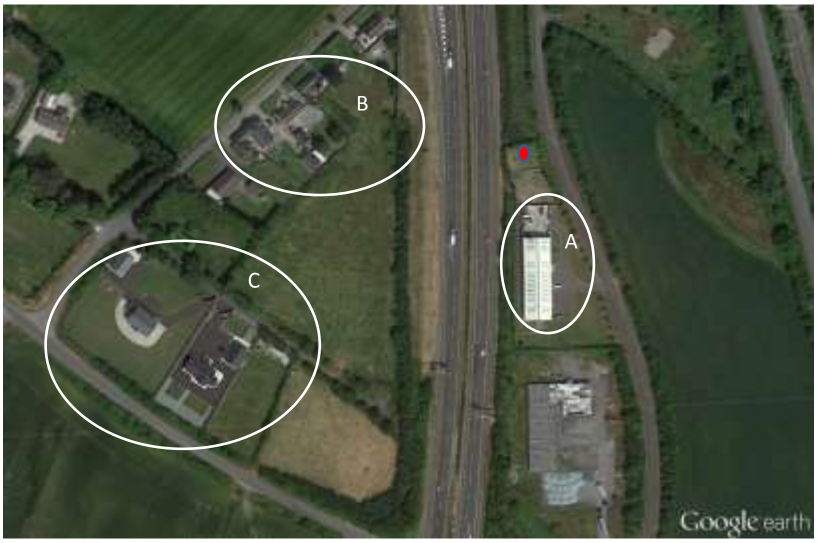


Figure 4.22 *: ● mast location*

Figure 4.23 : ● *mast location*

Obstacle	Distance Range(m)	Mean height(m)
A	50-185	5
B	270-400	4
C	75-240	4
D	420-510	9
E	500-600	9
F	415-720	5
G	360-570	5

Table 4.4

The local obstacles consist of the building itself to the south of mast location along with nearby single houses and clusters of houses to the westerly and easterly sides. Further south and northwest there are motor way service stations (D and E). There are also dispersed trees/hedge rows around the site and a motorway flyover bridge exist in the south south-westerly direction (i.e. between A and D).

Results of data analysis

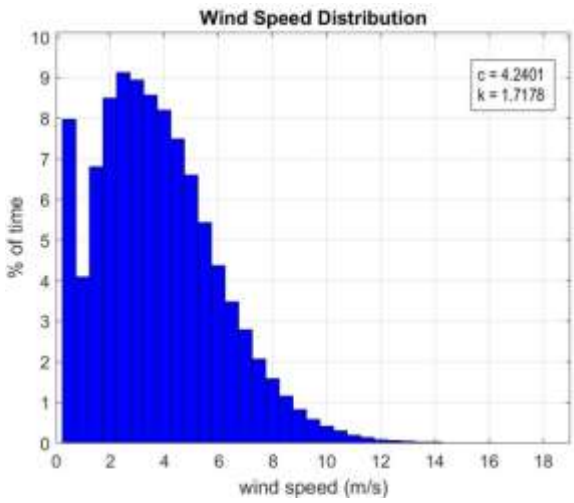


Figure 4.24

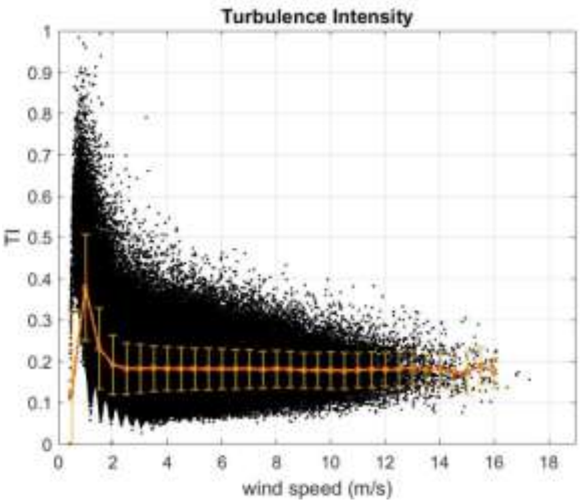


Figure 4.25

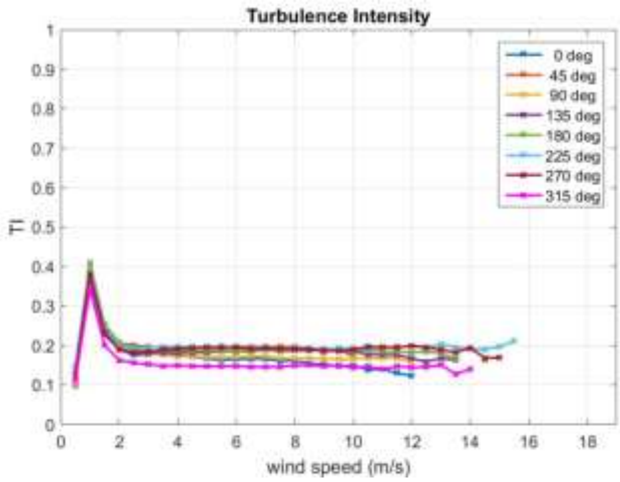


Figure 4.26

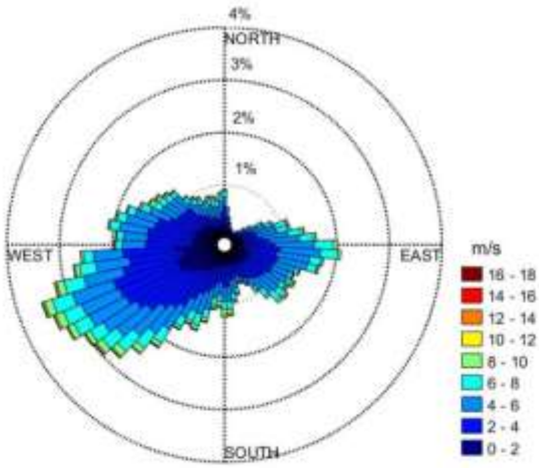


Figure 4.27

Measurement height (m) a.g.l	Mean wind speed (m/s)	1-second max Wind speed (m/s)	Turbulence Intensity @ 15 m/s
13	3.8	25.0	0.17

Table 4.5

Table 4.5 show the site has relatively low mean wind speed and increased turbulence intensity (@ 15m/s) for the given measurement height of 13m. Differences in turbulence intensity with direction can be seen in figure 4.26 with higher turbulence in the south to west sectors which is a reflection of the manmade obstacles (buildings) in these sectors. It is also noted that turbulence intensity exceeds 0.2 @ 15m/s in the south west sector. This is above the design turbulence intensity of 0.18 @15m/s in the current IEC 61400-2 Ed 3 small wind standard. The wind rose also shows distinct features with reduced wind to the north and northwest sectors and also the southerly sector. The building (A) at the site itself which is 50m from the mast combined with building (D) and a motorway flyover (~ 250m away) bridge further significantly reduce the southerly wind as seen by the mast. In the southwest sector the peak of the wind rose occurs between obsticals in B and C. There is a higher density of houses in B which appear to have more significant influnce on wind flow that the sparcer obsticles in C. Significant easterly winds are also observed due to proximity of site to east coast. An overlay of the wind rose on the site plan in figure how the wind rose is shaped by local obstacles. Referring to the distances show in Table 4.5 it is evident that obstacle less at significant distances may have influence on the wind flow at the mast itself. E.g. a broad clusters of houses in regions F and G which are ~ half the mast height and a least 360m away (~ 30 mast heights) appear to shape easterly wind flow.

Figure 4.28

Key learning from case study 2

- The energy output from small wind turbine sited at low elevations can be greatly impacted upon by local obstacles at significant distances from the site location (~ 30 hub heights by obstacles ~ half of the height). Clusters of low obstacles have bigger reduction impact than sparse single obstacles. Turbulence intensity can exceed that used in current small wind design standards (i.e.0.18 @ 15m/s). This may be significant for the operating life of a turbine if the high turbulence sector is also the prevailing wind direction.

4.3 Case study 3

DkIT Site – Peri-urban area

In this study a multi annual analysis of SCADA data recorded at 60m in 10 minute averages from an existing 850kW wind autoprodroducr was carried out. 2D measurements of wind speed and direction were also taken at 10m on the same site to assess conditions for small wind. In addition preliminary LiDAR measurements were made at the wind autoproducer site and in an urban back garden to assess the wind shear profiles in such areas.

Figure 4.29

Figure 4.30

The turbine is located on the east coast of Ireland at 9 m above sea level. 7 km to the northeast of the site there are hills that rise to elevations from 300 m to 600 mas shown in figure 30. The terrain to the south and west is low lying. The regional (mesoscale features) are outlined in Table 4.6

Regional site features		
Site	Distance [km]	Elevation [m]
A	7.5-15	75-563
B	13-18	10-540
C	17-40	0-663

Table 4.6

A range of local obstacles (building) exit around the turbine location. There are shown in Figure 4.31 and a description of these is given Table 4.7.

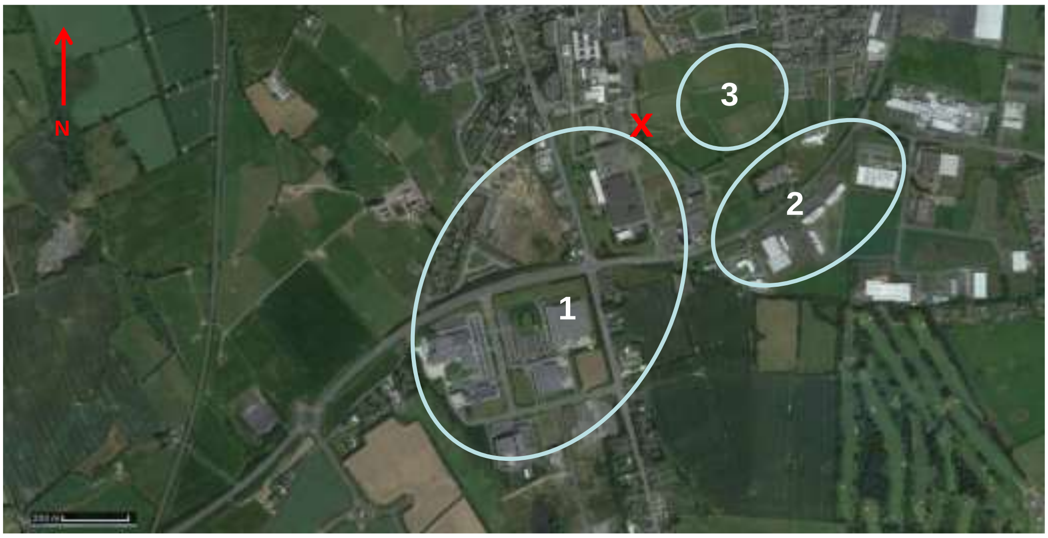


Figure 4.32

Local site features	
Obstacles	Distances, heights and description
1	Industrial buildings 150 m to 1.2 km away from turbine. Majority are 11 m high with one small block 25 m high. The total building cluster width is 670 m as seen from the turbine. The area also included a row of houses to the west that are ~ 7 m high.
2	Hotel and office blocks 350 m to 650 m away from turbine. The hotel 47 m high and 33 m wide. The office blocks are 12 m height and 220 m wide as seen from turbine
3	Sports field to north east with town to north (not shown)

Table 4.7

Results from Turbine data analysis

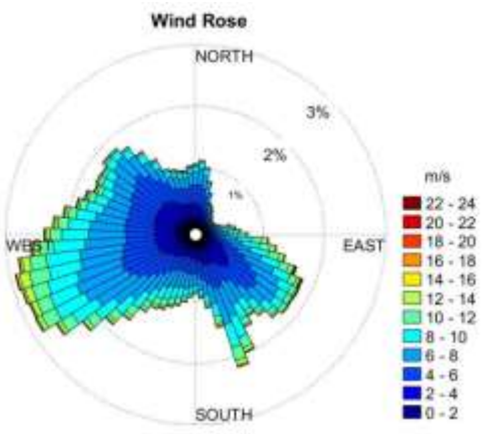


Figure 4.33

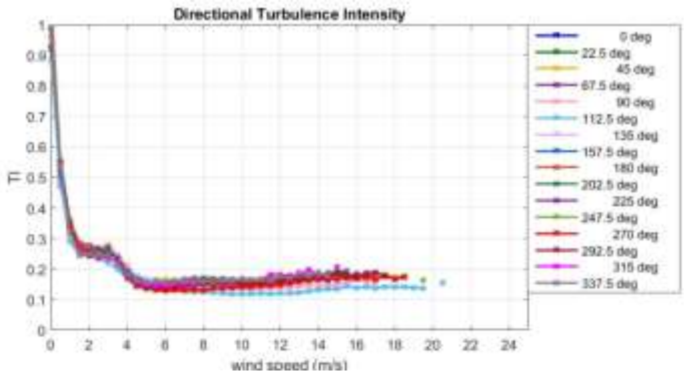


Figure 4.34

The wind rose show distinctive features with notable reduction wind as seen by the turbine at 60m in the south to south west directions and north east directions. The directional turbulence intensity also shows variation with lowest turbulence towards east south east (112.5 degrees) and the higher values in southwest and northwest directions. The turbine energy output with direction (energy rose) was further investigated as shown in figure 4.35. This reveals a very distinct shape particularly in the north east southeast and south west sectors.

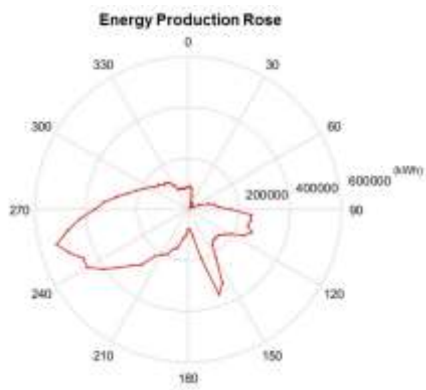


Figure 4.35

Overlays of the energy rose on the plan view of both local and regional maps are show in figures 4.35 and 4.36.

Figure 4.35

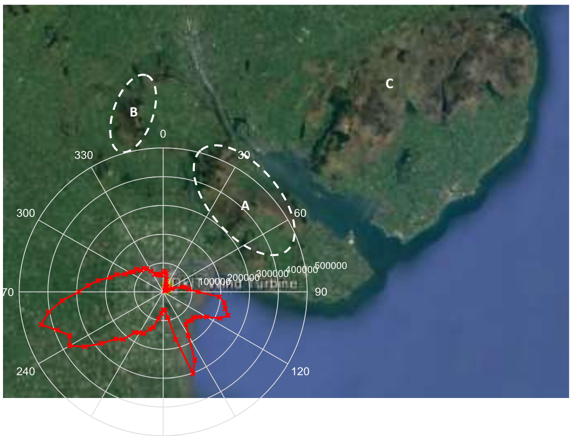


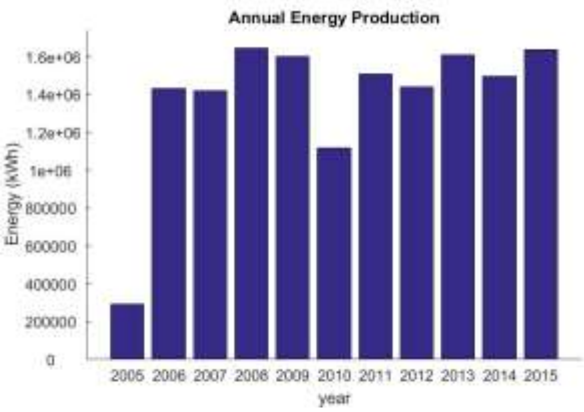
Figure 4.36

Referring to the local and regional site features given in Tables the follow is observed

Low broad buildings, ~ 1/5 of hub height within 20 hub heights of the turbine, in the south southwest sector appear to have a large energy reducing impact (similar observations in Case study 2). The view as seen the turbine a hub height in this directional sector is shown in figure 4.37. Taller narrow buildings appear to have less an impact i.e. building width is important. Hills to the northeast 7 km away at a higher elevation have a significant energy blocking effect (mesoscale impacts and was observed in Case study 1)

Figure 4.37

Ten year annual energy production totals are shown in Figure 4.38. Internal variation in energy output can occur depending on each wind year. In this case the mean annual energy production 1,507,200 kWh, standard deviation 173,880 kWh i.e. (+/- 11%). An exceptionally low wind year (e.g. 2010) can have big bearing on longer term annual energy output totals assessments. The power curve for the turbine is shown in Fig 4.39. All measured wind turbine power curves show some degree of scatter and are site and technology specific i.e. can deviate from manufactures published power curves. This is an ongoing area of research.



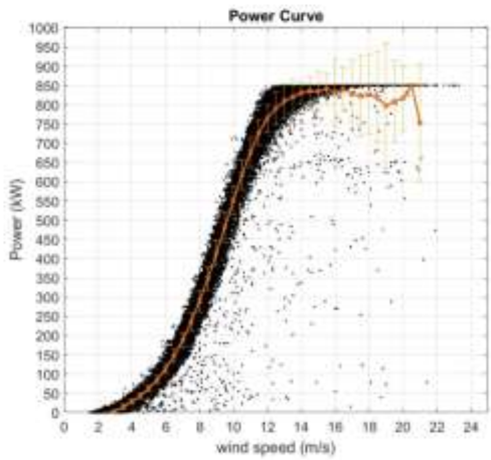


Figure 4.38

Figure 4.39

DkIT 10m mast measurements

In addition to data from the turbine measurements were also made at 10m at the DkIT site at ~ 80m to the east of turbine. The location is show in figure 4.40

Figure 4.40

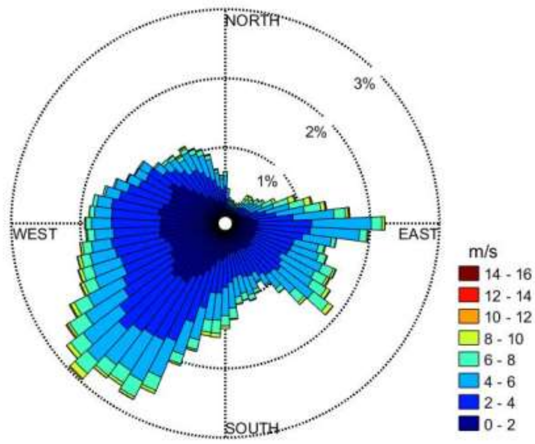


Figure 4.41

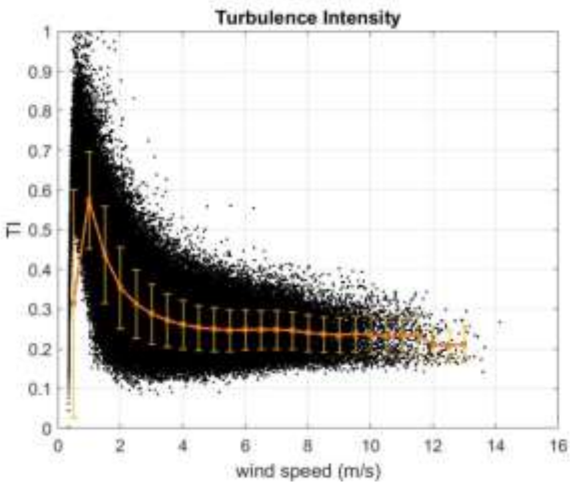


Figure 4.42

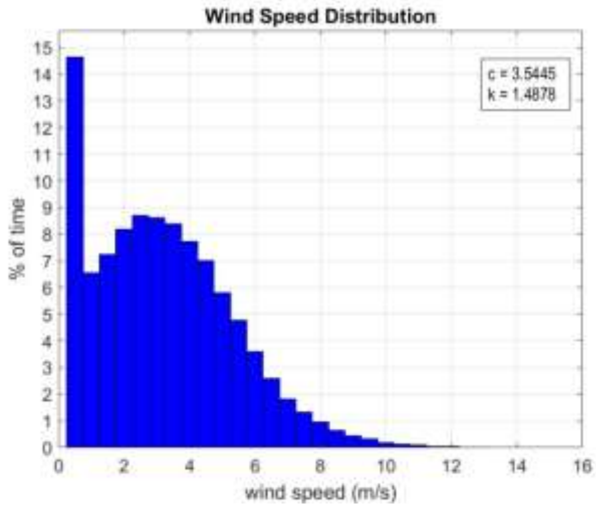


Figure 4.43

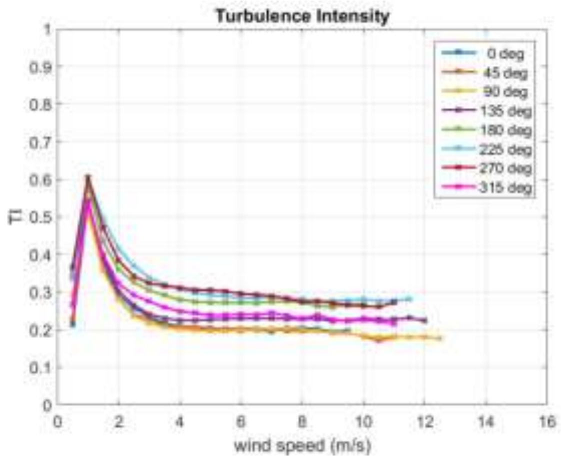


Figure 4.44

Measurement height (m) a.g.l	Mean wind speed (m/s)	1-second max Wind speed (m/s)	Turbulence Intensity @ 15 m/s
10	3.2	28.2	0.20*

Table 4.7 (*estimated TI @15m/s as measurements did not contain sufficient number of data points in this bin)

Table 4.7 show the site has low mean wind speed and high turbulence intensity (@ 15m/s) for the given measurement height of 10m. Differences in turbulence intensity with direction can be seen in Figure 4.44 with higher turbulence in the south to west sectors which is a reflection of the manmade obstacles (buildings) in these sectors with the lowest in the easterly sector which look across flat sports fields to the coast It is also estimated that turbulence intensity is close to 0.3 @ 15m/s in the south west sector. This is well above the design turbulence intensity of 0.18 @15m/s in the current IEC 61400-2 Ed 3 small wind standard. It suggest that 10m hub heights are suitable heights in this environment.

Preliminary LiDAR measurements in a garden of suburban house

As large scale wind turbines have become increasingly taller in recent years LiDAR is a remote sensing technology that gaining interest in the wind industry due to its ability to measure winds at multiple heights up to heights over 200m and also for its practical ease compared to very tall met mast installations.

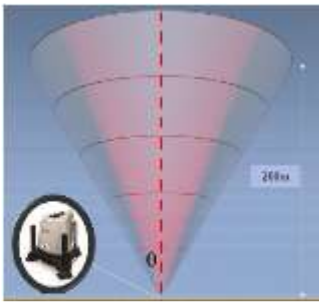


Figure 4.45

In this case interest the garden of house in a suburban area. The aim of the measurement was to assess the height above ground level where wind speeds became sufficient for realistic for small wind energy production (without the need of installing a met mast). The LiDAR used in this case was a Zephyr R300 shown in figure 4.46 due to its ability to measure from 10m to 300m.

Figure 4.46

Measurements were taken from the back garden of typical suburban environment surrounded my many neighbouring houses as shown figure 4.47. A general street view of location in shown in figure 4.48

Figure 4.47 : ● *Lidar location*

Figure 4.48

The measuring period was over 2 month period. Measurements of wind speed and direction were taken at 10m, 20m, 34m, 38m, 46m, 60m, 72m, 86m, 120m, 200m and 300m to assess the variation of wind speed (horizontal) with height. A graph of the measured wind shear profile is shown in figure 4.49.

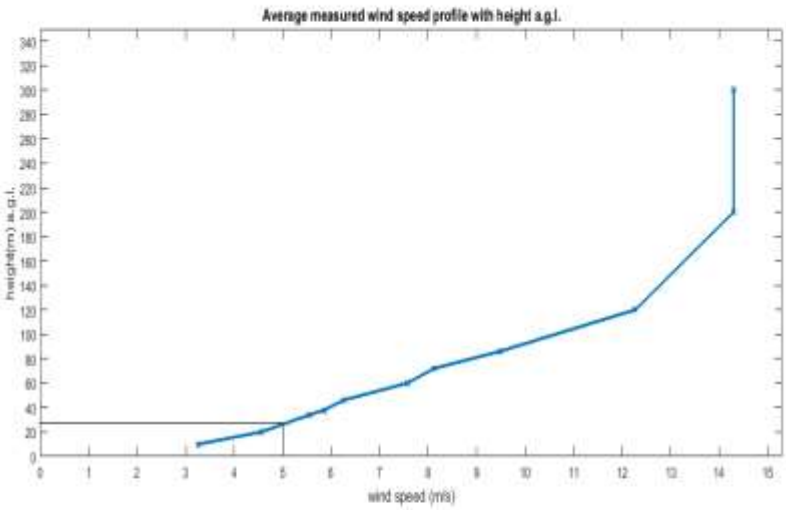


Figure 4.49

From this graph is can be seen that in order to see mean wind speeds of at least 5m/s for small wind turbine it show that tower heights of a least 30m are required. The measurement of just over 3m/s at a 10m height is broadly line with measurements taken at DkIT from the 10m mast which shows that short towers are likely to be not viable options in areas of low elevation.

Key learnings from case study 3

- Low broad buildings, ~ 1/5 of hub height within 20 hub heights of the turbine, in the south southwest sector appear to have a large energy reducing impact.
- Taller narrow buildings appear to have less an impact i.e. building width is important.
- Hills at higher elevations than the site location 7 km away at a higher elevation have a significant energy blocking effect
- Standard deviation in annual energy output for a single large scale wind autoproducer at DkIT 11% based on 10 years of data
- To see mean wind speeds of at least 5m/s for small wind turbine in areas of low elevation, tower heights of a least 30m are required.
- Short towers (e.g. 10m) are not likely to be energy viable options for small wind turbines in areas of low elevation.
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Summary conclusions

- When siting a wind turbine in any location the potential of mesoscale influences within a 20km radius of the site should be taken into account. This is particularly important when there is higher elevated topography within 20km, in what would be considered the general prevailing wind direction, that could result in blocking or direction steering of wind. Similarly a site within 20km of the coast may have extra energy to be gained from onshore winds due to land/sea influences and topography between the site and coast should be considered.
- The energy output from small wind turbine sited at low elevations can be greatly impacted upon by local obstacles at significant distances from the site location (~ 30 hub heights by obstacles ~ half of the height). Clusters of low obstacles have bigger reduction impact than sparse single obstacles. Turbulence intensity can exceed that used in current small wind design standards (i.e.0.18 @ 15m/s). This may be significant for the operating life of a turbine if the high turbulence sector is also the prevailing wind direction.

References:

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