Guernsey Offshore Wind

A Data Acquisition Strategy

Student: *Mr Marc Staddon*

Supervisor: Mr Richard Cochrane

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Disclaimer

This study, produced by a student at the University of Exeter in partnership with GRET, may contain views and conclusions that are not shared by GRET.

Abstract

Guernsey Offshore Wind – A Data Strategy Review

This research reviews wind resource assessment techniques in order to outline the best options for an offshore wind development for The States of Guernsey.

Traditional and modern technology, methods and costs for conducting measurement campaigns are reviewed and discussed.

Applicable strategies from other projects are assessed identifying a significant increase in the estimated wind speeds at one offshore site from 7.23 m/s to 8.7 m/s using a short term coastal LiDAR campaign.

An optimal solution is then derived and a cost effective strategy for Guernsey is proposed.

The study concludes that modern technology and methods can reliably replace the traditional at greatly reduced cost and thus mitigate financial barriers and increase certainty for offshore wind developments.

Common abbreviation and notations

Abbreviation	Meaning
AOWFL	The Aberdeen Offshore Wind Farm Ltd
AREG	Aberdeen Renewable Energy Group
Approx	Approximately
asl	above sea level
awl	above water level
CCA	Climate Change Act
CFD	Computational Fluid Dynamics
EOWDC	European Offshore Wind Deployment Centre
FLiDAR	Floating Light Detection and Ranging Systems
GE	Guernsey Electricity Limited
GRET	Guernsey Renewable Energy Team
IEC	International Electrotechnical Commission
LiDAR	Light Detection and Ranging Systems
m/km	meters/kilometres
MCP	Measure Correlate Predict
Met/MET	Meteorological
NM	Nautical Mile
NREL	National Renewable Energy Laboratory
OWA	Offshore Wind Accelerator
SoDAR	Sonic Detection and Ranging Systems
SoG	States of Guernsey
VMM	Virtual Met Mast
WRA	Wind Resource assessment
WRF	Wind Research and Forecasting
WTG	Wind Turbine Generator

1 Introduction

1.1 Background

The States of Guernsey (SoG) energy situation differs substantially from that of the UK, France and other nations. The existing infrastructure is wholly reliant on imported heavy fuel oil for the islands generators and imported French tariff electricity and consequently lacks the price-security and supply autonomy that indigenous solutions can bring[1]. The situation is becoming ever more pressing as part of the Guernsey Electricity Limited (GEL) generator fleet is due to retire within the next 5-6 years[2] along with two of the islands aging oil tankers, the latter of which is likely to require the creation of a deep water berth to serve larger replacements and increase the choice of suppliers[3].

Reducing fossil fuel reliance for commercial reasons is therefore a priority but is only a part of SoG's agenda. The 2011 Guernsey Energy Resource Plan reviewed targets set out in its 2008 Energy Policy Report and adopted targets similar to the UK's Climate Change Act (CCA) in order to demonstrate its commitment to addressing the issues surrounding climate change. The report also highlighted the need to diversify into low carbon and renewable energy generation to achieve this mandate[4]. The latest GRET report reiterates this vision; "generating local renewable energy which is low carbon and affordable and will provide greater energy security and independence as well as a lasting commercial, financial and environmental legacy"[5]. SoG is also in the unusual and enviable position of owning its electricity utility (GEL) and could therefore be the major partner in its own renewable energy development. Consequently SoG would also be able to manage the project in order to maximise economic returns and control other benefits such as employment[6].

To this end the Commerce and Employment department of the SoG government delegated the task of progressing the macro renewable energy mandate to the Guernsey Renewable Energy Team (GRET). Offshore wind is a rapidly maturing technology and in 2011 GRET conducted a feasibility study into the available wind resource on the island in an effort to provide an economic case for offshore wind development[7].

[1] (University of Exeter, 2013)

[2] (GRET, 2013)

[3] (States of Guernsey, 2011)

[4] (States of Guernsey, 2011)

[5] (GRET, 2015)

[6] (GRET, 2013)

[7] (GRET, 2011)

1.1.1 GRET report

The 2011 report found favourable conditions for the development of offshore wind at two sites to the North West. This has been reviewed and advanced in later reports and studies (Table 1-1) culminating in the GRET 2013 'Wind costings' report that confirmed the optimal site to be a 23km^2 area to the North East (the Schole bank) beyond the 3 nautical mile (NM) and slightly overlapping the 6 NM territorial water boundaries[8].

The report summarised its own recent research findings and those from previous reports and assimilated consultation with industrial parties and predictions from the Crown Estate and the US Department of Energy. It confirmed that Guernsey could benefit in the short term from a 30MW domestic project (Approx 30% of demand) with minimal electricity price rises and timetabled the need for more wind data (2 years) specific to a wind project for the period 2014-2017.

Table 1-1 Chronology of studies

Chronology of studies:
- Feasibility study into Offshore Wind Energy (GRET) – **Jul 2011** - Renewable Energy Feasibility Report (UoE) – **Jun 2012** - Feasibility of Offshore Wind in Guernsey Waters (Oliver Lee) – **Sep 2012** - Offshore Renewable Energy for Guernsey (UoP) – **Dec 2012** - Guernsey Energy Analysis and Strategy Recommendations to 2050 (UoE) – **May 2013** - Wind costings, a review of current knowledge and it's applicability to Guernsey (GRET) – **2013** - Review of the GRET report - Costed wind model for Guernsey (Aquatera) – **Jul 2014** - Renewable Energy Team (RET) Strategy – 2015 and Onwards (GRET) - **2015**

1.1.2 Territorial limits

Guernsey is currently in talks with the UK and France in an effort to officially extend its territorial water limits from 3 NM to 12 NM and to exploit the higher wind resource in the North-East[9]. The negotiations will redress the impact on the English Channels North-East bound shipping lane, confirm the median line with France to avoid territorial boundary overlaps and agree free passage and pollution management conventions to protect the Bailiwick[10].

[8] (GRET, 2013)

[9] (BBC (a), 2013)

[10] (BBC (b), 2013)

1.1.3 Aquatera report

In 2014 GRET approached consultancy firm Aquatera to review the 'Wind costings' and analyse the newly available wind data from 2012 and 2013 collected at the airport and the Choet anemometer mast. It drew conclusions and proposed recommended actions for the next steps for an offshore wind project. Aquatera described the project as being in the preliminary appraisal phase and three initial steps were identified[11];

1. Analysis of imported electricity prices from France
2. Site selection process
3. Strategy for wind data gathering and resource analysis

Of the three It was felt that step 3 was the most urgent and compelling and after contacting GRET initially through lecturer Dr Adam Feldman and latterly Mr Richard Cochrane, Director of Education and Lecturer, work started on producing a dissertation that would fulfil this scope.

2 Aims and objectives

The Aquatera report recommended that "better wind resource data is a priority for the project (over a more detailed financial model) and will be needed in order to attract finance" and that a "route-map tailored for GRET" would "outline options for data gathering and data analysis" (see Appendix E). This provided the scope for my report and the jumping off point to define the aims and objectives.

This **aims** of this report are:

- Research Wind Resource Assessment (WRA) techniques suited to the situation
- Outline the WRA options for GRET

With the optimal **objective** being:

- Identify the most economical and effective strategy that will help reduce project risk and increase confidence around further investment

[11] (Aquatera, 2014)

3 Literature review and research

3.1 Methodology

In the first instance an article on performing literature reviews was sourced and absorbed for guidance[12]. By referring to Cooper's (1988) Taxonomy of Literature Reviews within the article the scope of the review was defined and shown in Table 3-1 Coopers Taxonomy results table.

Table 3-1 Coopers Taxonomy results table

Characteristic	Category
Focus	Practises or applications
Goal	Identification of central issues
Perspective	Neutral representation
Coverage	Exhaustive
Organisation	Methodical (introduction, method, results, and discussion)
Audience	Specialised scholars

3.1.1 Literature review

The literature review focussed on the latest developments in offshore WRA techniques. An advanced search in *ScienceDirect* for 'offshore wind resource assessment' and 'techniques' for the period 2013-2015 and using the filters 'wind turbine', 'wind farm', 'wind energy', 'wind power', 'renewable energy', 'wind speed' and 'remote sensing' produced 29 results for 2015, 50 for 2014 and 32 for 2013. Reviewing these results proved disappointing with few articles relevant to the latest techniques with the exception of an assessment of offshore wind energy potential using mesoscale model and geographic information systems 2014[13].

Another search for 'wind resource assessment' and 'remote sensing techniques limited to the period 2013-2015 and topics 'remote sensing', 'wind speed', 'lidar datum' and 'wind turbine' yielded 27 results for 2015, 29 for 2014 and 21 for 2013 but no relevant articles were found on or comparing techniques. A search for technologies mentioned in the Aquatera report such as LiDAR (Light Detection and Ranging) and FLiDAR (Floating Light Detection and Ranging) as cheaper alternatives to traditional Met Mast methods over the last 3 years produced a plethora of articles highlighting the rapid and extensive development of this technology.

[12] (Randolph, 2015)

[13] (Yamaguchi & Ishihara, 2014)

3.1.2 Online research

A search of the Exeter University library catalogue produced no results for ‘wind resource assessment’ so online research was conducted to identify companies and organisations involved with offshore WRA and the development of the latest techniques. This was confined to UK and EU organizations as Guernsey lies within these geographical limits. An online search for relevant books yielded a very detailed publication that was ordered through the library and proved extremely useful[14].

An online search for LiDAR and FLiDAR with keyword such as ‘resource assessment’ and ‘techniques’ was performed and the plethora of results were scrutinised for relevance and the most pertinent saved for further review and consideration.

Relevant online news feeds such as offshorewindbiz[15] and windpowermonthly[16] provided a jumping off point for further investigation. Verbal or email conversations with a network of contacts spanning industry, alumni and academic staff also provided leads to follow.

3.2 4C Offshore

4C Offshore have constructed comprehensive databases for the offshore wind and tidal markets such as project specifications, supply chain and construction events, their interactive map is a very useful tool for obtaining details on wind farms around the globe. 4C provides ranked 10 year mean wind speeds for each offshore wind farm (100m hub height) derived from high resolution global satellite data from 6 NASA satellites[17].

Following leads generated from prior research on LiDAR WRA’s and using the 4C map, details on sites similar in scale the prospective Guernsey sites were obtained. The WRA’s were then closely examined for suitability. Unfortunately 4C charge £2300 per year for a single user subscription and so some project details such as milestone dates were unavailable for this report.

[14] (Bower, 2012)

[15] (offshorewindbiz (b), 2015)

[16] (windpowermonthly, 2015)

[17] (4C (a), 2015)

3.3 IEC 61400-12-1 Annex L requirements

IEC 61400 is a set of international standards for the construction of wind turbines. These design requirements are intended to ensure the engineering integrity of the turbine and protect against damage from hazards within the design lifetime. They cover all aspects of the turbine from structural design to commissioning, operation and maintenance. IEC 61400-12-1 relates specifically to 'Power performance measurements' including WRA requirements and Annex L relating to the application of new remote sensing technology[18].

Under current standards for energy projection and performance monitoring a meteorological (MET) mast must be properly sited a suitable distance from wind turbines or other obstacles. Wind data is required to be collected at or close to the intended turbine height usually some 80-100m above water level (awl). Data must be unaffected by wakes and with a sampling rate of 1 Hertz (Hz) or higher for wind speed and direction[19]. It is generally accepted that the measurement campaign is at least a year (12 consecutive months) in duration[20].

Under the current guidelines procedures concerning remote sensing technology are restricted to the following conditions[21]:

- Only deployments where the remote sensing device is monitored by a cup anemometer mounted on a mast at a height corresponding to at least the minimum of the turbine rotor lower-tip height or 40m
- Only ground based remote sensing devices are used (e.g. nacelle mountings are not included)
- The use of remote sensing for conducting power performance assessments is limited to flat terrain, that is, situations where site calibration is not required in accordance with Annex B of this standard.

[18] (Madsen, 2008)

[19] (IEC, 2013)

[20] (Bower, 2012)

[21] (IEC, 2013)

4 Technology

4.1 Overview

Until recently the classic offshore WRA solution has been the installation of MET masts with cup anemometers close to the prospective site to record wind data for a period of at least 12 months. Due to the high cost of this method remote sensing systems utilising Sonic Detection and Ranging Systems (SoDAR) and Light Detection and Ranging Systems (LiDAR) have been developed. Such systems provide wind measurement profiles at multiple heights simultaneously and are rapidly being validated as reliable and cost effective replacements. Figure 4-1 below from Leosphere[22] demonstrates how the costs of a WRA vary with the deployment of newer technology and methodology.

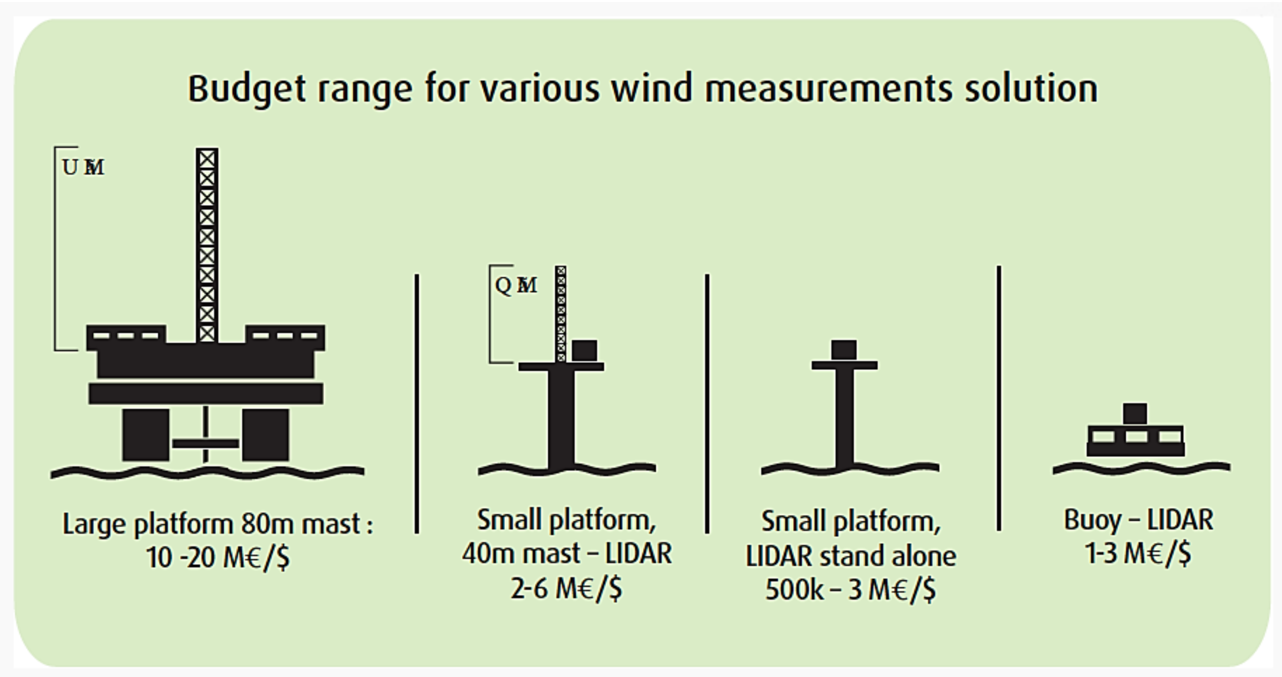

Figure 4-1 Solution budgets

[22] (Leosphere (b), 2015)

4.2 On site assessment

The following sections details the various applicable technologies and suggests the optimal technology for Guernsey and the stage of the islands project.

4.2.1 Offshore Met Mast

Overview

Offshore WRA utilising traditional MET masts are very expensive. Off shore MET masts are typically installed as close as possible to prospective sites to maximise confidence levels and the bankability of the data. The University of Exeter report for GRET suggested that "an offshore meteorological mast is deployed to reduce investor risk"[23] so this possibility was examined. Offshore MET masts are large complex structures consisting of a foundation, platform and mast complete with a suite of sensors and cup anemometers. The cups are set at a range of heights determined by IEC guidelines, as illustrated in Figure 4-2[24] below, to generate a profile of the wind at the site.

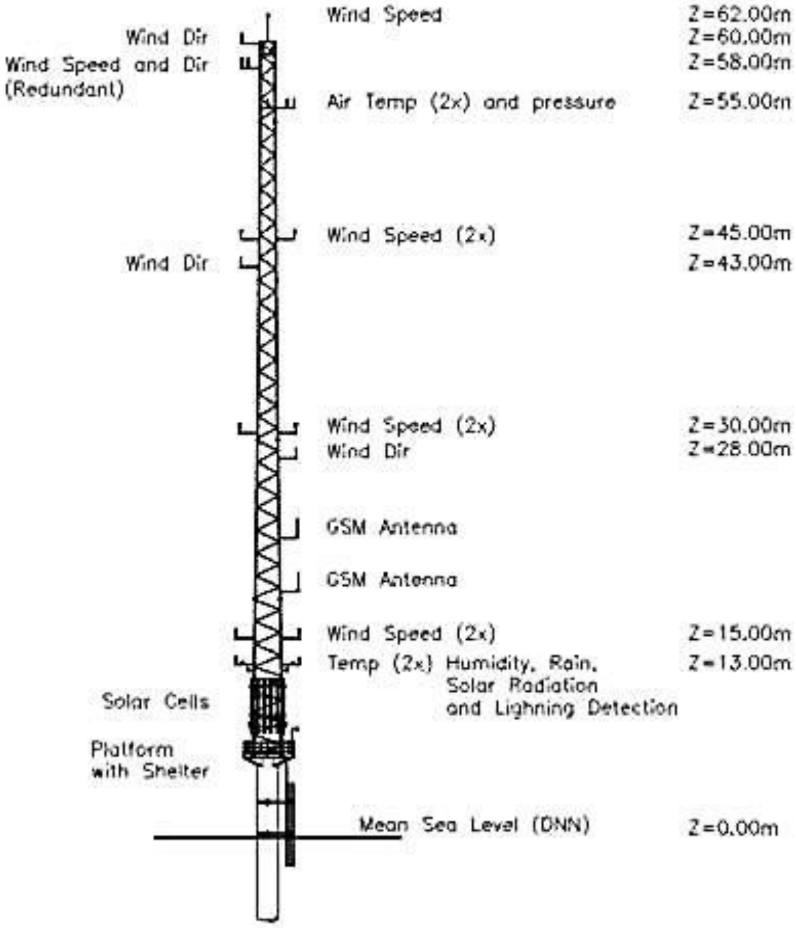

Figure 4-2 Horns Rev Met Mast schematic

[23] (University of Exeter, 2013)

[24] (WindData.com, 2015)

Met mast installations can require deep foundations that need to be drilled into the seabed with a jack up barge to fix the mast base in position. Costs can be as high a £7m per mast, with one leading industry expert suggesting 'real world' costs of £10-12m (Appendix C-3), a considerable investment in a project which may prove unviable after the WRA. Figure 4-3 serves to illustrate the scale of a MET mast deployment. This suction bucket foundation with 'human free' tower installation method is designed to minimise cost and personnel risk but is still a major undertaking.

Figure 4-3 Dogger Bank MET mast bucket foundation

The contrast in these cost figures could be due to the extra costs involving in maximising the data gathered by the installation. As well as the wind resource offshore permitting requires characterisation of many other factors including the sea state, current and tidal regimes, air and sea temperature, bathymetry and benthic, marine and other wildlife. Assessing all these parameters simultaneously would maximise the usefulness of the mast but requires more investment and deepens the complexity of the installation, raising costs[25].

Summary

Companies such as Offshore Marine Management (OMM) are developing a reusable sectional design that can be towed out to site as a more cost effective solution to construction and installation that is estimated to save up to 40% of the installation, maintenance and decommissioning costs.[26]. However this still represents an investment of around £4m putting it well beyond the objective of this report and it is unsuitable for the projects current stage of development.

[25] (Bower, 2012)

[26] (Hopwood, 2012)

4.2.2 FLiDAR

Overview

FLiDAR is an acronym for the floating LiDAR being developed by the many companies listed in Appendix A.

FLiDAR nv is the name of a joint venture between 3E and OWA (DEME Group) whose aims are to build, deploy and maintain an innovative floating wind measurement device to help reduce costs for offshore wind resource assessments. The approach utilises a moored floating platform and LiDAR technology from Leosphere and is intended to significantly reduce the high cost of MET masts and provide more flexibility for wind power developers and asset managers[27].

The device (shown in Figure 4-4) has successfully completed numerous validation trials culminating in the world's largest and most challenging validation trials of floating offshore wind measurement devices by the Offshore Wind Accelerator (OWA) at Neart Na Gaoithe in the outer Firth of Forth, 30km north of Torness[28,29] where it was used in where a MET mast would normally be used[30].

Figure 4-4 FLiDAR nv deployed for validation at Blyth

[27] (FLiDAR, 2012)

[28] (Carbon Trust (a), 2015)

[29] (FLiDAR (c), 2015)

[30] (4C (e), 2015)

Summary

The availability of commercially sensitive pricing information is extremely limited but the costs of such a device assumed to be considerable lower than a MET mast. Matt Smith mentioned in conversation (Appendix C-9) approximate costs of the latest FLiDAR devices as around “£2.5m for tension leg platforms, £750,000 for spar buoys (Fugro Seawatch) and less than £1m for a hull design (Axys WindSentinel)”. This represents a considerable cost saving over MET masts but still too large an investment for the project at this stage but given the timeline of development for both FLiDAR and Guernsey’s project it should be regarded solution for the onsite WRA in the future.

4.3 Remote sensing

4.3.1 Overview

Remote sensing systems include vertical profilers mounted on fixed or floating platforms and side scanning profilers deployed on shore near prospective sights and on offshore platforms. The main advantage of remote sensing technology is the ability to measure wind profiles at much greater heights than a wind mast and across the rotor plane of the turbine. This helps to reduce the uncertainty in the wind characterisation and the energy generation predictions[31].

Information gathered by the devices includes horizontal wind speed and direction, vertical wind speed, associated standard deviations, signal to noise ratio and maximum height of useable data. This information is used to produce wind profiles and identify wind shear and the level of turbulence within the airstream to characterise the wind at a site. Figure 4-5[32] illustrates the use of LiDAR and MET mast to generate a wind profile beyond the maximum height of a MET mast to a range that includes the hub height and rotor plane of the proposed wind turbine generator (WTG)

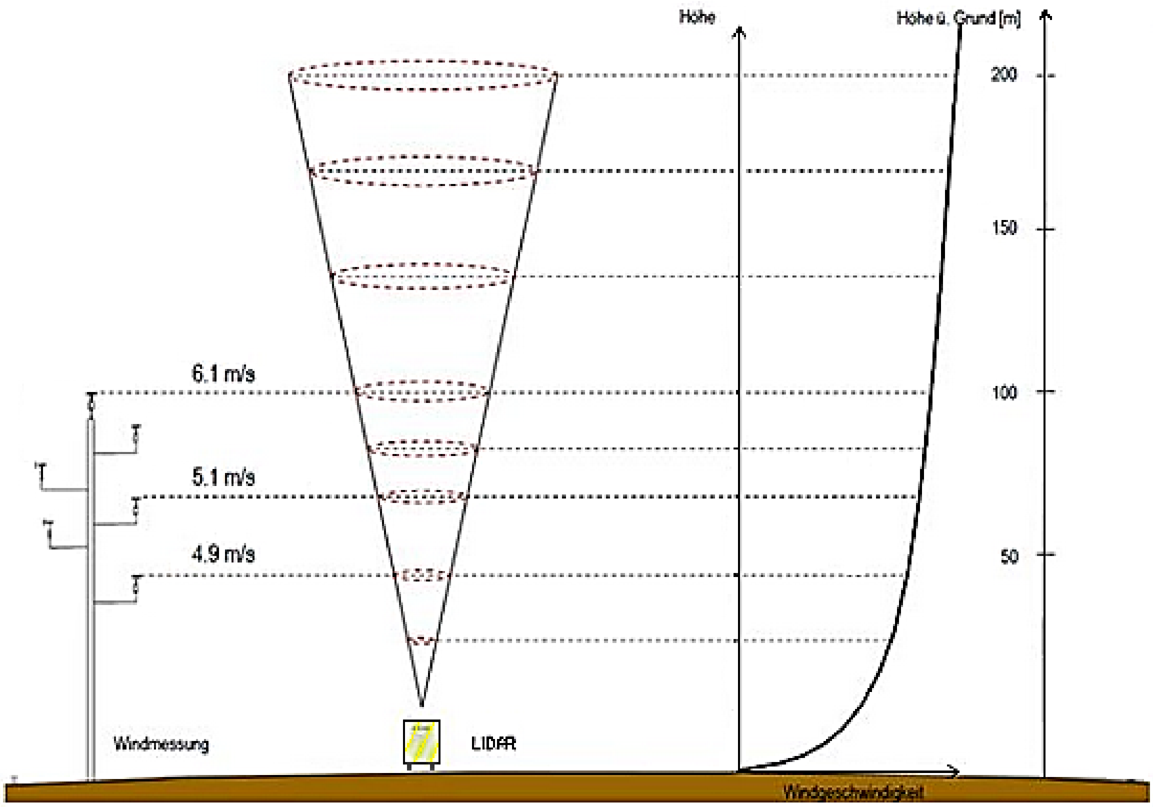

Figure 4-5 Wind Profiling

[31] (Bower, 2012)

[32] (Renewable Energy Magazine, 2013)

4.3.2 SoDAR

SoDAR systems utilise sound waves to record wind velocity. Acoustic pulses are emitted and the backscattered echoes caused by turbulent eddies within the wind are then analysed for the Doppler Effect frequency shift to produce a velocity measurement. They can measure wind velocities from 30m to 200m (agl) in increments of 5-20m[33]. SoDAR measures wind averaged over an area and can therefore also be used to predict the wind resource available for specific wind turbines[34].

SoDAR units such as Second Wind's Triton (Figure 4-6[35]) tend to be larger than LiDAR's and they are adversely affected by acoustic interference. Although successfully deployed offshore there is a higher risk of interference from other structural components such as the wind whistling past steel cables and wave and wildlife noise. Air temperature and precipitation should also be measured at a SoDAR site. Air temperature is required to accurately calculate the speed of sound and therefore the returning echo's altitude. Precipitation can cause noise and scatter and needs to be screened out of the collected data to improve accuracy.

Figure 4-6 Triton SoDAR

[33] (Bower, 2012)

[34] (Horsfield, 2014)

[35] (Windpower Egineering, 2015)

4.3.3 LiDAR

Overview

LiDAR systems emit either a continuous or pulsed laser light to measure wind characteristics. Leosphere's WINDCUBE v2 (Figure 4-7) and Sgurr Energy's Galion (Figure 4-8) use pulsed whilst ZephIR 300 (Figure 4-9) uses continuous. The backscattered reflections caused by suspended aerosol particles and analysed again for the Doppler Effect frequency shift that is used to infer a resultant velocity[36]. They are small enough to be deployed at the foot of an offshore MET mast or mounted on the nacelle of a wind turbine.

Whilst profiling LiDAR's are used to measure the wind in the vertical direction, side scanning LiDAR can be used to obtain a 3D grid of wind data over a wide area from ranges of several kilometres. Side scanning LiDAR can obtain wind data within a hemispherical volume from great range and is considered to be a competitor to profiling LiDAR by one leading industry expert (Appendix C-15). However it is not yet as prevalent as profiling and will therefore not be considered in this report.

Figure 4-8 Galion LiDAR

Figure 4-7 Leosphere WINDCUBE v2


Figure 4-9 ZephIR 300

[36] (Bower, 2012)

4.3.4 Summary

Remote sensing devices are easily moved around to gather data at multiple sites far more economically than masts and in less time. They can also be deployed in areas where masts are impractical or unlawful[37].

SoDAR systems are more prone to interference requiring more complex data quality control and are not considered as accurate as LiDAR which also has extensive verification[38].

DNV GL, international certification body and classification society considers the ZephIR 300 LiDAR as a stage 3 device (under 'benign' conditions). This makes it an accepted device for providing bankable and finance grade wind speed and energy assessment data. It has the added advantage of requiring limited or no on-site MET mast comparisons[39].

A WRA campaign utilising LiDAR is likely to provide the best 'next step' solution for Guernsey both in terms of data requirements and investment level.

[37] (Bower, 2012)

[38] (Bower, 2012)

[39] (offshorewindbiz (b), 2015)

4.4 Modelling

4.4.1 Virtual Met Mast™

Overview

The latest 'Intelligent' Virtual Met Mast™ (VMM) from the Met Office utilises site specific down scaling of world class numerical mesoscale weather prediction models (illustrated in Figure 4-10) to produce a report containing essential information for the prospecting, selection, and development of onshore and offshore European wind farm projects. VMM has a resolution of 100m (model grid length) at a specified height above sea level[40] and a typical VMM report content includes[41]:

- Site specific wind speeds
- Long term mean wind speed and direction (up to 22 years at hub height)
- W90 - wind speed certainty (%)
- Turbulence intensity
- Wind Shear
- Max wind speeds (gusts, extreme winds)
- Exceedance values
- Air density
- Turbine classification data
- 10 year time series data

The data is known to be accurate as it has been proven against 130 sites across UK and Europe including offshore locations[42]. The standard report is available for medium wind markets. It can be generated both with and without site data depending on the scale of the project and has become a bankable resource for the industry[43].

There are five versions of VMM covering a range of applications[44]:

- UK and Europe – For large scale wind projects
- Medium Wind – Smaller wind (down to 20m hub height)
- VMM Plus – Combines with MET mast observations for higher certainty
- VMM High Resolution – designed for sites with complex terrain
- VMM Global – Being developed for non UK or EU countries

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[40] (Wong, et al., 2012)

[41] (Norman, 2012)

[42] (Met Office (c), 2015)

[43] (Met Office (b), 2014)

[44] (Met Office (a), 2014)

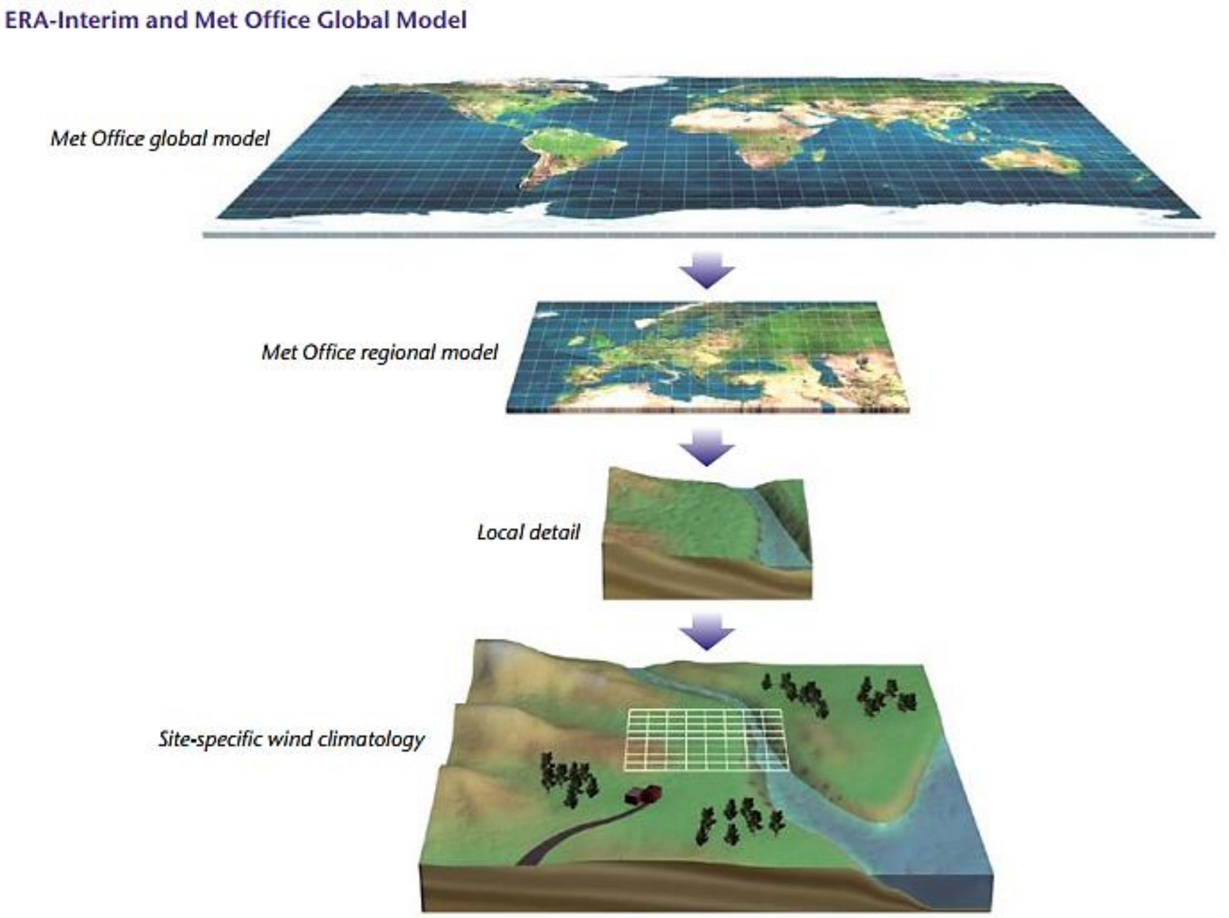

Figure 4-10 VMM Downscaling

4.4.2 MeteoPole - ZephyTOOLS®

Overview

Zephy-Science is MeteoPole's research, development and training centre. Zephy-Science is continually developing open source software tools with cloud based computing covering all the different phases of a wind power project development from site selection to final micro-siting and bankable energy yield assessment. It is specialized in developing numerical tools for designing the next generation of 'smart wind farms' as well as optimizing existing wind farms. The company mainly focuses on its wind farm design toolbox called ZephyTOOLS®[45].

Among the core Zephy-Science technologies are:

- Computational Wind Engineering (Mesoscale WRF and CFD OpenFOAM Wind Modelling)
- Advanced Wind Resource Assessment
- Energy Yield Prediction & Analysis
- Power Forecasting
- Condition Monitoring
- Power Performance Monitoring & Optimization.

ZephyCFD is the micro-scale part of ZephyTOOLS® Wind Farm Design software. It includes an automatic wind flow model using Computational Fluid Dynamics (CFD) for the final micro-siting of turbines.

ZephyWDG is the WRA part of ZephyTOOLS® that can be used for site prospecting, long-term correlation with on-site masts and wind power forecasts on operating wind farms. It includes VMM and wind maps that utilise a wind data generator based on mesoscale modelling.

[45] (MeteoPole, 2015)

4.4.3 Summary

Inquiries with a Met Office representative confirmed that a UK/EU report would be viable and that the cost of such a report would be £1975 (+VAT) (Appendix B-1). This presents a low investment opportunity to validate existing WRA's increasing certainty and encouraging further development.

The Channel Islands are part of the EU Customs Union and essentially part of the EU for trade of goods but are outside the EU in all other aspects[46], further checks should be made to ensure that Guernsey is covered by UK/EU VMM. A sample report is available from the Met Office website[47].

Similar to the Met Office, MeteoPole are a mesoscale data provider that can offer simulated historical data or wind maps at any location. However, ZephyWDG offers much more than just a report. The software can be used in-house and the model tuned (computation resolution, roughness length, simulation heights), to match specific requirements. The 'Entry' ZephyWDG licence is advertised at €9600, this includes half a day's training, 6 month subscription to support and updates for 1 user. It also includes 1 'Machine day' with the cloud based virtual private server ZephyCLOUD. The complete ZephyTOOLS® package including an 'Entry' licence ZephyCFD (€1800) would allow for a full wind farm design.

[46] (Channel Islands, 2015)

[47] (Met Office (d), 2015)

5 Similar projects

5.1 Havsul II

Havsul II was a proposed 800MW project in Norway. A LiDAR campaign was started in 2008 by EMD International A/S (EMD) and Alpha Wind Energy (AWE) using a Leosphere LiDAR sited on a small lighthouse rock near the prospective site and approximately 20km from a 60m wind mast installed on Ona island. The LiDAR, installed and operated by AWE, was the primary data source and collected data up to 160m and used the 60m wind mast for validation. EMD conducted the data analysis and AEP calculations for the now failed proposal[48]. No information could be found on wind speed estimates prior to the FLiDAR WRA but a figure of 10.49 m/s is recorded on the 4C offshore website and is presumed to come from the FLiDAR campaign.

5.2 Ulsan – South Korea

Kangdong-Ulsan is a consented 196MW wind farm in the Sea of Japan (East Sea) in South Korea. The project will consist of 28, 7MW turbines, in a 17km^2 area expected to power around 140,000 homes when completed. 4C offshore list the mean wind speed at the site as 9.29 m/s.

Galion LiDAR, a service offered by renewable energy consultants Sgurr Energy was used to conduct a 12 month wind measurement campaign for a South Korean construction company, SK Engineering & Construction (SK E&C), as part of wind flow modelling and pre-construction development work for a proposed offshore wind farm.

A Galion G4000 offshore LiDAR was used on the coast to measure wind conditions at a prospective wind farm site approximately 2-4km offshore. A MET mast was installed close to the LiDAR to provide a long term onshore reference throughout the campaign. The scope of the contract included campaign design, device installation and training, data management and analysis, and decommissioning.

An SK E&C representative stated: “In the early stages of this project, we are interested to find out about the wind resource at our proposed site. Deploying Galion LiDAR will provide a long term prediction based on traceable, accurate offshore measurements. We will look forward to seeing how the results of this campaign will inform the development of our project”[49].

[48] (Alpha Wind Energy, 2015)

[49] (Sgurr energy, 2014)

5.3 Aberdeen Renewable Energy Group (AREG)

AREG was set up in 2004 to develop the renewables industry in Aberdeen, Scotland and the UK. AREG is "widely recognised as an influential player and key enabler in the Scottish, UK and wider European marketplace. Membership has grown to more than 170 businesses, with AREG actively assisting these members to capitalise on new market opportunities"[50].

Aberdeen Offshore Wind Farm Ltd (AOWFL) is a joint venture between Vattenfall and Aberdeen Renewable Energy Group (AREG) (75% and 25% stakes respectively). Together they are developing the European Offshore Wind Deployment Centre (EOWDC), a ground breaking 83MW facility off the coast of Aberdeen. The centre will provide a platform for 'first runs' of offshore wind turbines to allow developers and supply chain companies to test new designs, prove existing products and receive independent validation and accreditation before commercial deployment as well as helping the industry reduce costs[51].

The EOWDC represents "a huge opportunity to help the region develop its energy-based economy and accelerate the growth of the Scottish and UK offshore wind industry, which has phenomenal potential, with an estimated value of £100billion. Lessons learned and skills developed through the EOWDC will be exportable, thus enabling our companies to win new business around the world"[52]

The grid connected wind farm (33KV) will consist of 11 turbines of between 6MW and 10MW located in a 7Km^2 area approximately 13Km from the coast in Aberdeen Bay. The project is estimated to cost £230m with a secured EU grant of £40m. It is estimated to produce enough electricity in a year to power the equivalent of over 68,000 UK households[53].

[50] (AREG, 2015)

[51] (4C (b), 2015)

[52] (AREG, 2015)

[53] (Vattenfall, 2014)

5.3.1 AREG WRA

The BERR atlas wind speed at the site was given as 7.23 m/s[54]. Short term wind speed data was recorded for approximately two and half months with a Natural Power ZephIR LiDAR at a site on the coastline approximately 7km adjacent to the EOWDC site and correlated with long-term data from Dyce Meteorological Station (65m asl) approximately 7km further inshore as seen in Figure 5-1.

The wind data analysis showed the average wind speed to be 8.7 m/s at 90m height, with a predominant wind direction to be from the south. A summary of the LIDAR measurements is shown in Table 5-1[55].

Table 5-1 Summary of LiDAR Measurements

Measurement device	Natural Power ZephIR
Location OS Grid Reference	395024 810254
Monitoring period	31 October 2008 to 22 January 2009
Wind speed measurement heights*	27 m, 70 m, 90 m, 125 m, 153 m
Data recorded	Horizontal and vertical wind speed, wind direction, turbulence, temperature, pressure, humidity
Configuration	Cloud correction turned on

*Note: 1m added to the LIDAR measurement heights to account for height of device

[54] (4C (c), 2015)

[55] (Vattenfall, 2011)

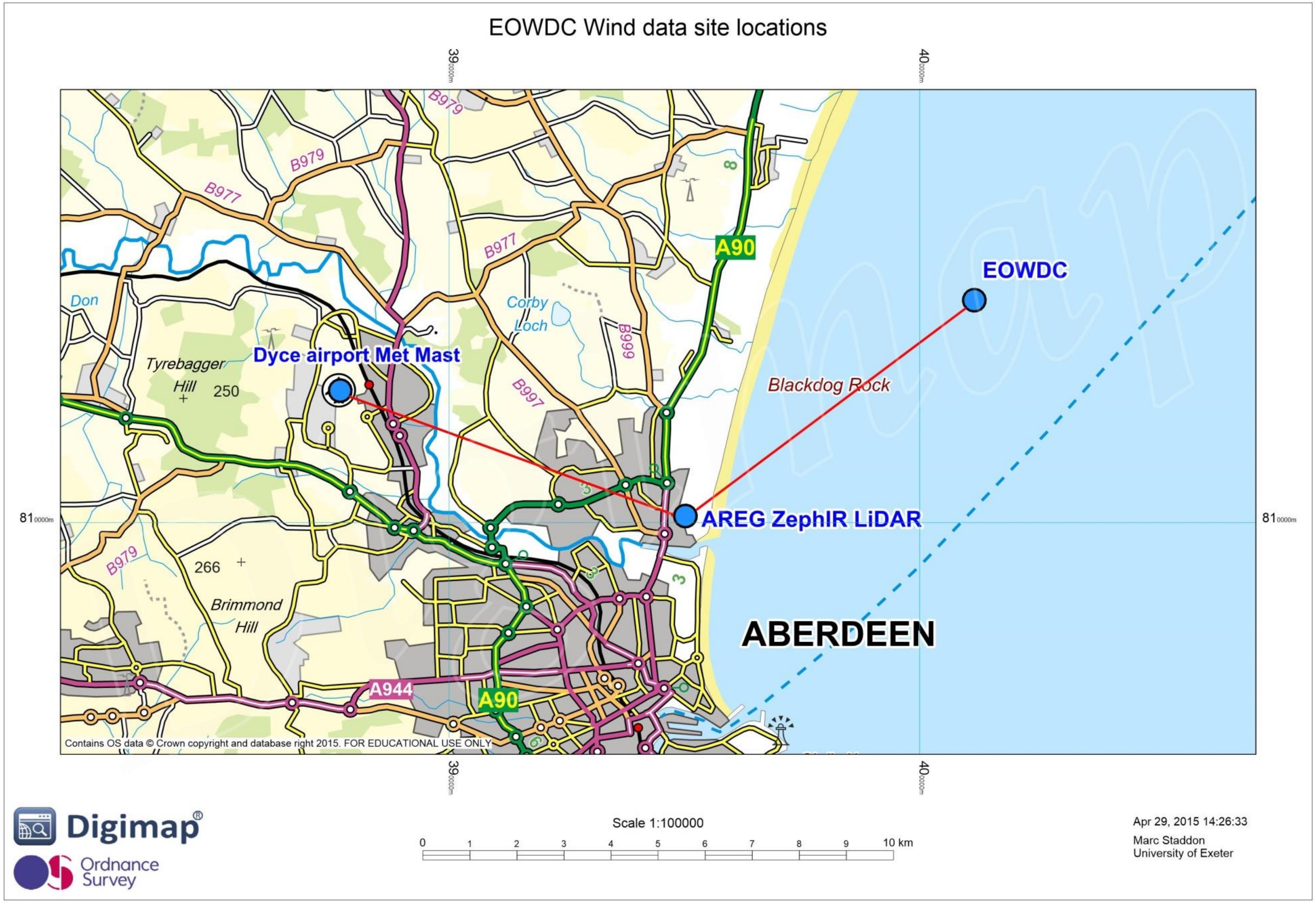

Figure 5-1 AREG WRA data location points

5.4 Summary

Although no comparison can be drawn for wind speeds at the Havsul II site it serves to highlight that this methodology has been used successfully in the past.

The Ulsan campaign followed the same methodology but no further details could be found about its effectiveness and the site was much closer to shore than the Guernsey site.

The EOWDC methodology found the wind speed to be 8.7m/s at 90m, significantly higher than the BERR figures of 7.23m/s. The chosen WRA was apposite for the stage of the project and would have been much more economical than either a MET mast or FLiDAR installation. It is likely to have succeeded in increasing confidence in the viability of the project and encouraged investment. Work is ongoing and 6 turbine manufacturers have signed a Memorandum of Understanding (MoU) with the project[56].

[56] (4C (b), 2015)

6 LiDAR Strategy

According to the Ecofys 'Improved Bankability' report[57] LiDAR is now regarded as a proven mature technology that is as accurate as conventional anemometry and recommends LiDAR for deployments "next to a relatively short on-site MET mast. This can be a cost-effective solution to quantify the wind shear and extrapolate wind speeds to hub height". This is also supported by independent reviewers such as DTU Wind Energy. Deutsche WindGuard, GL Garrad Hassan and ECN.

Leosphere state on their website that when used onshore combined with a MET mast and 12-18 months' worth of data, a mobile LIDAR continuously collecting wind profile data can better characterize the wind resource and reduce project risk and that it has been proven to save millions in equity investments by providing bankable data to investors and owners[58].

According to Lackner (2008), the scale and complexity of a MET mast installation means that a short term campaign does not represent value for money and recorded data still requires extrapolation for wind shear at turbine hub height. Lackner's short-term shear measurement strategy seems applicable since it considered a scenario with short-term (60 day) hub height measurements from a ground-based device (LiDAR/SoDAR) and only a single lower measurement height reference (such as Chouet) for estimating the shear characteristics at the site.

Lackner (2008), concluded that this method could "drastically improve the accuracy of shear predictions on average" over a tall reference mast and that "the uncertainty of the predictions decreases as the short-term measurement length increases". He also concluded that "The true value in this method lies in the substantially reduced uncertainty that it produces in shear extrapolation predictions. Utilizing this approach allows for substantially more confidence in hub height mean wind speed predictions".

Bower, (2012) states that "when paired with the long term data from a MET mast a LiDAR measurement campaign period need only be enough to get a statistically representative sample of the wind characteristics. This could be as little as a few weeks to a few months"[59].

[57] (Ecofys (a), 2013)

[58] (Leosphere (a), 2014)

[59] (Bower, 2012)

6.1 WRA methodology

Guernsey's current measurement equipment consists of a 10m anemometer mast at the airport[60], approximately 102m asl[61], and a second 10m anemometer mast installed in the north east of Guernsey at Chouet, approximately 20m asl[62]. The Chouet mast has provided coastal wind data close to prospective sites since 3/11/2011[63] and has confirmed the wind resource to be in line with previous years analyses[64].

A strategy similar to that of AREG strategy could be adopted with a LiDAR installed at the Choet wind mast location providing data for extrapolation to the prospective site. The IEC guidelines reviewed in this report are likely change to incorporate the use of LiDAR for performance prediction. Until this time the measurements should follow accepted principles as stated in the installation manual[65].

Should on site verification be required the Chouet mast can be used as the long term fixed reference point. ZephIR can measure as low as 10m and so could periodically return to the mast height to validate, reducing uncertainty about the site data[66].

It is possible that the low height of the Chouet mast and the minimum height of the LiDAR range could be too close for an adequate campaign. This being the case "jack-up" towers or "trailer towers" of around 20m in height could be used. This would obviously come at extra cost but could be included within a package WRA solution as suggested by TUV NEL[67].

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[60] (Guernsey Met Office, 2012)

[61] (Citizen Weather Observer Program, 2015)

[62] (University of Exeter, 2013)

[63] (Lee, 2011-2012)

[64] (Aquatera, 2014)

[65] (Vattenfall, 2011)

[66] (ZephIR, 2012)

[67] (Jones, 2015)

6.2 TUV NEL

Communications with Leon Youngs and Patrick Jones of TUV (NEL) investigated the possibility of utilising a dormant LiDAR for future wind data acquisition on Guernsey. Guernsey's existing equipment and data acquisition as well as future requirements were ascertained to help develop a deployment plan and 'ball park' costings. TUV NEL responded with a figure of £20,000 +VAT for a 6 month hire period including training, calibration and service costs to prepare for deployment (Appendix B-2).

6.3 Summary

The use of a LiDAR in conjunction with the masts on Guernsey for a short term measurement campaign would be an economical solution to better characterise the wind resource before progressing to a campaign more acceptable for lenders and manufacturers such as MET mast and FLiDAR.

7 Conclusions and Recommendations

7.1 Conclusions

Different WRA methodologies most suited for Guernsey's current situation have been identified and reviewed and are listed in Table 7-1 below with approximate costs and scope;

Table 7-1 Methods and Costs

Method	Scope	Approximate Cost
Virtual Met Mast™	Single report on prospective site	£1975 +VAT
ZephyWDG or (ZephyWDG + ZephyCFD)	Unlimited VMM (+ CFD for design)	€9600 (€11400)
TUV NEL LiDAR campaign	6 months 'real' data acquisition	£20,000

7.2 Recommendations

Given the findings it is obvious that more answers are needed especially official quotes from LiDAR service providers such as Sgurr Energy and Leosphere.

In the interim it may be worthwhile obtaining a VMM from Met Office to see how this affects the WRA for the prospective site, with the expected result being an increase in the wind speed estimation. Similarly Aquatera could be approached for their 'routemap' to compare with the findings in this report.

It is highly recommended that the provisional quote from TUV NEL is followed up and invested in as this will very likely represent the most economical LiDAR campaign producing 'real' data to accomplish the optimal objective. Maintaining momentum on this could see a LiDAR deployed in June 2015 for 6 months covering a range of conditions that are fairly representative of a whole year, with the option to extend the campaign.

The deployment and subsequent data analysis could be conducted by elements at UoE with GRET support and easily meets the criteria for the 4th year MEng Renewable Energy industrial project module running from September 2015 to January 2016, representing a fantastic mutually beneficial opportunity.

7.3 Summary

An outline of the most suitable WRA options has been given and the optimal solution for Guernsey identified and discussed. The aims and objectives of the thesis have been successfully achieved.

Modern technology and methodologies are found to be reliably replacing the traditional at greatly reduced cost thus mitigating financial barriers and increasing certainty for wind speed estimation for offshore wind developments.

7.4 Limitations

The author found it understandably difficult to obtain commercially sensitive information such as costings and even to establish contact with relevant companies even when in association with GRET. Access to essential details, knowledge and contacts was restricted by limited finances such as the subscription to 4C and attendance at the 4th Annual *WindPower Monthly* Wind Resource Assessment Forum.

7.5 Further work

There is great deal more work to be done to capitalise on a very competitively priced LiDAR campaign and contribute to an offshore wind development in the States of Guernsey.

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9 Glossary

Table 9-1 Glossary

Abbreviation	Meaning
Computational Fluid Dynamics	The prediction of the behaviour of fluids and of the effects of fluid motion past objects by numerical methods rather than model experiments[68]
OpenFOAM	A free, open source CFD software package developed by **OpenCFD Ltd**
Measure Correlate Predict	Established method for estimating the long term wind resource at a target site by using short term site data and long term reference data.

[68] (Collins English Dictionary, 2015)

Appendix A – Company information

Company contacts

Contact	Organisation
Mat Desforges; *Policy advisor, Financial Services and Renewables*	GRET
Peter Banes; *Renewable Energy Scientist*	GRET
Matt Smith; *Head of Business Development*	ZephIR Lidar
Amy Evans; *Account Manager Renewables*	Met Office
Rebecca Martin; *Offshore Wind O&M Research Engineer*	EDF
Leon Youngs; *Team Leader, Wind Energy*	TUV SUD UK Ltd (NEL)
Patrick Jones; *Senior Engineering Consultant*	TUV SUD UK Ltd (NEL)
David Quarton; *Senior Technical Advisor*	DNV GL
Ervin Bossanyi; *Senior Principle Researcher*	DNV GL
Will Laird; *Senior Product Engineer*	Sgurr energy

WRA equipment providers

FLiDAR (ZephIR)	
Axys (Sentinel)	http://axystechnologies.com
Babcock (Forecast)	http://www.babcockinternational.com
Fugro (Seawatch)	http://www.fugro.com
Eolus	http://www.eolusvind.com
Fraunhoffer (IWES)	http://www.iwes.fraunhofer.de
FLiDAR (WINDCUBE v2)	
3E	http://www.3e.eu
FLiDAR nv	http://www.flidar.com
KONA	http://konastructures.com
oldbaum	http://www.oldbaumservices.co.uk
SoDAR	
Second Wind Inc (Triton)	www.secondwind.com
LiDAR	
ZephIR	http://www.zephirlidar.com
WINDCUBE v2	http://www.leosphere.com/en
Sgurr energy	http://www.sgurrenergy.com
Meteorological masts	
Sgurr energy	http://www.sgurrenergy.com

Appendix B – Email communications

Amy Evans: *Account Manager - Renewables*, Met Office

1. **From:** Evans, Amy

   Sent: 16 February 2015 13:25

   To: Staddon, Marc

   Subject: RE: VMM costs

   The cost for a VMM based on the turbines you are looking at would be £1975 + VAT.

   Many thanks,

   Amy Evans

Patrick Jones: *Senior Engineering Consultant*, TUV NEL

2. **From:** Jones, Patrick

   Sent: Wed 06/05/2015 01:19

   To: Staddon, Marc

   Subject: RE: Guernsey information

As a rough cost estimate we are looking at around £20K to provide the training and hire for a 6 month period and would include the necessary service and calibration costs for the instrument deployment.

Bullet points of service offering as follows:

- Prescribe outline measurement campaign procedure in discussion with client.
- Detail appropriate measurement methodology/ approach taking into account standards and industry best practices.
- Provide wind speed measuring equipment on a hired out basis including servicing and calibration. 6 Months with pro-rata increase if extended.
- Provide training on installation, commissioning, operating and data gathering from the loaned equipment.
- Data recovery and analysis services quotable as extra, as an option.

Continues…

One option is to include deploying a taller temporary MET mast (mobile and likely not requiring the benefit of having planning permission) and NEL are happy to quote for this. There could be economies if including this and Leon has suggested that the additional cost could be £5K for the simplest of services.

The provision of electrical power, comms connectivity options and insurance would incur additional costs and subject to specific location, access and available services. This may require a separate short up front feasibility/ site survey visit as precursor which would be chargeable and could apply to any equipment NEL propose.

Regards,

Patrick

Appendix C – Phone conversations

Matt Smith: *Head of Business Development*, ZephIR

Fri 13/02/2015 12.00

After introductions I explained to Matt the aims of my project and that I would be very grateful for input to the following questions:

- What are advantages and disadvantages of LiDAR over other techniques?
- What would be the best strategy for GRET?
- What advantage does ZephIR have over other competitors?
- What are the likely costs of a LiDAR resource assessment?

His response was very detailed and the salient points are listed below:

Advantages and Disadvantages

1) "One of the main advantages of using LiDAR for resource assessment over more traditional techniques is the 'future proofing' with regard to hub height selection. LiDAR measurement campaigns typically provide 10 sets of data from 10m to 200m above installed position (and occasionally up to 300m) and so more easily provide equivalent wind speeds for rotor heights"
2) "Unlike Met Mast anemometry LiDAR also considers profile changes and veer"
3) "The major advantage was the considerable cost savings to be had. Met Mast went from a predicted £6m to £10-12m"
4) "Added value to be gained by keeping FLiDAR on site during construction include:
    1. Monitoring of conditions for risk assessment (health and safety etc.)
    2. Site calibration of turbines for power delivery checks (not an IEC requirement but will influence manufacturers
    3. Forecasting for optimising performance and reducing fatigue
5) "Continuous Wave (CW) device takes 50 measurements at hub height and 'screens out' motion of support structures where Pulsed Wave (PW) devices can't "

Continues…

General information

6) “A large proportion of the cost of deploying measurement devices is the support structure”
7) “Currently, fixed foundations similar to those required for a Met Mast are the industry standard and are preferred by DNV GL”
8) “Newer, lower cost structures are in development for use with LiDAR. For example floating LiDAR or ‘FLiDAR’ has been developed through the Offshore Wind Accelerator (OWA) programme and utilise spar buoys or tension leg platforms as low motion platforms for LiDAR”
9) £2.5m for tension leg platforms, £750,000 for spar buoy (Fugro Seawatch) and less than £1m for a hull design (Axys WindSentinel)”
10) “The market wants 18 months’ worth of data tendered as contract”
11) “Companies using ZephIR include:
    1. Babcock (Forecast)
    2. Fugro (Seawatch)
    3. Axis (Sentinel)
    4. Eolus
    5. Fraunhoffer (IWES), previously Leosphere Windcube v2”
12) “Windcube users such as:
    1. 3E
    2. FLiDAR nv
    3. KONA
    4. oldbaum
13) “essential for getting P50 and P90 figures for energy production at sites”
14) “there is an aggressive movement toward LiDAR in the UK and EU from the likes of DONG (now using LiDAR exclusively for offshore wind), EDF, GDF (SUEZ), EDP Inovação (EDPI)”

Competition

15) “3D or hemispherical LiDAR’s are a competitor to ZephIR and although they can scan the whole site providing greater certainty for horizontal extrapolation they have questionable financial acceptance and the sample rate is effected by range”
16) “Optimum large site scenario would be a combination of island based Windcubes , hemispherical LiDAR and floating LiDAR (ZephIR)”

Continues…

Guernsey strategy

17) "two options for Guernsey would be to invest in the resource assessment and then recoup the cost from the developer or auction the sites and assess from potential bidders"
18) "Stage 1: for 4-10 turbines in shallow water would involve modelling and/or floating LiDAR for 12 months with the added bonus of future proofing with regard to hub height data"
19) "Stage 2: floating LiDAR also used for tidal and wave data in deeper sites, particularly relevant for floating wind sites"
20) "Met Office VMM used in initial feasibility stages but 'real' data required for finance and warranties"

Appendix D – GRET Meeting

Meeting with Mat Desforges and Peter Barnes of GRET, Richard Cochrane and Ilie Bivol

09/12/2015.

Salient points:

1) Discussed projects scope and deliverable/timescales
2) NDA progress discussed – Actioned, GRET to sort out with RC
3) GRET has 'green light' for next steps toward offshore wind
4) GRET working to releases electricity data from Guernsey Electricity Company (GEC)
5) PB working on permanent planning for Met Mast in Choet – will consult ref LiDAR
6) NDA definitely required for recent bathymetry data (30m contour)
7) Other data (geology etc.) available without NDA
8) RC to pursue LiDAR with NEL and VMM details through Met Office contact
9) Bi-weekly updates going forward
10) Dissertation to be commercial in style with NDA data in separate detailed report
11) Prioritise wind data strategy report over site selection
12) Search GIS map of island for possible LiDAR deployment sites (PB to provide)
13) Interim report scheduled for end of Feb to <u>outline</u>:
    a. Options
    b. Costs
    c. Providers
    d. Industry standards
    e. Multiple site solutions
    f. Recommendations – most 'value for money' option
    g. Timescale for final report

Appendix E – Aquatera

Strategy for wind data gathering and resource analysis

A small change in average wind speed over 25 years can have a large impact on the projected cash flows and is crucial in making the correct investment decision. Accurate wind data is crucial to the viability of the project and therefore we would suggest that better wind resource data is a priority for the project (over a more detailed financial model) and will be needed in order to attract finance. Also, a conversation with the AREG (Aberdeen Renewable Energy Group)[69] who are developing a medium scale wind farm offshore Aberdeen City would be worthwhile. They have been trying to develop a small wind farm with support from the Local Authority, so they understand some of the issues facing Guernsey.

An economical alternative to constructing a MET mast would be to use LIDAR equipment which measures wind speeds from ground level (or sea level) to the proposed turbine height. There are several providers of land-based LIDAR which can be purchased or rented[70]. Therefore, one approach would be to seek advice on LIDAR type and placement onshore but as close as practicable to the selected offshore site. An alternative, but more expensive approach would be to install a floating LIDAR set moored within the proposed offshore site. Floating LIDAR is a relatively new advance. It is being evaluated at NAREC and at least two developers (DONG and Mainstream) have already installed units offshore[71]. The FLiDAR set consists of state-of-the art measurement equipment including a buoy adapted Leosphere LiDAR mounted on a standard marine buoy and powered by its own renewable energy system comprising solar photovoltaic and wind power technology.

Consultation with wind resource analysis experts (such as Sgurr Energy) could be useful in determining the best pathway for obtaining more accurate data. They will be able to offer advice on the limitations and advantages of different measurement options.

A 'routemap' report tailored to GRET would outline options for data gathering and data analysis.

[69] http://www.aberdeenrenewables.com/

[70] See for example: http://www.sgurrenergy.com/wp-content/uploads/2013/01/Galion-Brochure-B2.pdf

[71] http://www.3e.eu/flidar-and-dong-energy-start-europes-first-commercial-floating-lidar-offshore-wind-measurementcampaign/ and http://renews.biz/54015/north-sea-flidar-first-by-mainstream/