A GIS-based spatial multi-criteria analysis (SMCA) for wind farm site selection in Cornwall.

Edward Coveney

AALBORG UNIVERSITY DENMARK

Abstract

Wind energy technologies in the UK have the highest installed capacity and also generates the most GWh out of any of the renewable sources and it continues to be an industry on the rise. This paper presents a method of site selection for wind turbines in Cornwall (UK), based on a spatial multi criteria analysis. The method used for this is built in ESRI ArcGIS Desktop 9.3.1 software and is split into four stages. The first, a land exclusion exercise, to redact unsuitable land from contention. The second, a resource and cost analysis. The third, is a site selection and visibility analysis and the last stage is the development of a web application designed to give access to the results of the assessment over the web. The assessment acts as preliminary tool in site selection and aims to assist with the planning of wind developers or other interested parties.

Table of Contents

Table of Figures

1 - Introduction

1.1 Global Warming: The need for renewable energy technology

The need for renewable energy technologies, in short, has arisen from the adverse consequences of societies current reliance on fossil fuels as an energy source. Although the utilization of fossil fuels has enabled large-scale industrial development, fossil fuels such as coal, fuel oil and natural gas, have severe negative impacts on the environment when combusted for energy (Boyle, 2012). The most significant of these, is the emission of by-product gases such as carbon dioxide or methane into the earth's atmosphere (Sorensen, 2004).

These gases are greenhouses gases and are responsible for trapping heat in the earth's atmosphere by absorbing infrared radiation (Sorensen, 2004). By releasing large quantities of these greenhouse gases into the atmosphere, the fossil fuel industry is responsible for intensifying the Earth's natural greenhouse effect, resulting in the increase of Earth's average surface temperature (Sorensen, 2004). This global phenomenon is better known as global warming. Over the period 1880 to 2012 the globally averaged combined land and ocean surface temperature has shown a warming of 0.85 °C and the period of 1983 to 2012, was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere (Intergovernmental Panel on Climate Change, 2014).

To combat global warming and reduce the amount of greenhouse gases entering the atmosphere a global effort is being made to use more renewable energy resources as an alternative to fossil fuels to meet modern societies energy demands. Renewable energy can be defined as 'energy obtained from the continuous or repetitive currents of energy recurring in the natural environment' (Twidell & Weir, 1986) or as 'energy flows which are replenished at the same rate at which they are "used"' (Sorensen, 2000).

Renewable energy sources principally come from solar radiation but can be broken down in to three main categories: Direct solar energy uses, Indirect solar energy uses and Non-solar renewables. The first of these, direct solar energy, can be used in a variety of manners. Solar radiation can be collected, directed and used to heat water or air and in turn provide services such as hot water or space heating, it can also be converted directly into electricity by using photovoltaic technologies.

Indirect Solar energy goes through more than one change to become usable energy and it can be seen as the result of the effects solar radiation has on the world naturally (Boyle, 2012). Solar energy can be the catalyst for lots of naturally occurring energy sources such as the water cycle, plant growth and atmospheric wind, all of which can then be in turn, utilised by technologies capable of generating electricity. Hydro-electric power stations can utilise hydropower, wind turbines can harness wind energy and biomass power stations can process organic matter created though photosynthesis.

The last category of renewable energy resources consists of those whose sources are not dependant on solar radiation. Tidal energy and geothermal energy are two such types. Tidal energy springs from the movement of strong underwater currents primarily caused by the gravitational force of the moon on the earth's oceans and geothermal energy is essentially heat radiated out from the earth's core (Boyle, 2012).

Since the discovery of global warming and the emergence of other liabilities on an over reliance on fossils fuels, such as the oil embargo of 1973/74, international efforts have been made to tackle the problem of anthropogenic climate change (Sorensen, 1991). One of the first truly global gatherings focusing on climate change specifically was he First World Climate Conference, it was held on 12-23 February 1979 in Geneva and was sponsored by the World Metrological Organisation (WMO) which was a specialised agency of the UN. In this first conference, the focus was preliminary on the science behind global warming and not political action. The conference did however have some lasting effects, importantly, it led to the creation of the UN's International Panel of Climate Change (IPCC), a task force dedicated to providing the world with an objective, scientific view of climate change and its political and economic impacts (Weart, 2008).

The IPCC's first official report on climate change was completed in 1990 and comprehensively concluded that emissions from fossil fuel combustion are responsible for enhancing the atmospheric greenhouse effect and in turn contributing to global warming. This report in combination with the Second World Climate Conference also in 1990 were principle in setting up the famous 1992 "Earth Summit" in Rio de Janeiro. It was at this summit The United Nations Framework Convention on Climate Change (UNFCCC) was bought into place, in was the first global international treaty with the goal of stabilising greenhouse gas concentrations in the atmosphere, and although it lacked specific goals or targets, it did become the framework for future conferences where these could be implemented. Annual meetings after the implementation of the UNFCCC, known as Conferences of the Parties (COPs), were created to discuss how to achieve the treaty's aims. The most famous of theses COP's was in Kyoto and produced the first legally binding international treaty to reduce greenhouse gas emissions. Fully adopted in 1997, it has been the UN's show piece for a global solution to a global problem ever since.

1.2 Renewable energy in the UK: Past and future

On the international stage, the UK has been an active protagonist of a global deal to limit human-induced climate change. Signing all major international treaties on reducing greenhouse gases, despite being one the heaviest greenhouse gas emitters at the time of the Rio de Janeiro Earth summit (Pearson & Watson, 2012). In 1990, the UK's share of renewables in the country's electricity generation was around 2%, with electricity generation only being a part of the UK energy demand (Bowen & Rydge, 2011). Progress in switching to renewables was slow throughout the 1990's, with more focus on nuclear power and increasing energy efficiency. At the turn of the century however the Royal Commission on Environmental Pollution (RCNP) released a new report titled: Energy – The Changing Climate (Royal Commission on Environmental Pollution, 2000). It concluded on a very important note, that the UK should reduce carbon emissions by 60% from then current levels by the year 2050. The number was chosen carefully, and mirrored the Commission's views that the UK should reduce emissions in a way that was consistent with global action to stabilise greenhouse gas concentrations. The commission's report had a swift and significant impact on UK energy policy. It sparked an energy review in 2001 by Tony Blair's government that was adamant in meeting the RCNP's recommendations.

The biggest response however to the RCNP's report came in 2003 when the UK government published its White Paper on Energy (Our Energy Future – creating a Low Carbon Economy), establishing the first formal energy policy for the UK that targeted the RNCP's goal of a reduction in carbon emissions by 60% by 2050. It also included the target of a reduction in greenhouse gas emissions by 12.5% below 1990 levels by 2008-12 that was given to the UK in the Kyoto Protocol (Department of Trade and Industry, 2003). Although bold, the 2003 white paper did face criticism for focusing more on analysing the issues than providing actual detailed policies to meet the aforementioned targets. Subsequent follow on reports did attempt to rectify this but it general it was seen as a continuation or pre-report polices rather than a revolutionary attempt to reduce carbon emissions (Pearson & Watson, 2012).

By 2007 the promotion of renewable energy technology had become the main talking point of the EU's energy policy, it became evident that the EU had big plans in forcing EU member states to reduce greenhouse gas emissions and by March 2007 EU leaders had already reached agreement that, in principle, 20% of the bloc's final energy consumption should be produced from renewable energy sources by 2020. This idea stuck and was the principal behind the EU's DIRECTIVE 2009/28/EC that was published two years later in April 2009. Although the goal was to produce 20% of the total EU's energy by renewable sources, it did not force all member nations to meet this target individually, individual targets were set for each member nation. Furthermore, the means of meeting these targets were not dictated and were left to the member states to resolve. Each individual member state's target was calculated depending on the current percentage of renewably sourced energy at the time of implementation and the practical potential to produce more in the future. For the UK, 15% was the given target to reach in 2020.

Article 4 of DIRECTIVE 2009/28/EC states:

"*Each Member State shall adopt a national renewable energy action plan. The national renewable energy action plans shall set out Member States' national targets for the share of energy from renewable sources consumed in transport, electricity and heating and cooling in 2020*,"

The UK's National Renewable Energy Action Plan (NREAP) was produced in accordance to this directive and broke down exactly how it planned to meet the 15% target. In the summary section of the report it stated that the UK could achieve it targets with the following proportion of energy consumption in each sector coming from renewables:

- Around 30% of electricity demand, including 2% from small-scale sources;
- 12% of heat demand;
- 10% of transport demand.

The idea of focusing primarily on electricity generation in order to meet the directive's target was a sentiment that was echoed in the 2009 UK Low Carbon Transition Plan, an energy policy built upon the 2003 and 2007 White Paper's and focused on the reduction of carbon emissions in the UK. It premises that by 'decarbonising' electricity generation it would allow for low carbon electricity to be utilised in other sector of energy supply, such as heating and transport.

By law the UK has to submit a progress report every two years to establish if it is on target to meet its obligations set down in DIRECTIVE 2009/28/EC. The third instalment was published in January 2016; it reports on the data available up until 2014 and summarises that, as of the end of that year, the UK is on target to reach its goal of 15% of energy generated from renewable sources. Having started from a low base of 1.3% in 2005, the UK has seen renewables meet 7.0% of energy demand in 2014 (Department for Business, Energy and Industry Strategy, 2016). The breakdown of this number by energy sector is seen in Figure 01 It also shows that the UK has prioritised electricity generation from renewable sources, as was suggested in its NREAP, with 17.8% coming from renewable sources already. The UK is therefore set to meet its ambitious objective of 30% of electricity from renewables in 2020.

	2013	2014
Heating & Cooling from renewable sources[2] (%)	3.8	4.5
Electricity from renewable sources[3] (%)	13.8	17.8
Transport fuel from renewable sources[4] (%)	2.8*	3.2*
Overall share of energy from renewable sources[5] (%)	5.6	7.0
Of which from cooperation mechanism[6] (%)	-	-
Surplus for cooperation mechanism[7] (%)	-	-

*Overall supply was low due to double counting certificates.

Figure 1 - Share of UK's energy demand met by renewable energy, 2013-2014 (DBEIS, 2016)

More recent UK renewable energy data was published in October 2016 as part of the Department for Business, Energy & Industrial Strategy's quaternary energy statistics package (Department of Energy and Climate Change, 2016). The statistics show a continuous growth in Britain's renewable energy market past 2014 up until the 2nd quarter of 2016, best summarised in Figure 02. It shows an increasing installed capacity in renewable electricity generation.

This progress has driven some significant reductions in the cost of renewables deployment. For example, the cost of solar has fallen 60% since 2010 and it has also confirmed the UK as the world's leading offshore wind market (Department for Business, Energy and Industry Strategy, 2016). Overall it shows these reports show that the UK is on target to meet its ambitious renewable energy targets, but still requires a sustained effort in producing a larger renewable energy infrastructure.

1.3 Wind power in the UK

Wind Power plays a vital part in the UK's capacity for electricity generation. It has the highest installed capacity and also generates the most GWh out of any of the renewable sources in the UK (Figure 03). In 2015 wind energy produced over 40,000GWh or 40 TWh in the UK, this accounts for

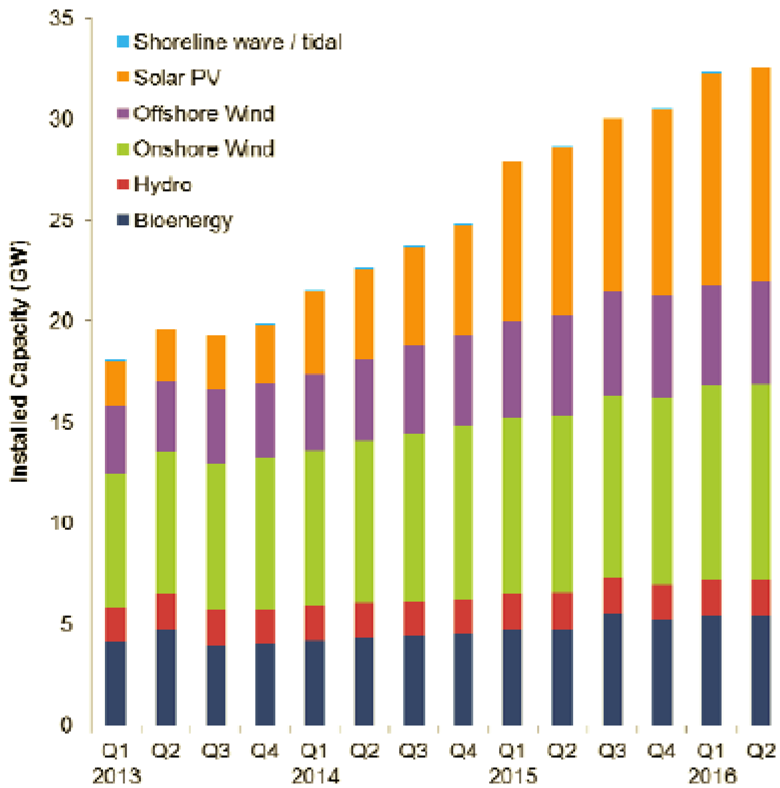


Figure 2 - Installed capacity of UK renewable energy market, 2013-2016 (DECC, 2016)

11.93% of the total electricity generated in that year and almost half of 83.3TWh generated from the all renewable energy sources (Figure 03). It is also a growing industry, with total installed capacity rising 10.38% from 2014 to 2015 and similar expectations are set for 2016 (Figure 03).

	2014	2015	per cent change	2014 2nd quarter	2014 3rd quarter	2014 4th quarter	2015 1st quarter	2015 2nd quarter	2015 3rd quarter	2015 4th quarter	2016 1st quarter	2016 2nd quarter p	per cent change [11]
Cumulative Installed Capacity [1]												MW	
Onshore Wind	8,536r	9,188	+7.6	8,003	8,263	8,536	8,708	8,807	9,003	9,188	9,498r	9,558	+8.5
Offshore Wind	4,501	5,104	+13.4	4,084	4,420	4,501	4,749	5,024	5,104	5,104	5,095r	5,095	+1.4
Shoreline wave / tidal	9	9	+2.9	9	9	9	9	9	9	9	8	8	-9.2
Solar photovoltaics	5,424	9,188	+69.4	4,429	4,841	5,424	7,930	8,224	8,581	9,188	10,413	10,638	+29.4
Small scale Hydro	252r	282	+12.0	242	245	252	261	267	272	282	302r	303	+13.5
Large scale Hydro	1,477	1,477	-	1,477	1,477	1,477	1,477	1,477	1,477	1,477	1,477	1,477	-
Landfill gas	1,058r	1,061	+0.4	1,054	1,057	1,058	1,061	1,061	1,061	1,061	1,061r	1,061	-
Sewage sludge digestion	215r	216	+0.4	212	212	215	216	216	216	216	235	235	+8.9
Energy from waste	681r	925	+35.9	621	630	681	826	834	902	925	980r	980	+17.4
Animal Biomass (non-AD) [2]	111	111	-	111	111	111	111	111	111	111	111	111	-
Anaerobic Digestion	238r	286	+20.2	197	207	238	260	263	284	286	315r	315	+19.7
Plant Biomass [3]	2,245r	2,619	+16.7	2,145	2,225	2,245	2,297	2,298	2,976	2,619	2,749r	2,749	+19.6
Total	24,746r	30,465	+23.1	22,583	23,695	24,746	27,904	28,592	29,994	30,465	32,243r	32,529	+13.8
Co-firing [4]	15	21	+37.6	15	15	15	21	21	21	21	7	7	-66.5
Generation [5]												GWh	
Onshore Wind [6]	18,562	22,887	+23.3	2,994	2,897	6,002	7,182	4,775	3,825	7,106	6,394r	3,877	-18.8
Offshore Wind [6,7]	13,404	17,423	+30.0	2,092	2,242	4,686	4,676	3,578	3,412	5,757	5,147r	3,251	-9.1
Shoreline wave / tidal [6]	2	2	-10.0	1	0	1	1	0	0	0	0	0	-
Solar photovoltaics [6]	4,040	7,561	+87.2	1,475	1,558	536	951	3,125	2,690	795	1,454r	3,751	+20.0
Hydro [6]	5,893	6,289	+6.7	1,114	784	1,753	2,012	1,426	1,028	1,823	2,079r	927	-35.0
Landfill gas [6]	5,045	4,872	-3.4	1,266	1,245	1,266	1,240	1,212	1,201	1,220	1,191r	1,170	-3.5
Sewage sludge digestion [6]	846	888	+4.9	228	212	211	223	231	215	219	223r	236	+2.0
Energy from waste [8]	1,923	2,782	+44.7	471	491	486	656	653	736	737	731r	669	+2.5
Co-firing with fossil fuels	133	183	+37.6	37	37	34	36	36	57	55	51r	11	-70.5
Animal Biomass (non-AD) [2,6]	614	648	+5.5	161	132	162	170	171	142	165	170r	166	-3.2
Anaerobic Digestion	1,019	1,429	+40.2	245	258	286	323	346	364	396	411r	416	+20.3
Plant Biomass [3,6]	13,105	18,587	+41.8	3,064	3,565	4,242	4,351	4,409	4,383	5,443	5,589r	5,043	+14.4
Total	64,584	83,550	+29.4	13,150	13,420	19,665	21,819	19,961	18,053	23,717	23,440r	19,517	-2.2
Non-biodegradable wastes [9]	1,923	2,784	+44.7	471	491	486	656	653	737	738	731r	669	+2.4

Figure 3 - Breakdown of the UK's renewable energy industry from 2014-2016

The popularity in the UK for renewable wind energy is predominantly down to two factors; the first is price. Onshore wind is one of the most technologically mature renewables, making it not only the cheapest form of renewable energy but also cheaper than coal-fired and combined-cycle gas (both averaging at $115) (Zindler, 2015). The second factor is availability, according to the European Environment Agency, the onshore locations in the UK offer about 11 per cent of the total generation potential of wind energy in the whole of the European Union (EEA, 2009). It is therefore no surprise that the UK has relied on wind energy to help meet its various climate change obligations.

Despite these clear benefits however there are still sizable challenges that face the onshore wind energy market. Perhaps the biggest of these is the intermittent nature of wind, which results in not being able to produce electricity on demand, generation is therefore unequivocally reliant on wind speed (Boyle, 2012). This harsh fluctuation in generation output is seen by many to be a significant limiting factor on how much wind energy can be generated in a healthy national energy system, it is unarguable however, that renewable energy sources that are reliant on an intermittent source must continue to be used as part of a portfolio of different energy technologies to balance (Department of Energy and Climate Change, 2015). And also, that onshore wind will continue to have a role in that mix. There are also means of lessening the effects of an unpredictable energy source. Other significant challenges still remain for onshore wind, including both environmental and visibility concerns. Wind turbines have a substantial effect on bird and bat population in areas where they are constructed and also can affect another local fauna that habitats in the vicinity of wind turbines (Boyle, 2012). Visual impacts on land and seascapes are perhaps the most important environmental cost of wind developments, the rural areas in which wind turbines are predominantly built are usually highly contested by different interest groups. The problem is also exacerbated by the fact that the areas with the best wind resources tend to include coastal and upland areas, many of which are of high aesthetic value (Bassi, Bowen, & Fankhauser, 2012). This stresses the need for extremely careful placement of new wind turbines in order to reduce the amount of public backlash against new projects.

The difficulties that face of onshore wind in the UK have not stopped the industry from growing, but they have made it so that the future growth of the industry is not secure. The current UK government (as of 2016) has picked up on some of these disadvantages and have used them to become a major advocate against new onshore wind farms. Perhaps the first sign in a shift in policy came in the government's 2015 general election manifesto, to end publicly-funded support for onshore wind projects by removing the programme of subsides for all onshore projects (Aberystwyth & Rudd, 2015). They argued that that energy technologies need to "stand on their own two feet" and not be reliant on public subsidies (Evans-Pritchard, 2016). This will come into full effect in April, 2017 (OFGEM, 2016). However, a blow to onshore wind energy companies in the UK, the removal of subsides was not a devastating hit to wind companies, many argued that the technology invested into the latest generation of wind turbines meant that the government was correct and that the industry was ready to compete economically with all other producers of energy in the UK.

There were however still major problems for the industry, most of these were highlighted by Anders Runevad, chief executive of Vestas Wind Systems, the world biggest producer of wind turbines, in an interview with daily telegraph in 2016. He firstly echoed the sentiment that wind turbine companies were ready to compete in the UK energy market, but insisted that this was only the case if companies such as Vestas were able to use their latest generation of turbines. But he then goes on to accuse the government of actively trying to shut down the development of onshore wind farms by implementing an excessive number of impediments to a free market (Evans-Pritchard, 2016). The biggest impediment he lays out is the UK's tip-height restriction of 125 meters which is dictated to local governments, this is considerably lower than the than Vestas new generation which can reach around 200m (Evans-Pritchard, 2016). With half of all new turbines in Sweden being between 170 and 200 meters, and latest projects in Germany averaging 165 meters. Such limits mean the UK is being left behind in international markets. Anders Runevad also levied that un-reasonable "fears" in the technology were making it near impossible to get planning permission on new farms (Evans-Pritchard, 2016).

The Government maintain the stance that restrictions are down to public opinion on the subject of onshore wind turbines and that height restrictions are necessary. With Amber Rudd, Secretary of Energy and Climate Change, insisting that Britain was “reaching the limits of what is affordable, and what the public is prepared to accept” (Evans-Pritchard, 2016). This stance however doesn’t match public polling on the subject however. With 71% of people supporting onshore wind within the UK compared to only 8% who oppose, and this is coming from government’s own Public Attitudes Tracking Survey (wave 19) published in October 2016 (Department for Business, Energy & Industrial Strategy, 2016b).

Figure 4 - Application pathway for new wind projects (West Devon Borough Council , 2013)

The political decisions of a Conservative government can be a frustration to those who wish to see more wind turbines onshore in the UK, but there is hope for the industry in the UK. It is still an internationally growing industry with a rapidly decreasing price per MWh, as well as a high approval rating among the general public, mean there could be a time in the future where the onshore returns to the UK.

1.4 Cornwall: Case Study area

Cornwall is the most south westerly county in the UK. It has a population of 536,000 and has historically been important for its tin-mining industry (Office of National Statistics, 2016). In present day, the county relies heavily on tourism, with it making up about 24% of Cornwall's gross domestic product. Despite this fact however, Cornwall remains one of the poorest counties in England. Currently Cornwall has 15 operational wind farms (with an additional one being constructed), with an installed capacity ranging from 20 MW (Carland Cross Wind Farm Repowering) to 1MW (Goonabarn Farm Wind Turbines) (Department of Business, Energy and Industry Strategy , 2016b). For a small contested county, this reinforces Cornwall Council’s commitment “to make a meaningful contribution towards reducing harmful emissions from our energy use (through cleaner energy production)” (Cornwall Council, 2016).

Figure 04 shows the full pathway of which a new wind turbine project can get planning approval. The local planning authority of Cornwall Council is responsible for the initial approval or refusal of new wind farm applications. However, there remains the right for all interested parties to appeal to the Secretary of State at the national level in order to overturn decisions.

So why try to develop wind energy in Cornwall? The first point to note about why Cornwall is a popular place to put wind turbines, is to do with the resource its self. The average yearly wind speed is approximately 5.45 m/s (Department of Energy and Climate Change, 2017). It also has a lower than average population density, with 144 people per km² compared to 55 people per km². This lower density tends to mean more non-urban landscape and more opportunity for wind turbines.

Lastly, for a remote county, Cornwall has a surprising adequate infrastructure in place, mainly thanks to the dependence on tourism and this infrastructure can in turn be taken advantage of by the wind energy industry (Cornwall Council, 2016).

On the contrary however, there are challenges that make further development of wind energy in Cornwall difficult. Too many, wind farms are a form of visual pollution and have the ability spoil views. This criticism is abundant within Cornwall as its scenic landscape is seen as unique and is heavily valued, no just scenically but also economically (Cornwall Council, 2016). This sentiment, along with some strong anti-wind lobby groups, can make new wind turbine construction difficult and geographical placement analysis extremely important, even with a local council receptive to the industry.

To construct new wind turbines, a variety of factors must be taken into account, including economic social, environmental and political factors. One method for tackling this challenge of where to construct new wind turbines is to use a Multi-Criteria Decision Making Analysis on GIS platform. By using GIS, it is possible to analyse all the varying spatial factors that affect planning application and show in map format where within a certain area it is most suitable for new wind turbines. It is also possible to use web GIS skills to convey this information on the world-wide web to all interested parties.

1.5 Problem Statement and Research Questions

Problem Statement:

Cornwall has not fully utilised the potential the county has for wind energy development. The county has moral and fiscal obligation to continue pursing renewable energy technologies and wind power should be at the fore-front of this.

Research Questions:

1. Has the most accurately available and relevant geodata been incorporated into this wind energy assessment? And if not, why?

2. How to justify the steps taken to create a Cornish Wind Resource Mapping System (WRMS)? and what effect have they had on the overall confidence in the WRMS?

3. Do the results of the cost analysis sufficiently help the Cornish wind energy assessments meets its principle aims?

4 How best to tailor the web application so that it visualises the results of the wind energy assessment to the correct target audience?

1.6 Thesis Roadmap of the Cornish Wind Energy Assessment

The Wind Energy assessment will be broken down into 4 stages, to offer clarity on how the assessment will go about tackling the problem statement. Figure 05 shows this breakdown.

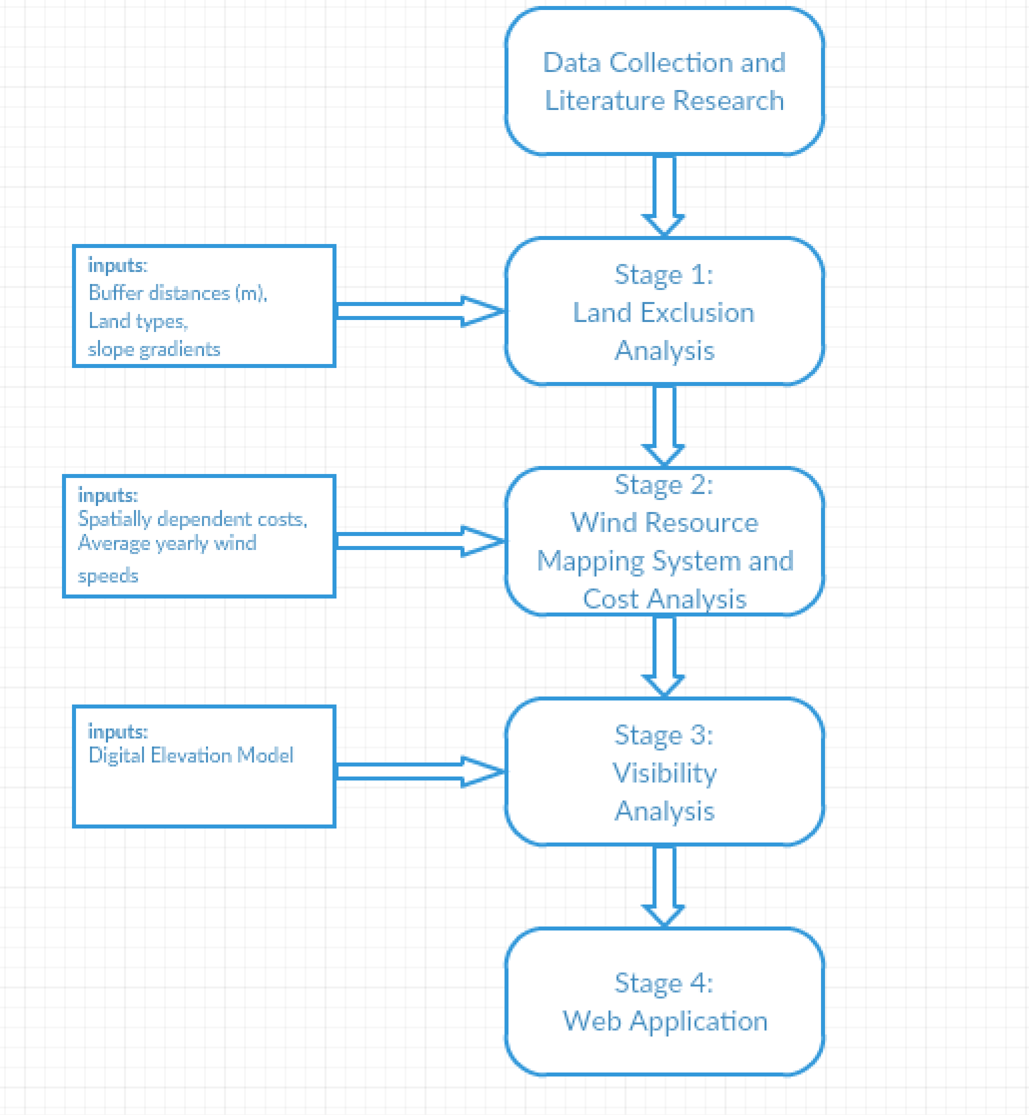


Figure 5 - Schematic of the SMCA methodology.

Aims and objectives

This study aims to estimate and visualise the achievable onshore wind energy resource potential of Cornwall, in order to provide itself as a decision support system for wind energy related policies and plans in the county. The assessment is only designed as a preliminary tool in finding the most suitable area for wind energy development, and to do this, many factors affecting turbine location are taken into account. This assessment cannot make completely accurate predictions on the cost and potential energy output of each conceivable part of available land and should not be an alternative to a full site analysis on a potential site for wind development.

2 – Background/Theory

2.1 Background Introduction

In this section of the assessment academic literature, governmental policies and technical reports are all taken into account to define the development of the Cornish Wind Energy Assessment. Using the resources available, the parameters of the assessment are defined based upon the agreement of the supporting literature.

2.2 Stage 1: Ruling out unworkable land

Stage 1 of this Assessment it focused on eliminating the land within Cornwall that is unsuitable to host a new wind turbine. To do this, there is a need to establish what affects wind turbines have on their surroundings and then determine which of these affects could cause the turbines to have issues with a pre-existing land use that is present in its vicinity. Once the potential harmful aspects have been identified it should then be possible to identify what specific land uses needs to be protected from wind turbine development. Once established, the last task is to know how best to remove this land from a GIS based Spatial Multi Criteria Analysis wind energy assessment.

This section of the literature review will be broken-down by the varying potential harmful issues wind turbine could cause to certain land types.

2.2.1 Noise and Health & Safety

Wind turbines have been proven to have negative effects on people's health. The extent of the reported health issues however has been the subject of great debate. The primary focus of these debates tends to be that of noise pollution, specifically in terms of audible and inaudible noise. For audio sound, rural residential noise limits are generally set at 35 to 55 dB, and these levels are also the targets for the wind industry (Knopper & Ollson, 2011). Any higher and living conditions are said to drop rapidly. For infrasound or inaudible noise the effects on human health are more controversial, a range of medical side effects have been claimed to be the result of wind turbines, including: sleep disturbance, headache, tinnitus (ringing in the ears), ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia (rapid heart rate), irritability, problems with concentration and memory, and panic episodes) (Knopper & Ollson, 2011). Many of these supposed health problems have been debunked by peer-review scientific journal articles and others have been exaggerated by anti-wind groups, but still the debate remains (Knopper & Ollson, 2011).

The uncertainty in the extent of health issues caused by wind turbines has resulted in varying methodologies in attempting to minimize the effects on humans. Varying minimum setback distances have therefore been established world-wide in an attempt to reduce or avoid potential effects for people living in proximity to wind turbines. Minimum distances can vary greatly depending on a countries or regions legislation. There are generally two ways to set a minimum distance, the first is to implement a fixed distance, for example Belgium has 350m set distance from a settlement and Bavaria has a 10 x turbine mast height set distance from a settlement (Drechsler, Masurawski , & Frank, 2016). The second method is a distance based of a pB level, for example the minimum distance in Swedish law is the distance that ensures the nearest dwelling is not subject to a dB level of over 40 (Siyal, et al., 2015).

The UK is different to many EU countries; in that they do not have any fixed minimum setback inscribed into law (Barclay, 2010). Instead the UK central government has allowed the constituent countries within the UK to establish their own wind turbine proximity distance guidelines. In Scotland, current Scottish Planning Policy (SPP) 2010 recommends that authorities apply a 2km separation distance between areas of search for onshore wind farms and the edge of cities, towns and villages (Onyango, Illsley, & Radfar, 2013). This long buffer distance is one of the largest distances guidelines used in planning applications around the world. Originally created with landscape protection in mind rather than health and safety, the proximity distance has been heavily criticised for being over excessive.

The Welsh planning policy on separation distance is set out in Technical Advice Notice (TAN) 8: Planning for Renewable Energy (Cave, 2013). This states that:

"500m is currently considered a typical separation distance between a wind turbine and residential property to avoid unacceptable noise impacts, however when applied in a rigid manner it can lead to conservative results and so some flexibility is advised."

Again, this is just guideline advice for those submitting a planning application and not a legal requirement. Lastly in England, the country in which Cornwall resides, there is no minimum separation distance in planning law or guidance (Barclay, 2010). This results a high variable minimum distance that is unique from application to application and this in turn makes it difficult to apply a uniform buffer to preliminary county-wide potential wind energy assessment. It is however noted in a house of commons briefing paper titled Wind Farms - Distance from housing, that the primary factor in whether a wind farm is too close to a human settlement, is noise. Meaning the model and type of wind turbine is very important in establishing the setback distance to areas of human inhabitance.

Fixed Minimum distance setbacks are usually set against human settlements. Buildings or areas that humans spend extended periods of time, ie. Houses and places of work. There are however, other human influence areas in which this definition does not fit but nevertheless still need to be taken into account when doing a multi criteria spatial analysis, some of these include; railways and roads.

Previous GIS attempts at finding suitable land for wind energy development have tackled the issue of minimum distance setbacks in a variety of ways, most have used a buffer analysis around areas of human development to ensure that that land is excluded from the analysis. In Rob van Haaren and Vasilis Fthenakis's spatial multi-criteria analysis (SMCA) for New York state, they applied a 1 km buffer around towns and 2 km buffer around cities (van Haaren & Fthenakis, 2011). This 1 km buffer has been used in multiple SMCA's, including ones in Sweden and Crete, with the Crete analysis defining an urban area of a population of over 2000 (Tsoutsos, Tsitoura, Kokologos, & Kalaitzakis, 2015) (Siyal, et al., 2015). Figure ## also shows the minimum distances used for railways and roads, these distances are significantly less that urban areas due to not being areas of prolonged human residence. The overall consensus seems to be a between a 120-500m buffer for these areas.

For the SMCA in this report, both the UK's guidance and planning laws, and previous GIS wind farm placement studies need to be taken into consideration when deciding what buffer sizes ensure the safety of the human population near to potential new wind turbines. As England is lacking any real planning guidance in this respect, it is better to look primarily to previous studies to make sure that human safety. Taking into account these studies, the buffers that have been applied to this study have been added to figure 06.

Restricted area	**Sweden case study (Siyal, et al., 2015)**	**Crete case study (Tsoutsos, Tsitoura, Kokologos, & Kalaitzakis, 2015)**	**New York case study (van Haaren & Fthenakis, 2011)**
Urban areas (pop > 2000)	1000m	1000m	1000m (2000m for cities)
Roads	200m	120m	500m
Railways	200m	120m	-

Figure 6 - Comparison of minimum setback from human population with other GIS studies

2.2.2 Physically impractical installation sites

Not all land is suitable for wind turbine construction, installation is a difficult and complex undertaking and there are many natural variations in landscapes that make it extremely difficult or even impossible to complete.

One of the most obvious hurdles for a wind farm is the issue of hill slope. Naturally, many wind farms appear on raised land to best take advantage of the natural resource the sustains them, this means the areas in which wind farms are placed tend to have steep slopes. Construction of wind turbines on steep slopes are logistically more difficult and as a result are costlier and can have a variety of logistical issues arise, including road construction and foundation construction. Another parameter which highlights the complications of having wind turbines on steep slopes is the flow inclination or in-flow angle. When wind turbines are placed on steep slopes the wind might hit the rotor non-perpendicularly, and instead at an angle. If the angle at which the wind hits the rotor is undesired and not designed for, it will not only reduce the energy production of the wind turbine but will also lead to an increased level of fatigue of some of its mayor components (Røkenes, 2009).

Karst landscapes are another land type that can be a hazard to potential new wind turbines and therefore another factor that needs to be taken into account when eliminating unsuitable land for new wind projects. Karst topography is a landscape formed from the dissolution of soluble rocks, the landscape is epitomised by large sinkholes and caverns (White, 1990). It can be especially difficult to build large scale projects on karst landscape as their foundations are determined unstable and compromise the safety of the project (Miceli, 2015). This is true for wind turbines as well. In some cases, foundations have been opened up and workers have discovered huge holes that can be several cubic meters big.

The majority of other GIS studies into wind turbine site selection have taken slope into account. However, the means to determine what the slope degree cut-off have varied. In van Haaren and Fthenakis's New York's study the cut-off of slopes greater than 10° was derived from detailed survey replies from four major private wind developer companies (van Haaren & Fthenakis, 2011). In other studies, slope cut-off values have been derived from academic studies into maximizing turbine efficiency, previous GIS studies or wind farm construction protocol. In a 2015 GIS study into Swedish wind potential for example, a slope value of 15° was used in the analysis, this value was derived from 2 previous GIS studies into wind energy potential and also a peer reviewed journal entry into the optimal spatial allocation of wind turbines (Siyal, et al., 2015). Overall, at least in the other GIS studies examined in this literature review, physical constraints for slopes were set between a range of 10° - 25° cut-off. A full view of each study's individual cut-off limit is seen in Figure 07. For the hazard of porous ground, which can make construction of wind turbines practically impossible, far fewer studies saw fit to include it. As a rarer hazard, it has been tended to be overlooked, but some studies did attempt to incorporate porous ground types into their analysis's. For the 2011 New York study, data was acquired from the United States Geological Survey on the karst land in America, a selection was then made for karst that is above 100 m depth and these areas were then considered infeasible. It is also noted in the study that for New York State it had no locations that were subtracted from the analysis due to these constraints (van Haaren & Fthenakis, 2011).

Restricted area	Sweden case study (Siyal, et al., 2015)	New York case study (van Haaren & Fthenakis, 2011)	Poland case study (Sliz-Szkliniarz & Vogt, 2011)	Greece case study (Latinopoulos & Kechagia, 2015)	Cornwall, UK Case study 2017
Slope angle	15%>	10%>	25%>	25%>	15%>
Porous ground	--	Karst 100m>	--	--	--

Figure 7 - Comparison of hazardous land types with other GIS studies

2.2.3 Protection of Wildlife

Many researchers have found that wind energy is one of the healthiest and environmental friendly options among all the energy sources available today. One predominant reason for this is that it is seen as the most compatible with animals and human beings in the whole world. With that being said however, there are still some noticeable negative side-effects that wind farms can have on local wildlife, the most significant and most discussed of these is their directly negative impact on the populations of local and migratory bird and bat species that co-inhabit areas utilizing wind energy (Leung & Yang, 2012). There are also other minor disruptions to local wildlife which will also be covered. The need stands however, to analyse the environmental cost of wind farms in terms of wildlife and then to establish what land has to be excluded in Stage one of this assessment to ensure wildlife protection.

The primary emphasis of the majority of wind farm–wildlife research has been devoted to how wind farm development has impacted bird populations, with the focus of these studies being mainly to quantify collision mortality with wind turbines. Most of the research has been conducted in Europe and the United States. Results from this research indicate that the number of bird collisions vary greatly, with anywhere between 0 collisions per turbine per year up to 30 collisions per turbine per year (Saidur, etal., 2011). Although the numbers can seem alarming at first, many have attempted to put them into context. In Saidur's and et al. study into the environmental impact of wind energy they do this by listing wind turbine related deaths against other leading human-related causes of bird deaths in the United States (Figure 08) (Saidur, etal., 2011). The figure shows how miniscule the number of wind turbine related birds death is and is compounded by a complementary fact that "if wind energy were used to generate 100% of U.S. electricity needs, wind energy would only cause one bird death for every 250 human-related bird deaths".

Human-related causes	Number of birds kill per year (million)
Cats	1000
Buildings	100
Hunters	100
Vehicles	60–80
Communication towers	10–40
Pesticides	67
Power lines	0.01–174
Wind turbines	0.15

Figure 8 - Human-related causes for bird death in the USA (Saidur, etal., 2011).

Bat deaths caused by the wind energy tell a similar story. There is still reliable evidence that bat populations are negatively affected by wind turbines but the number of deaths has been deemed, rather unanimously, manageable (Leung & Yang, 2012). This is not to suggest that the environmental health of both bats and birds should not be taken into account when finding suitable new wind energy sites, but that perhaps it would require a potential site to be of intrinsic ecological value to specific rare or vulnerable bird or bat species to actually cancel an otherwise sound new wind project.

With this in mind for Cornwall, it is important to establish what parts of the county are protected for environmental reasons, especially with relation to the protection of bird or bat species. The United Kingdom has a large variety of Environmentally Protected Areas (EPAs), some of which have been created though local and county level and others established at a UK or European wide level. Figure 09 shows a full list of all the protected areas present in England which were established explicitly or at least partially to protect local wildlife. The Figure also explains each individual protected zone's character and aims.

Name	Reason for Creation	Aim	Protect the intrinsic ecological value of specific rare or vulnerable bird or bat species	Included in stage 1: land exclusion
Special Protection Areas (SPA)	In accordance with Article 4 of the EC Birds Directive (79/409/EEC)	They are classified for rare and vulnerable birds and for regularly occurring migratory species	Yes	✓
Special Areas of Conservation (SAC)	In accordance with Article 3 of the EC Habitats Directive (92/43/eec)	To establish a European network of important high-quality conservation sites (excluding birds), including the 189 habitat types in Annex i	No	✓
National Nature Reserves (NNR)	Designated by national bodies within the United Kingdom	to protect some of the UK most important habitats, species and geology	Yes	✓
Local Nature Reserves (LNR)	has its origin in the recommendations of the Wild Life Conservation Special Committee	Establishment of nature reserves by local authorities, to protect nature deemed important at a local not national scale	Yes	✓
Environmentally Sensitive Areas (ESA)	The scheme was introduced originally by the UK's Ministry of Agriculture, Fisheries and Food	designation for an agricultural area which needs special protection because of its landscape, wildlife or historical value.	No	✕
Ramsar Sites	Formed as a result of the UN's Convention on Wetlands of International Importance, also known as the Ramsar Convention.	The initial emphasis was on selecting sites of importance to water birds within the UK, and consequently many Ramsar sites are also SPA's	Yes	✓
Sites of Specific Scientific Importance (SSSI)	Maintained by Natural England	Sites of special scientific interest (SSSIs) are protected by law to conserve their wildlife or geology.	Yes	✓
National Parks	Concept of National Parks dates back to early 19th Century. It was the 1945 White Paper on National Parks that gave them legal status however	Conserve and enhance the natural and cultural heritage of the area	Yes	✓

Figure 9 - List of Environmentally protected areas in England

The question remains however, as to which of these environmentally protected areas would prohibit wind turbines from being built and which land should therefore be excluded from a wind potential assessment map (Stage 1). The two key points in this regard are whether the specific protected area is legally protected against wind turbine development and if not, would be placing a turbine there be a danger against the intrinsic ecological value of specific rare or vulnerable bird or bat species, as was concluded earlier.

Upon review, there are no explicate laws singling out wind turbines from being built in any of the environmentally protected areas shown in Figure 09. Instead their interests are protected by having Natural England, the non-departmental public body responsible for protecting environmentally sensitive areas and also advising the government on the natural environment, involved in the wind farm planning application process, on a case by case basis (Natural England and Department for Environment, Food & Rural Affairs, 2015). This makes into difficult to evoke county wide guidelines for where a wind farm cannot be built upon wildlife conservation grounds in a GIS-based assessment. It therefore forces us to look for other means to establish which areas should be removed from stage 1 of the assessment. One way should be to analyse the aims of each of the individual protection zones (in Figure 09) and judge if the effect of a wind turbine would pose an intrinsic threat to the ecological value of any rare or vulnerable bird or bat species in the area. Another should also be to take into account the opinions of Natural England, due to their important role in the application process

Six types of environmentally protected areas in Figure 09 will be safeguarded in this assessment, as they contribute to protecting the ecological value of the UK's specific rare or vulnerable bird or bat species. These were in no particular order: SSSIs, SPAs, National Nature Reserves, Local Nature Reserves, National Parks and Ramsar Sites.

Natural England echo the importance of some of these environmental protection areas by requiring any new wind development project in a SSSI, SPA, SAC or Ramsar to assess how they would affect their respected areas (Natural England and Department for Environment, Food & Rural Affairs, 2015). There is one additional protected area in the Natural England assessment process that does not focus on bird or bat species, this is the Special Areas of Conservation. Due to importance of Natural England in the wind development application process SAC's will also be excluded, even though there is no direct aim in protecting bird or bat species. It is probable the Natural England deems even the construction process too detrimental for SAC's. Not only is the land within these protected zones under the care of Natural England, they also have the right to reject any new developments on it.

In fact, any proposed development that could affect any *nearby* SSSI, SPA, SAC or Ramsar site will still need approval from Natural England. Natural England have fortunately attempted to spatially define the "near" part of this statement by releasing GIS data that shows where a wind development project could interfere with any of the aforementioned protected zones. These areas have been labelled as Impact Risk Zones (IRZs). Any potential new wind energy development inside an IRZ will not necessarily be refused approval, but will be intensely assessed on the risks of '*collision impacts and disturbance for birds*' in the nearby EPA (Natural England, 2016). It would therefore be improper to exclude Cornish IRZs directly in stage 1 of this assessment as wind development is still possible within them, but it is important information that is relevant to any end user of this assessment so must be incorporated somehow into the GIS based web application.

To conclude, there will be 7 EPAs excluded from any potential wind development as part of stage 1 of this assessment. They are: SSSIs, Nation Parks, SPAs, SACs, Ramsar Sites, NNRs and LNRs. IRZs will not be excluded from any wind development but their presence and purpose should be made clear in some way to any user of the web application that will be produced in Stage 4 of this assessment.

2.2.4 Protection of Landscape Character

The Cornish Landscape is widely agreed to be one of the most unique and diverse in the whole of the UK. It has significant economic and social/community value to the county. Cornwall Council goes so far as to say that the landscape is the county's biggest economic asset, attracting both businesses and tourists, the latter of which makes up 24% of the county's economy (Cornwall.gov, 2016). It also contributes to the sense of identity and well-being to the Cornish people and brings enjoyment and inspiration to all who reside within the county (Cornwall.gov, 2016). As such a valued commodity, it is therefore vital to attempt to minimise the impact of a new wind turbine on the Cornish landscape.

In this analysis, this will be done twice. The first is in stage one, where there will be an attempt to categories the entire landmass of Cornwall in accordance to the potential impact a wind turbine would have on the landscape value. It would then in turn rule out any areas where the potential impact would be deemed too high. The second, which will be conducted in Stage 3 of the analysis, will attempt to only assess the impact of newly identified potential sites.

The idea of categorising's England by landscape type is not a new concept. Many attempts have been made with various success. One of the first national level assessments was developed by the then Countryside Agency and English Nature (now Natural England), and was called the National Character map, it provided an assessment of the landscape of England by dividing it into 159 Joint Character Areas (JCAs). The JCA are the result of grouping together similar landscape types, specifically taking into account to the physical, natural and historic environments of each landscape. There are seven of theses JCAs in Cornwall and one covering the Isles of Scilly (Cornwall Council, 2011). Although successful in fulfilling it national level aims, the National Character map lacks detail for county level use. There was therefore a need to expand on the national Land Character Assessment (LCA) and produce more detailed county level LCA's. This agenda pushed the local Cornwall Council, as well as other councils, to produce its own LCA between 2005-2007 (Cornwall Council, 2011). The aim of the local Cornish LCA was to be able to provide support by delivering good quality sustainable development guidance that respects and, where possible, enhances local distinctiveness and the intrinsic qualities of the landscape (Cornwall Council, 2011). It resulted in Figure 10 which shows the breakdown of Cornwall into the 40 unique Landscape Character Areas.

The question still remains however, as to how a potential new wind turbine would affect each of the 40 existing LCA area's in Cornwall. Naturally, a constructed wind turbine would affect the ambience of each landscape type differently, where the presence of one might be seen as acceptable in some LCA area's and unacceptable in others. To carry on in this vein of thought, it is therefore ok to accept that some LCA areas are more valuable and more worthy of protection from wind development than others. Luckily, in 2016 Cornwall Council took on the task of evaluating the potential affect a wind turbine could have on each of its collective landscapes, using the 40 LCA area's generated in 2007 as its basis (Cornwall Council, 2016). The result was the Renewable Energy Planning Advice service, it aimed, in the simplest of terms, to inform the local council on how best to accommodate wind and solar electricity generation installations in the Cornish landscape and as a result, make robust, well-informed decisions on the planning applications that they received (Cornwall Council, 2016).

As previously mentioned the primary source for this Renewable Energy Planning Advice service comes in the form of the LCA. But there are a variety of other landscape based key source information that is taken into account. The following is a complete list, compiled in the Annex 1 of the Cornwall Renewable Energy Planning Advice (Cornwall Council, 2016):

- *"The 1994 Cornwall Landscape Assessment and Historic Landscape Character (HLC) Assessment.*
- *Cornwall Council's Historic Landscape Character and Sensitivity Mapping for Wind Farm and Solar PV installations (December 2010).*

- *The AONB Landscape Assessments for Cornwall, and the Tamar Valley (Cornwall AONB: 1997; Tamar Valley AONB, 1992).*
- *The special 'scenic qualities' and spatial boundaries of the AONBs, as outlined in their Management Plans.*
- *The Outstanding Universal Value (OUV) and Management Plan (2005) for the Cornish Mining World Heritage Site.*
- *The descriptions of Cornwall's Areas of Great Landscape Value (AGLVs) derived from the November 1995 Technical Paper (No.7) of the Cornwall Structure Plan.*
- *Historic and nature conservation designations such as SACs, SSSIs, Scheduled Monuments, Registered Parks and Gardens, and Conservation Areas.*
- *Ordnance survey base maps (1:250K, 1:50K and 1:25K) and aerial photographs.*
- *Field survey to check results on the ground (taken place in January 2011)."*

The Inclusion of conservation and historic geodata alongside that of visual landscape data is not surprising, it echoes the broader definition of landscape character created by the National Character map.

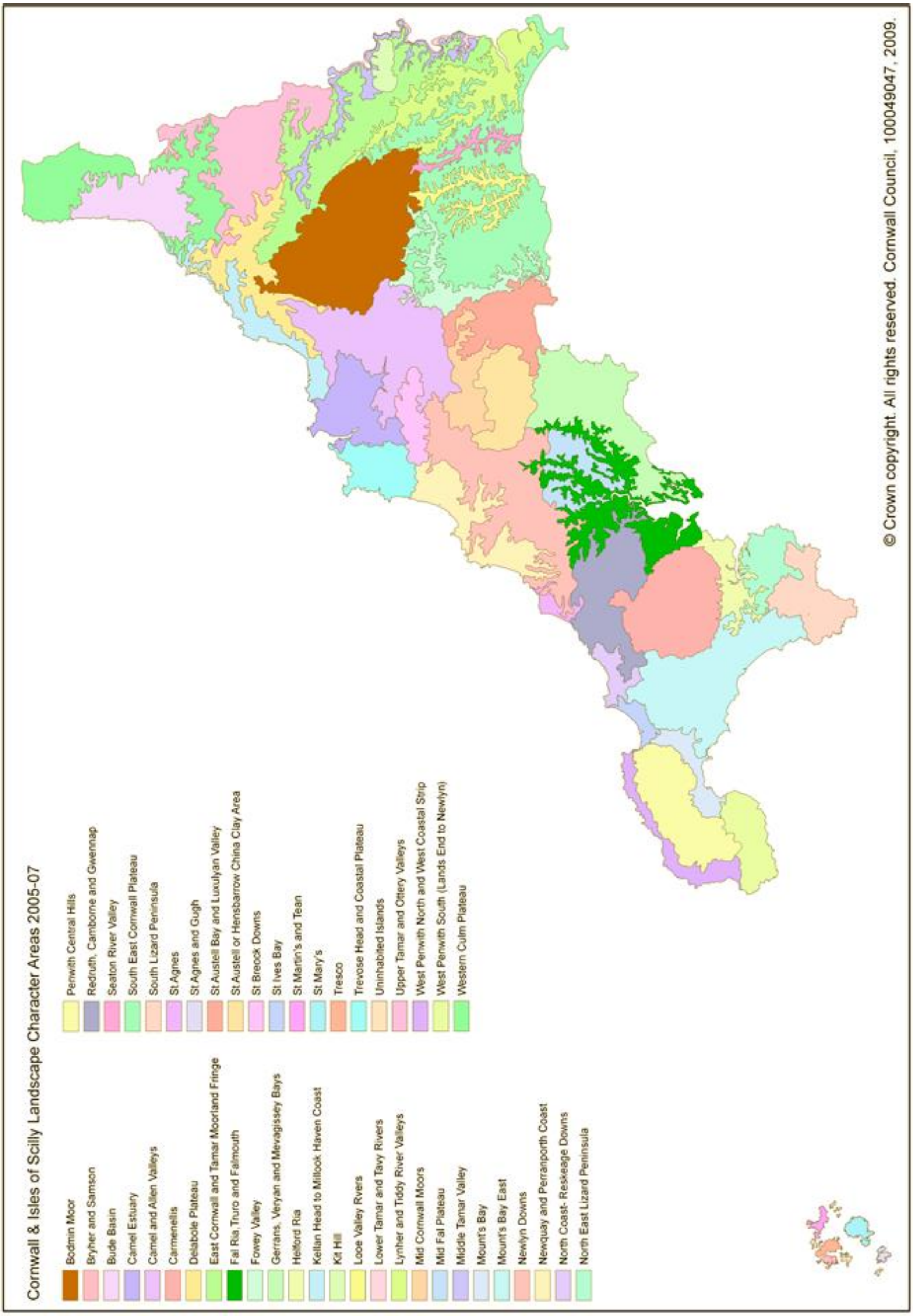


Figure 10 - Map of Cornwalls 40 LCA's (Cornwall Council, 2011)

The output of the study is that each of the 40 Cornish LCA's is given a grade signifying that particular landscape's vulnerability to a significant change in character in the event of a wind turbine being built. There are 5 sensitivity scores that can be given to a LCA: Low, Low-Moderate, Moderate, High-Moderate and High. The higher the sensitivity, the more vulnerable the LCA (Cornwall Council, 2016). Each LCA is analysed on a variety on criteria before an overall sensitivity level is given. These individual criteria are all weighed equally when combined to produce the overall sensitivity level for the LCA. It should also be noted that there is additional detailed and in-depth local assessment for each LCA, but as this study is attempting to be a county-wide wind potential assessment, the uniformity and simplification of the overall sensitivity level system makes itself a sufficient means of measuring landscape sensitivity.

There is however, still some additional information from the Cornish landscape sensitivity assessment aside from the overall score that could be useful, and it comes about due to the different nature wind farms can manifest in. Both the number of turbines and turbine height can drastically alter how a wind farm impacts a certain landscape. The potential effects of different sized wind turbines have been categorized into 4 groups for the assessment: Band A – for the effect of turbines with a hub height of 18-25m, Band B - for the effect of turbines with a hub height of 26-60m, Band C – for the effect of turbines with a hub height of 61-99m and Band D – for the effect of turbines with a hub height of 100-150m (Cornwall Council, 2016). In a similar manner, the number of turbines has also been categorized into groups, these are: Single turbine, Small scale clusters (up to 5 turbines), Medium scale clusters (6-10 turbines), Large scale clusters (11-25 turbines) and Very Large scale clusters (>26 turbines) (Cornwall Council, 2016).

Although this study won't take into account the localised planning advice for each individual LCA set out the in the general descriptive advice section of the Sensitivity assessment, there is one piece of guidance that appears for almost all of the LCAs. It advices that all land from a LCA that falls within an Area of Outstanding Natural Beauty (AONB) should be classified at a high sensitivity level (Cornwall Council, 2016b). AONB's are areas of countryside that have been designated for conservation due to their significant landscape value, they also enjoy levels of protection from development similar to those of UK national parks (Landscapes for life, 2017). With this knowledge and the recommend high sensitivity level produced the Cornish landscape sensitivity assessment, the Areas of Outstanding Natural Beauty in Cornwall will be outright excluded from the wind potential map of Cornwall, in a similar vein to that of SSSI's, Ramsar sites … etc.

To summarise, the Renewable Energy Planning Advice service produced by Cornwall Council in 2016 will be used as a means to ensure Cornwall's complex and valuable landscapes are protected adequately in this wind potential assessment. The overall sensitivity ranking of LCAs along with advice regarding turbine height and AONBs will be incorporated into the Cornish wind potential assessment.

2.2.5 Issue of Radar

At present day, it is widely accepted that the presence of on-shore wind turbines can affect the performance of radar systems. This is especially true for Air Traffic Control (ATC) radars which are vital parts of airports across the UK. Many studies have shown that wind farms, if positioned with certain geometries and distances relative to ATC radars, can cause those radars to not function correctly (Lemmon, Carroll, Sanders, & Turner, 2008). This has the capacity, in worst case scenarios, to have adverse implications for safety-of-life, and in the case of military air bases, national security (Lemmon, Carroll, Sanders, & Turner, 2008). A commissioned report by the Department of Trade and Industry in the UK set out to find in what exact manner wind turbines can affect ATC radars and it managed to summarise that problems they can pass on ATC (Alenia Marconi Systems Limited, 2003):

"*i) A large reflection can result in amplitude limiting within the receiver or signal processing and therefore induce distortion, possibly resulting in desensitisation and reduced detection of aircraft in the vicinity.*

ii) The operator is unaware of desensitisation and missing aircraft responses.

iii) Turbine blades are moving and therefore impose a Doppler effect on the reflected signal. Techniques currently included in most radar processing to distinguish between reflections from moving and stationary objects are unable to differentiate between the Doppler effects imposed by moving turbine blades and Doppler effects imposed by a moving aircraft.

iv) The operator is presented with a confused picture that declares both aircraft and wind turbines as moving objects."

Many of the investigative studies into this subject have confidence that wind turbines can affect ATC radars, but stop short of declaring that a wind turbine *will* have an effect on an ATC radar. This is because the affects generated by wind turbines can vary greatly, with some even having no impact at all. This is hardly surprising when considering the amount of variables that can have influence on the relationship between wind turbine and Radar. Both the number of wind turbines and size can have an effect with large heights and quantities contributing more to the interference. even the individual type or model of a wind turbine can have an effect (Alenia Marconi Systems Limited, 2003).

The vast difference in how wind farms affect ATC radar makes building new turbines to ensure no adverse effect on ATC radar very difficult, this is especially true for producing a wind energy potential map which cannot possibly take into account all the varying factors discussed. Obviously, a buffer zone is needed around ATC radars to endure that they remain unaffected, but the size of that buffer is difficult to calculate. Luckily other GIS-based SMCA's have attempted to do this before and offer themselves as good guidelines for this Cornish study.

Some previous SMCA's have decided to neglect adding a uniform buffer around airports deciding instead to do a "per case review after the approval of the relevant public body" (Tsoutsos, Tsitoura, Kokologos, & Kalaitzakis, 2015). However, plenty of others have applied a buffer, including in S.H. Siyal & etal Swedish wind energy assessment, they conclude on a 2500m buffer around all airports (Siyal, et al., 2015). Other, such as the 2011 Polish assessment and 2015 Greek assessment decided on a slightly larger of buffer of 3000m (Sliz-Szkliniarz & Vogt, 2011) (Latinopoulos & Kechagia, 2015). Due to small nature of Cornwall a buffer limit of 2500m should be a good fit in protecting its airfields and can be expanded if necessary.

2.3 Stage 2

Stage two is focused on Cost analysis and the Wind Resource Mapping systems (WRMS). The cost analysis is about understanding the spatial components that make up the total cost of a wind energy development and then using this knowledge to estimated spatial costs for potential sites. The WRMS is the fundamental to any wind energy assessment, in this stage the focus will be understand past WRMS and how to produce the best available one for this assessment.

2.3.1 Connecting to national grid

In order to be a useful commodity, the electricity generated from most commercial windfarms needs to find its way into a nation's electrical grid. The infrastructure that has to be created in order for this to happen is therefore of vital importance in securing the economic viability of a wind energy development. The journey starts at the wind turbine's generator, located in the nacelle. The generator is able to function and generate electricity by transforming the kinetic energy of the wind turbine's gear box (which is in turn powered by the kinetic energy of the wind turbines rotors) into electrical energy (Deutsches Windenergie-Institut GmbH, 2001). Once the electricity has been generated in the nacelle it then flows down the tower section of the wind turbine to the wind turbine's transformer, which is usually situated at the base of the tower. This transformer steps up the generation voltage, which is normally at around 690 volts (V), to a medium voltage of between 25–40 kilovolts (kV) (Green, Bowen, Fingersh, & Wan, 2007). This voltage range is the most preferred due to fact that standardised equipment is available at a more competitive price and also because higher voltage transformers would be too big to fit readily into the towers. From here the electrify enters the collection grid, otherwise known as the supply grid, this is the name of the network of cables that takes electricity from each of the wind turbines present in a wind farm and converges them into an onsite step-up substation (Green, Bowen, Fingersh, & Wan, 2007). This step-up substation will contain another transformer that transforms the medium voltage electricity into High Voltage AC (HVAC) (Green, Bowen, Fingersh, & Wan, 2007). The HVAC electricity is then sent, normally via overhead cables, to connect to the national grid. Sometime however, if a wind farm has a low installed capacity and the option to join a low voltage section of the national grid close by, the developer my wish to skip the building of a transformer installed step-up station and connect the collection directly to the national grid (Miceli, 2012). Large wind farms do not have that option as they generate too much electricity.

A wind farm is a generator in the UK's electrical industry. In order to sell the electricity, it generates, it needs to be connect to a national level electricity grid that will distribute electricity to homes and businesses across the country. The UK's national electricity grid can be split into two part, first the national transmission network which is owned by National Grid and the regional transmission network, owned by multiple Distributing Network Operators (DNO) (Western Power, 2017). The national transmission network is a HVAC transmission network that operates as the backbone to the UK electrical needs, in short, it can take energy generated from one place and transfer it across the country to be used where it is needed. The network is made up of over 8,600km 400kV and 275kV powerlines and they can run either overhead or as underground cables, there is also 330 substations (Energy Network Assocsiation , 2014). Distributing Network Operators (DNO) are regional operators and are responsible for taking power from the National Grid's 400kV and 275kV powerlines, lessening the voltage, and distributing it to every user within their regional constituency (Western Power, 2017). At Grid Supply Points (GSP) (transformer installed substations) on national grid the voltage is lessened to 132kV and then falls under the DNO's responsibility (Western Power, 2017). From there it is dispersed to further substations, where the voltage is reduced again to 66,000, 33,000 and 11,000 volts (Western Power, 2017). The Regional distribution network then carries electricity to individual towns and villages throughout their respected area's where distribution substations transform the voltage to 230 volts or UK plug socket voltage. Cornwall's DNO is a company called Western Power Distribution PLC and it is responsible for the South West, Midlands and Wales.

The means in which a power generator, such as a wind firm, can integrate with the national and regional transmission grid, is very much dependant on the installed capacity of the power station. In the UK's transmission industry, commercial power generators are classified into 4 groups dependant on their installed capacity: Large generators with direct link to national transmission grid, Large Embedded Generators, Medium Embedded Generators and Small Embedded Generators (any generator with an installed capacity of less 50kW have their own application process) (Figure 11). Embedded generators are simply generators into the regional DNO's transmission grid.

Large generators are defined in UK grid code as power stations with an installed capacity of over 100MV, in England these large power stations have the ability to be connect to both the national and the reginal transmission systems but usually connect to the former due to the higher amp powerlines (Natioanal Grid, 2009). As of 2010 no on-shore wind farm in England or Wales was large enough to be classified as a large power generator and as a result, there are no on-shore wind farms directly linked to the national transmission grid (Natioanal Grid, 2009).

This means that most wind farms in the UK fall into either the small or medium sized generator classification. These are defined as below as having an installed capacity of 50MV for the former and between 50MV and 100MV for the later (Figure 11). These power station connect to the distribution grid only, although medium sized generator have to have to apply for Licence Exemptible Embedded Medium Power Stations (LEEMPS) status. the LEEMPS generator is exempt from obtaining a generation licence as long as they agree to a contract with both National Grid and the DNO, meaning the embedding into the distribution grid still has to be okayed by the overall systems operator, aka the National Grid (National Grid, 2012).

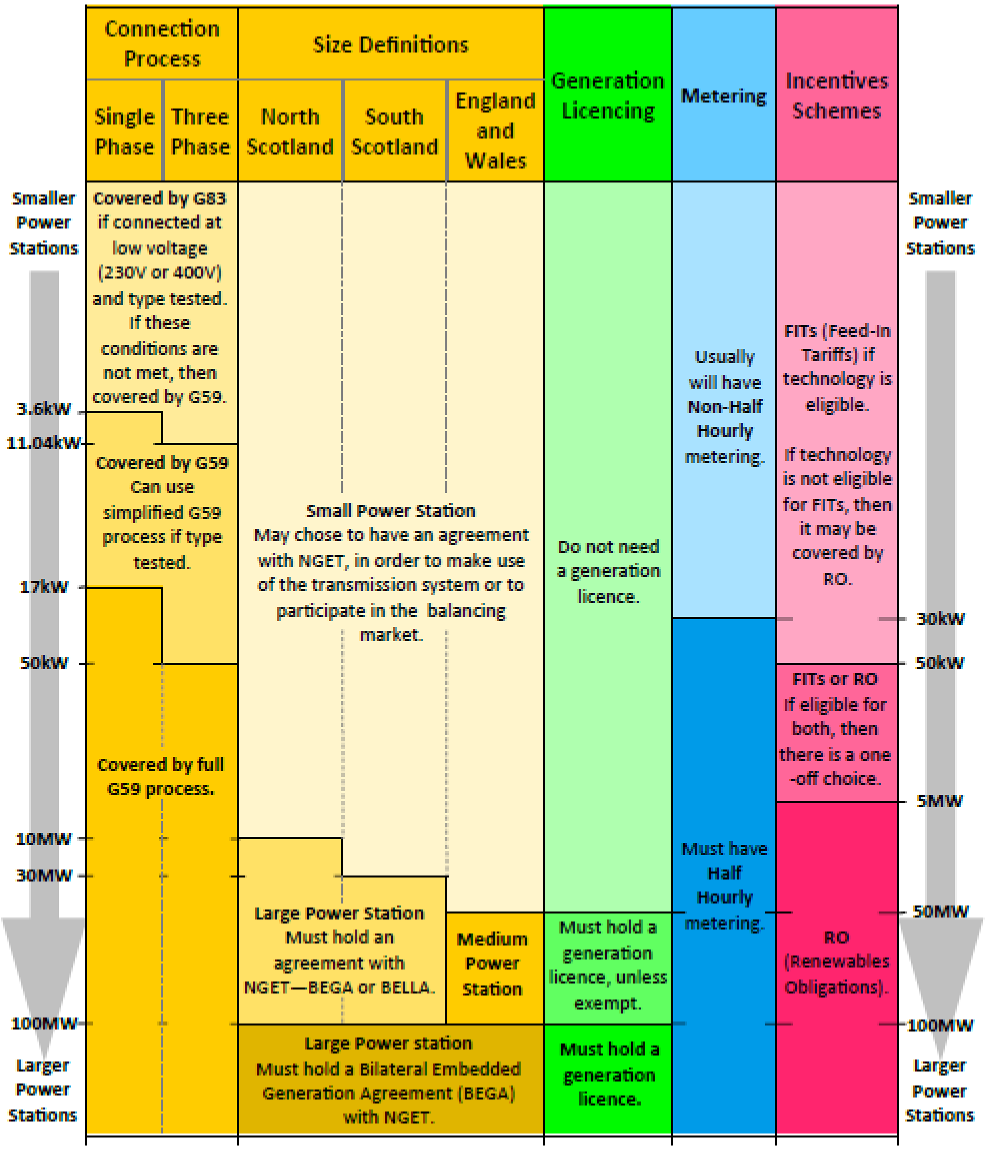


Figure 11 - A breakdown of the UK's power stations by installed capacity (Energy Network Assocsiation , 2014)

The problem still remains however, as to how to establish the connective relationship between wind power stations and the extend UK transmission grid in a GIS-based wind potential assessment. Clearly the size of any wind farms drastically effect the options of connectivity and this should, if possible, be modelled in any analysis. Other GIS-based wind potential assessments have tackled this problem in a variety of ways, one of the most common ways is not to include it all. Wind assessment in Crete, Poland and Western Turkey all make note of grid connectivity but do not include the variable in their respective economic assessments (Tsoutsos, Tsitoura, Kokologos, & Kalaitzakis, 2015) (Sliz-Szkliniarz & Vogt, 2011) (Aydin, Kentel, & Duzgun, 2010).

The studies that do include grid connectivity first have to establish what cost of the connection are deemed spatially dependant and what cost are spatially independent. For example, the costs of the collection grid (i.e. each wind turbine's transformer, connecting powerlines and on site substation) are spatially independent, not matter where the wind farm is placed in Cornwall, these costs are fixed and cannot be lessened. Whereas, the cost of the powerlines used to transfer electricity from the collection grid to the reginal or national transmission grid are spatially dependant; the closer the wind farm is to the existing transmission grid, the lesser the cost. Knowing this, and the fact that the powerlines just mentioned can cost between 100,000$ and 125,000$ per km, many studies have tried to factor in how close a potential site is too the transmission grid (van Haaren & Fthenakis, 2011).

In the 2015 Swedish wind potential assessment, they acknowledge the importance of proximity to the nation's transmission grid, but take a rather Boolean approach by using a scenario where only land within 10km of the transmission grid is included (Siyal, et al., 2015). This decision is based on economic grounds, the reasoning being is that any wind farms outside this zone is not economically feasible, also that the difference in connectivity costs between a wind farm 10km away to one a few hundred meters away is neglectable for a preliminary country wide potential assessment. Alternatively, in the 2011 web-based Tuscany wind assessment application, the creator allows the user to spatially define how far they are willing to allow the wind turbine to be from the transmission grid, it therefore becomes a controllable variable (Mari, et al., 2011). Essentially however, it works in a similar manner to the Swedish assessment by the land being either acceptable or unacceptable, albeit upon economic grounds.

One of the more economically in-depth attempts to model the spatial costs of connecting to the grid is seen in the 2011 New York State wind farm site-selection assessment (van Haaren & Fthenakis, 2011). It does not remove land on the basis of grid connectivity, however, it applies two mathematical formulas to all available land to find the minimal spatial cost of connecting the transmission grid. These are as follows (van Haaren & Fthenakis, 2011):

The cost of connecting to an existing substation is given by:

$$C_s = C_{up\ grade} + (c_{line} \times {}_{w\rightarrow s})$$

The cost of adding a substation and connecting to an existing line is given by:

$$C_l = C_{new} + (c_{line} \times {}_{w\rightarrow l})$$

With the variables being defined as the followed:

$C_{up\ grade}$ = *Cost of up grading an existing substation on the regional distribution network*

C_{new} = *Cost of building a new substation on the regional distribution network*

C_{line} = *Cost of connecting powerlines (per km)*

${}_{w\rightarrow s}$ = *Distance to existing substation (km)*

${}_{w\rightarrow l}$ = *Distance to existing transmission powerline (km)*

The final part of the formula would then be to select the cheapest option between the two and apply that to the economic analysis.

The cost of a typical connective powerline has already been stated, it is estimated to be between 100,000$ and 125,000$ per km (van Haaren & Fthenakis, 2011). The cost of a new or up-graded substation however have not been discussed. In the same New York State study the authors calculate these figures based on a report into the *'Electrical Collection and Transmission Systems for*

Offshore Wind Power' by the USA's National Renewable Energy Laboratory. This report estimates on aver the cost of a new substation is around 5.6 million dollars and to upgrade an existing substation, it's 2 million dollars (Green, Bowen, Fingersh, & Wan, 2007).

2.3.2 Access Road

Access roads are a vital to the construction and maintenance of any new wind farm. They offer a means to transport all the necessary components directly to the wind farm site. These components can consist of heavy construction equipment and the prefabricated sections of the wind turbines, both of which force any access road to typically be around 5 meters wide. They are generally constructed by flattening and compressing the surface of the ground and then depositing gravel to prevent slipperiness in wet weather conditions. All of this is estimated to cost approximately $82,000/km.

The length of any access road is therefore a spatial cost and a cost that ideally would be minimised when possible. To have a short as possible wind farm access road, the wind farm would have to be as close as possible to the already existing public road network. This spatial factor therefore has to be applied to any preliminary wind assessment to accurately analyse economic feasibility.

Applying the variable cost of an access road into a GIS based wind energy site selection assessment can be done in many different ways. In a regional scale application in Greece, the variable of distance to existing road is inputted into the multi-criteria decision making assessment as a fuzzy data set (Latinopoulos & Kechagia, 2015). This is done by taking an economical variable and reclassifying it by assigning a score of 1 where a site is in an ideal location in relation to that variable and a score of 0 where it is in its least desirable location. This is therefore a method for standardising all possible economic variables into the same multi-criteria analysis. For the Greek study, the value of 1 was set at 0-200m and the value of 0 was set to 5000m>, with a linear progression between the two (Figure 12) (Latinopoulos & Kechagia, 2015).

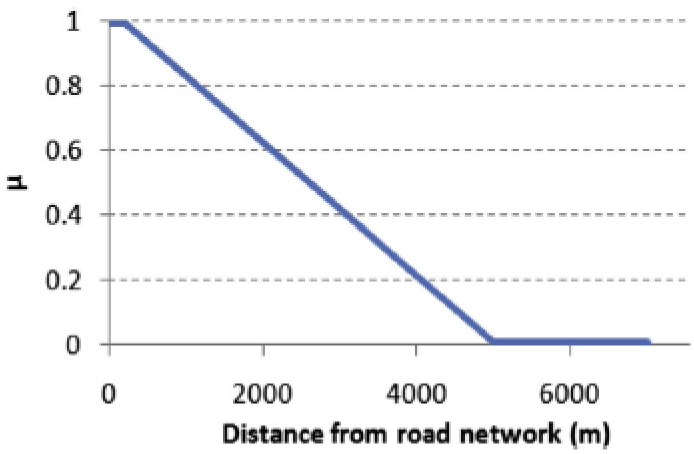


Figure 12 - Example fuzzy dataset to favour shorter distances from road network (Latinopoulos & Kechagia, 2015)

The positive of this method is the ease at which all economic factors can be standardised and weighed, but alternatively, this method does however lack actual numerical cost data. Clearly the fuzzy dataset is weighted on economic grounds but it does not attempt to calculate the cost of any new hypothetical assess road.

Other studies that have tried to calculate the hypothetical cost of an access road to any potential new wind site, include the 2011 New York State assessment (van Haaren & Fthenakis, 2011). It calculates the cost of an access road for all land that can feasibly hold a wind farm (this land is determined by a land exclusion stage of the analysis). It does this by multiplying each available grid cell's distance away from the road network (km) by the average cost of an access road (per km), resulting in the total cost of a potential access road. The use of just the average cost of an access road and the unrealistic straight measurement between road network and wind farm site result in a less than perfect modelling of how any real access road would cost. However, it does fulfil its purpose of spatiality prioritising land at a regional level based on the would be economic cost of a connecting access road. Because of this, a similar method will be adopted in this Cornish wind farm site selection assessment.

2.3.3 Land Clearance

The necessity of having an open and workable space when constructing wind turbines means that the cost of any required land clearance is a factor that must be taken into account for an economic assessment of potential new wind farm sites. The cost of any land clearance will depend greatly on the type of vegetation that covers any potential site, thicker, more dense vegetation coverage will have a higher cost of clearance and sparser, lighter vegetation coverage will generally cost less. And as vegetation coverage varies from place to place, it makes the cost of land clearance a spatially dependent cost. Although generally, land clearing costs are rather minimal, especially in comparison to other variables that can affect the location of new wind energy site, they are still a significant cost factor and one that can be easily be implemented into a GIS based Multi-criteria analysis.

In Van Haaren and Fthenakis's 2011 study into potential new wind energy sites in New York State, they too included land clearance costs as a part of their economic feasibility sub-section (van Haaren & Fthenakis, 2011). They started by retrieving land vegetation data for the USA from the United States Geological Survey's (USGS) National Land Cover Database (NLCD) (United States Geological Survey, 2007). This geographical dataset mapped the fluctuating vegetation coverage for New York state but didn't however provide any information on the cost of removing that vegetation. In fact, in their Journal article Van Haaren and Fthenakis state the prices of land clearance are instead based on a few references found online, claiming *"no published information about land clearing costs is available".* Out of the 17 varying vegetation types listed in the USGS's National Land Cover Database, van Harren and Fthenakis highlight only 8 types that are in need of clearance for a wind farm site. These can be seen in Figure 13, along with the cost of land clearance the authors attributed to each of the respective vegetation type.

Land clearing costs for different types of vegetation in the USGS database.

Category	Description	Clearing costs ($/acre)	Clearing costs for 50 MW wind farm* ($)
Evergreen forest	>5 m tall evergreen	~3000	741,000
Deciduous forest	>5 m tall sheds foliage seasonally	~3000	741,000
Mixed forest	>5 m tall, both deciduous and evergreen mixed.	~3000	741,000
Shrub/scrub	<5 m tall (true shrubs, young trees)	~1000	247,000
Hay/pasture	Grasses, legumes, plants for livestock grazing	~60	15,000
Barren land	Bedrock, desert pavement, scarps, talus, slides, sand dunes, etc.	~40	10,000
Cultivated crops	Annual crops (corn, soybeans, vegetables)	~40	10,000
Herbaceous	Grassland/herbaceous > 80% of total vegetation	~40	10,000

* The clearing costs for a 50 MW project correspond to an area of 1 km² [31].

Figure 13 - Land clearing costs used in van Haaren and Fthenakis's 2011 New York GIS-based wind farm site selection assessment (van Haaren & Fthenakis, 2011)

The first essential for mapping potential land clearance costs then is geographical data on the existing land vegetation within in the area of interest. For Cornwall (and indeed the whole of the EU) the most detailed and affective dataset can be found in the 2012 CORINE land cover dataset. The 2012 CORINE land cover dataset is derived from the EU's Copernicus programmed which is aimed at developing European information services based on satellite Earth Observation (Copernicus, 2017). The dataset has 44 different land use classifications. A lot of these however are of no use in calculating land clearance costs are they are already land uses that have been excluded during stage one of this assessment, such as water bodies (lagoons, rivers, lakes ….) and Urban areas (roads, airports, commercial buildings ….).

The cost of Land clearance for a wind energy site therefore comes down to two factors: first how much vegetation needs to be cleared for a wind farm and secondly the cost of removing the specific vegetation present at a site.

Firstly then, approximately only 5-10% of a new wind farm site would need to be permanently cleared of its vegetation (Bureau of Land Management, 2005, pp. 5-38). Van Haaren and Fthenakis choose to use the 5-10% figure in their US analysis, however this figure does not truly cover all the required area of clearance needed for construction as more clearance would be needed temporarily for additional constructive purposes (ie. laying of electrical cables for the supply/collection grid). In truth, *"the extent of clearing at the wind energy project would depend on the topography and wind characteristics at the site and on the relative height and placement of the turbines*" as stated in the US's Bureau of Land Management's Final Programmatic Environmental Impact Statement in 2005 (Bureau of Land Management, 2005, pp. 5-39). Clearly then, there is no absolutely correct percentage of a potential site that has to be cleared of obstructive vegetation. But for this preliminary GIS-assessment the upper end of the 5-10% figure will be used to account for some of additional temporary destruction.

In the 2011 New York GIS based assessment van Haaran and Fthenakis attach fixed clearance cost by acre to each of the NLDS vegetation classification groups. It seems that they categorise this into three groups: forest areas, that have a clearing cost of 3000$ per acre, shrubs and young forests, that have a clearing cost of 1000$ per acre and natural grassland/crops that have a clearing cost of 40-60$ per acre. An alternative online source can also be used as a check and validation for the costs posted by Haaren and Fthenakis, in figure 14, costhelper.com's (a free independent consumer advice website) clearing costs have been added as a balance check (costhelper.com, 2017). Fortunately, they correspond well with Van Haaren and fthenakis's cost estimates. Costhelper.com's defines its cost into three groups as well, claiming the following:

- *"Clearing heavily wooded or forested land can cost **$3,000-$6,000** or more an acre."*
- *"Clearing more sloping land with overgrown brush and a few trees might cost **$500-$2,000** per acre."*
- *"Hiring an excavation or land clearing company to clear flat land with light vegetation and few trees might cost **$20-$200** per acre."*

The costs chosen for the Cornwall assessment have taken into account both sources listed in Figure 14 and have been added to the figure as well.

2012 CORINE land Cover classification group	USGS's NLCD corresponding classification group	Van Haaren and Fthenakis's cost per acre attachment to NLCD's classification groups ($)	Costhelper.com's corresponding clearance costs per acre ($)	Cost per acre to be used in the cornwall assessment ($)
Broad Leaf Forest	Deciduous Forest	3000	3000-6000	4500
Coniferous Forest	Evergreen Forest	3000	3000-6000	4500
Mixed Forest	Mixed Forest	3000	3000-6000	4500

Transitional woodland shrub	Shrub/Scrub/Young Forest	1000	500-2000	1500
Sclerphyllous vegetation	Shrub/Scrub/Young Forest	1000	500-2000	1500
Moor and heathland	Barren Land	40	20-200	100
Natural Grassland	Herbaceous	40	20-200	100
Non-Irrigated Land	Barren Land	40	20-200	100
Permanently Irrigated Land	Cultivated Crops	40	20-200	100
Pastures	Hay/Pasture	60	20-200	100
Annual Crops associated with permanent crops	Cultivated Crops	40	20-200	100
Land primarily associated with agriculture; with areas of natural vegetation	Cultivated Crops	40	20-200	100
Agro-Forestry Areas	Shrub/Scrub/Young Forest	1000	500-2000	1500

Figure 14 - Various cost of removing vegetation in order for wind farm construction

2.3.4 Wind Resource

The most important factor that plays a role in economic feasibility of a wind farm is the base wind resource. This makes obtaining accurate and extensive wind data for a preliminary GIS-based wind power assessment equally important. There are many different ways of procuring the necessary data, and from a variety of different sources.

Perhaps the most desirable resources are the global commercial interactive GIS-based wind resource mapping systems (WRMSs). Commercial WRMSs offer detailed and relevant wind datasets (calculated through extensive modeling), such as wind speed, wind direction and air pressure, and are aimed specifically at servicing the wind energy industry. They also offer wind speed data at varying hub heights, something that is essential in calculating the potential energy output of a wind turbine. Examples of commercial WRMSs include the “FirstLook” system built-up by 3Tier and the “WindNavigator” system developed by the Associated Weather Services (AWS) Truewind, the latter of which was used in van Haaren and Fthenakis’s 2011 New York State study. AWS have tested their modelled data against in use wind turbines and have concluded that AWS Truepower estimates the overall uncertainty in gross energy production of a wind farm to be between 10% and 15% (AWS, 2011). Although desirable these Commercial WRMSs are expensive and hard to use for academical purposes.

Not all interactive GIS-based WRMSs are commercial products however. Smaller country or regional-wide WRMSs are present, each using their own complex modeling formulas to produce wind speed data at various hub heights. Examples of this include the US nation-wide WRMS built-up by the National Renewable Energy Laboratory (NREL), the interactive WRMS built-up by Suisse Eole, operative over Switzerland, and the one by Action Renewables over Northern Ireland.

Other national organisations and institutes have also published national level wind geodata, albeit no always with the intent of wind energy exploration. Ground level average wind speeds are useful for a many number of interest groups and industries, but are still generally seen as too unreliable when trying to estimate potential output of any new wind energy sites. Having said this however, ground level average wind speeds can be a useful indicator on where there could be new potential wind energy sites and can also be a base from which to estimate wind energy potential at varying hub heights. An example of this can be seen in a 2015 Swedish wind energy assessment (Siyal, et al., 2015). Here, a spatial dataset of annual average wind speed with 1 km _ 1 km resolution throughout the land area of Sweden produced by Swedish Energy Agency (SEA) was used as a base for the Meteorological Institute of Uppsala University (MIUU) to create a three-dimensional meso-scale higher order numerical model that then approximated the average wind speed at a hub height of 90m.

Wind speed data Extrapolation

Even with just basic wind data there are still ways of manipulating it in order to use it for a wind energy potential assessment. In a 2011 Polish Wind energy assessment, the authors only had access to average daily speed wind data which was collected at the National Climatic Data Centre's 28 meteorological stations in the study area (Sliz-Szkliniarz & Vogt, 2011). From just this data, Sliz-Szkliniarz and Vogt managed to interpolate the data points by using the ordinary kriging spatial interpolation technique to cover the study area with workable wind speed data. From here they extrapolated the average wind speed to different hub heights using the formula seen below:

$$V_{ZR} = V_z \frac{\text{In}(Z_R/Z_O)}{\text{In}(Z/Z_O)}$$

"where Vz is the wind data collected at the anemometer height of Z, Vzr is the wind velocity at hub heights Zr of 50, 80 and 100m and Zo is the roughness length that was derived from the CORINE land cover data (CLC). (Sliz-Szkliniarz & Vogt, 2011)*"*

This formula is relatively simple and only requires an addition land cover spatial dataset. This is needed at land cover can have significant effect on wind speeds. A roughness length chart derived from the CLC can be seen in Figure 15.

Roughness	CLC classes
1.200	Continuous urban fabric
0.750	Broad-leaved forest
	Coniferous forest
	Mixed forest
0.600	Green urban areas
	Transitional woodland-shrub
	Burnt areas
0.500	Discontinuous urban fabric
	Industrial or commercial units
	Port areas
	Construction sites
	Sport and leisure facilities
0.300	Complex cultivation patterns
	Land principally occupied by agriculture, with significant areas of natural vegetation
	Agro-forestry areas
0.100	Vineyards
	Fruit trees and berry plantations
	Olive groves
	Annual crops associated with permanent crops
0.070	Road and rail networks and associated land
0.050	Non-irrigated arable land
	Permanently irrigated land
	Rice fields
	Inland marshes
	Salt marshes
0.030	Pastures
	Natural grasslands
	Moors and heath land
0.005	Airports
	Mineral extraction sites
	Dump sites
	Bare rocks
	Sparsely vegetated areas
0.001	Glaciers and perpetual snow
	Peat bogs
	Salines
	Intertidal flats
0	Beaches, dunes, sands
	Water courses
	Water bodies
	Coastal lagoons
	Estuaries
	Sea and ocean

Figure 15 - Roughness length based on the CLC data (Sliz-Szkliniarz & Vogt, 2011)

Overall however, the scarceness of ground source data points and rather basic extrapolation modelling lead to higher uncertainty in result reliability, but it does show that even with basic data an attempt at estimating average wind speed at various hub heights can be made.

For the county of Cornwall and indeed the whole of Great Britain there is no free-to-access wind speed data that covers all the wind turbine hub heights required for this assignment, there is however annual average wind speed with 1 km _ 1 km resolution at the hub heights of 10m 25m and 45m. This data was originally developed by the Department of Trade and Industry (DTI) at some point before 2001 (Department of Energy and Climate Change, 2017). The data is stored in The Department of Energy and Climate Change's (DECC) website as an electronic interactive wind speed Database. Although there is the option of downloading it in an GIS format (.asc file). The wind speed database gives estimates of the annual mean wind speed throughout the UK by using an air flow model to estimate the effect of topography on wind speed at various hub heights (Department of Energy and Climate Change, 2017). Although it makes no allowance for the effect of topography on a small scale, or local surface roughness (Department of Energy and Climate Change, 2017).

The 10m hub height average wind speed data is useful in helping predict the potential generational output of smaller wind turbines, but as the industry continues to favour larger and larger wind turbines, higher hub height wind data is also needed. One way in which to extend the wind speed data currently offered by the DECC to higher heights. As the details on how the air flow model were not produced, the only option is to model the wind average speeds using a different method. One such method has been discussed already, the extrapolation formula used in Sliz-Szkliniarz and Vogt 2011 paper on the Kujawsko–Pomorskie Voivodeship in Poland. It requires only the average wind speed at a known hub height, which is now covered, and a terrain roughness scale factor. Handily, the scale factor used in the 2011 polish study could be reused, the Corine land cover (seen in Figure 15), as this data will already be in use for calculating land clearance costs in this assessment.

Wind speed Distribution

A wind speed distribution provides the frequency of occurrence of a particular wind speed at a location (Hollnaicher, McKenna, & Fichtner, 2014). To calculate potential energy output of wind turbines, there is a vital need to model wind speed distribution. This is especially true when there is access too only long-term yearly averaged wind speed datasets such as will be the case for this study (Siyal, et al., 2015). The need to assess distribution patterns is primarily due to two reason. The first being the distribution of wind speeds is a non-normal distribution. There will be, at every site of recording, a skewness or kurtosis to the distribution in favour of either higher or lower speeds. The second, is that the relationship between wind speed and kW output is a complex and nonlinear relationship. For example, if two different potential sites had the same wind speed average it would not guarantee they would produce the same amount of kWh's in a shared amount of time.

Unfortunately, lacking the short-term recordings of wind speed data that make up the average wind speed dataset, makes it impossible to calculate per site distribution of wind speed. There is however the possibility of using a universal distribution calculated specifically to model wind speed distribution as a whole. In 2009, the European Environment Agency (EEA) published an overall wind speed distribution equation, that was a modified form of the Weibull distribution, i.e. the Rayleigh distribution with the shape factor k = 2 (European Environmental Agency, 2009). In the presence of the modelled annual average wind speed of each grid cell, it was designed to estimate the preliminary wind energy potential on county or country level in GIS-based studies. The Formula is as follows (Siyal, et al., 2015):

$$f(U) = \frac{\pi}{2} \cdot \frac{U}{U_{mean}^2} \cdot \exp\left\{ -\frac{\pi}{4} \left(\frac{U}{U_{mean}} \right)^k \right\}$$

'where f(U) is the probability of occurrence of a specific wind speed reading, U is wind speed reading with intervals of 1 m/s, U_{mean} is the average wind speed of a single grid cell, and k is the dimensionless shape factor equal to 2.'

The variability of the wind speed at any location is shown by the dimensionless shape factor (k-value). the lower the value, the more varied (or the wider the probability distribution) of the wind speed (Hollnaicher, McKenna, & Fichtner, 2014). Without access to short-term site specific wind speed distribution data this value has to be kept at 2, as per suggested by the EEA study.

The availability factor of a wind turbine is the percentage of time that a wind turbine is available or capable to produce electricity from the wind. It should not be confused with the amount of time a wind turbine is physically producing energy. There can be a lot of time when a wind turbine is operational but the wind resource itself is inadequate. The availability factor of modern wind turbines now ranges from 96% to 99%, with 1% to 4% of time often being used to fix technical problems or conduct scheduled maintenance (Siyal, et al., 2015). Must other wind assessment GIS studies have used 96% as their availability factor and so will be the case for this study (Katsigiannis & Stavrakakis , 2013) (Nedaei , Assareh, & Biglari, 2014).

2.3.5 Non-spatial economic factors effecting cost

At this point of the Literature review, it should be clear that there are two significant non-spatial variables that would greatly affect the energy production of a wind energy development and to a lesser extent, the spatial costs as well. These are the number of turbines present in a wind energy development and the model or type of wind turbines present in a wind energy development.

The relationship between the number of turbines and energy output of a wind farm is simple; the greater number of turbines present, the greater the energy output. A greater number of turbines can also increase the spatial costs as well, as with more turbines it can result in higher costs for land clearance and grid interconnectivity.

Although the economic effects of this non-spatial variable maybe be rather simple to calculate for a single wind energy development, the idea of trying to calculate the energy production and spatial costs for hypothetically varying-sized wind farms in all available land, is unnecessary complicated. It is also a step-in development that is beyond the purpose of this wind energy assessment. Ultimately the decision of how many wind turbines to be present in a wind farm is a developer's choice and one that is very site specific decision. This wind energy assessment should still provide data that aids in the decision of how many wind turbines to use in potential new wind farm, such as the size of available land and the economic potential of a single wind turbine, but ultimately should not address wind farm size.

With this knowledge, the economic assessment will continue based on a singular turbine.

The make and model of that turbine is another variable that hugely alter the economic potential of a wind energy development. There are numerous different wind turbine manufactures and hundreds of different turbine models available in the modern industry. To try and calculate the potential output of all of these, would be folly.

Due to the emphasis laid out in the 2016 Renewable Energy Planning Advice service on how important turbine height is in interacting with the Cornish landscape, it is especially important to include turbines from an array of different hub heights (Cornwall Council, 2016). The Renewable Energy Planning Advice service split wind turbines into 4 height based categories: Band A – for turbines with a hub height of 18-25m, Band B - for turbines with a hub height of 26-60m, Band C – for turbines with a hub height of 61-99m and Band D – for turbines with a hub height of 100-150m (Cornwall Council, 2016). Band A is not applicable for this study, which is designed for grid-connecting wind energy developments but the other three categories offer themselves as good guidelines for choosing a set of wind turbine. The decision is therefore to use 3 different wind turbine models in this study for demonstrating the wind energy potential of Cornwall, which each of the three models having a hub height corresponding to a different Band type.

That make and model of these three wind turbines though, still must be determined. There are two important characteristics that each of the wind turbines must have to be included in this study. The first is that each of the wind turbines must be currently in production and available to purchase. The second is that there must be available power curve data for said turbine, that allows this study to calculate output wattage from wind varying wind speeds.

The chosen wind turbines are seen below in figure 16, along with a selection corresponding data.

Full wind turbine name	Online-link to manufactures product information	Cut-in wind speed (m/s)	Cut-off wind speed (m/s)	Hub Height	Online-link to power curve data	Rated power (kW)
Vestas V 126-3.45	https://www.vestas.com/en/products/turbines/v126%203_3_mw#!technical-specifications	3	22.5	117m (also available 137m, 147m, 149m)	https://en.wind-turbine-models.com/turbines/1249-vestas-v-126-3.45#powercurve	3450
Nordex N90/2500	http://www.nordex-online.com/en/produkte-service/wind-turbines/n90-25-mw/product-data-sheet-n90-25mw.html?no_cache=1	3	25	70m (also available 75m, 80m, 100m, 120m)	https://en.wind-turbine-models.com/turbines/734-nordex-n-90-2500#powercurve	2500
Enercon E48	http://www.enercon.de/en/products/ep-1/e-48/	3	34	50m (also available 55m, 60m, 65m, 76m)	https://en.wind-turbine-models.com/turbines/529-enercon-e-48#powercurve	800

Figure 16 - List of wind turbines to be included in the Cornish wind energy assessment

3 - Data Collection

3.1 Stage 1

The data to be used in Stage 1 of this assessment comes from a variety of different sources. they range from European-wide geo-datasets made available from the European Environmental Agency at the bequest of the EU's INSPIRE Directive to voluntarily crowd sourced geo-data collaborations like OpenStreetMap.

The data to be used for showing urban areas with a population of over 2000 people and the data modelling slope gradients in Cornwall both come from the European Environmental Agency. The urban areas data is incorporated in the 2012 Europe-wide CORINE land cover raster. The land cover raster is a product of the Copernicus programme, an EU programme aimed at developing European information services based on satellite Earth Observation and in situ (non-space) data (Copernicus, 2017). The data of which slope gradients of Cornwall can be extracted from, comes from a different European-wide data set, albeit produced from the same Copernicus programme. It comes from the European Digital Elevation Model (DEM), a 3D raster dataset with elevations captured at 1 arc second postings (2.78E-4 degrees) or about every 30 metre.

Road and Railway spatial data in Cornwall is necessary for ensuring that existing human infrastructure remains protect from the wind energy industry. This data will be taken from the Ordnance Survey (OS), the national mapping agency for Great Britain. The OS is a non-ministerial government department; which means it is British governmental department but is bereft of any direct political oversight as it has been judged unnecessary and inappropriate. To access the road and railway data for Cornwall, a larger more comprehensive and detailed geo-dataset was downloaded, the OS Open Map – Local.

Natural England are the British government's adviser for the natural environment in England, they aim to help to protect England's nature and landscapes for people to enjoy and for the services they provide. Similar to the Ordnance Survey, Natural England is another quasi-autonomous public body attached to the British government, however Natural England is a non-departmental public body instead of a non-ministerial government department. This simply means Natural England is even further removed from political intervention, with its official relationship defined as being a sponsored party of the Department for Environment, Food and Rural Affairs. Natural England is the source of data for all the datasets required for the wildlife/environmental protection part of stage 1, this includes: Ramsar sites, local and national nature reserves, SPAs, SSSIs, National Parks and the Development Consultation Zones.

The Landscape Character Assessment spatial data, which will be vital for taking into account a variety of the local landscape concerns held by interested parties, was obtained from the Cornwall Council. This data was not free available online. It was however given free of charge via email upon request for this assessment, along with the condition a confidentiality agreement was signed.

Lastly the data displaying airports with ATC radars in Cornwall was taken from the voluntarily crowd sourced world map known as OpenStreetMap. Although the Airport data used in this assessment comes from OpenStreetMap another website was used to extract only the relevant airport data, Overpass-turbo. Overpass-turbo is a web based data mining tool for OpenStreetMap and is in essence a query based overpass API. The specific query used to extract airport data is seen in Figure 17. This data was extracted in the form of a GeoJson file, one last step was required in order to make this data useable in ArcGIS software and it was to convert this file into an ESRI shapefile by using the conversion website https://ogre.adc4gis.com/.

```
/*
This query looks for ways
with the given key/value combination.
Choose your region and hit the Run button above!
*/
[out:json][timeout:25];
// gather results
(
  // query part for: “aeroway=aerodrome”

  way["aeroway"="aerodrome"]({{bbox}});
);
// print results
out body;
>;
out skel qt;
```

Figure 17 - Query to extract airport data from OpenStreetMap

Figure 18 summarises the sources of data used in Stage 1 of this analysis and includes, where applicable, the URL address from where the data can be accessed.

Required Data	Source	URL address where applicable (correct as of April 2017)
Road, Rail Network and Rivers	Ordnance Survey	https://www.ordnancesurvey.co.uk/opendatadownload/products.html
Urban Areas (Pop. >2000)	European Environmental Agency – Copernicus Programme	http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012/view
Landscape Character Assessment	Cornwall Council	*Not openly made available to the Public*
Environmentally protected areas (Ramsar sites, SSSIs ….)	Natural England	http://www.gis.naturalengland.org.uk/pubs/gis/GIS_register.asp
Slope Gradients	European Environmental Agency – Copernicus Programme	http://www.eea.europa.eu/data-and-maps/data/eu-dem
ATC Radar systems	OpenStreetMap	http://overpass-turbo.eu/

Figure 18 - List of GIS data incorporated into stage 1

3.2 Stage 2

Some of the data to be used in stage 2 of the assessment will be exactly the same as the collected data in stage one. The Corine land-sat coverage will be used again twice in stage 2 of the assessment, once to help extrapolate wind speed data to higher heights and the other to help produce cost estimates for land clearance. Likewise, the road data used for the in the buffer analysis in stage one, will be used to calculate the length of necessary access roads.

Some new GIS data was however needed. To help calculate the cost of connecting a potential wind turbine to the national electrical grid, three different data sets where needed. Firstly the 400 kV lines that run as part of the Nation Grid came as direct download from their website. For the supply network of cable, running at 132kV or less, there had to be a request of data from Cornwall's Distribution Network Operator, Western Power Distribution. This data, along with that of substation data, came via email.

The Wind resource came from the Department of Energy and Climate Change' geodatabase for average wind speeds across the UK. The data was Originally in ASC format, but need manipulation before being able to be exported into an ArcMap map-book. First it was delimited with ';' and replaced by spaces in Microsoft excel and then given the headers of:

'ncols 700

nrows 1300

xllcorner 0

yllcorner 0

cellsize 1000'

After this the Wind data was added to ArcMap.

3.3 Stage 3

The only external data needed for stage 3 of the analysis was a digital elevation model. The EEA's EU-DEM was already in use for the slope analysis in stage one, so it would be re-used again in stage 3 to act as the basis for the visibility study.

4 – Methodology/Implementation

4.1 Methodology introduction

This phase of the paper will set out how the Cornish Wind Energy assessment was implemented, focusing on the geoinformatics processes in working the external GIS data into relevancy in the Cornish wind energy assessment,

4.2 Stage 1 – Land Exclusion

Map Books 1-5 in the Appendix show the completed analysis of the section containing: Road and Railways, Urban populations, Slope gradients, Environmentally Protected Areas and ATC radar.

4.2.1 Road, Railway and Airport buffers

All the data for the roads, railways and airports came as vector data; with the roads and railways represented as polyline features and the airports represented as polygon features. Although the features types vary, all three layers were applied a buffer analysis to calculate the areas which would be protected on their behalf. The buffer sizes were determined though theoretical/ background section of this assessment and are as follows: Railways – 200m, Roads – 200m and Airports – 2500m. To produce the correct buffer zones around the features, the geoprocessing tool *buffer* was used in ArcMap after all three feature layers had been added to a Map Book.

As it is possible to see in figure 19 the only requirement for the buffer tool was an input layer, destination for new shapefile and the specified buffer size. Once the analysis (which was run for each of the three layers) was completed, the multi-polygon feature layer containing the buffer zone was added into the map book. They indicate what parts of Cornwall are out of contention for wind development based on their corresponding development issue.

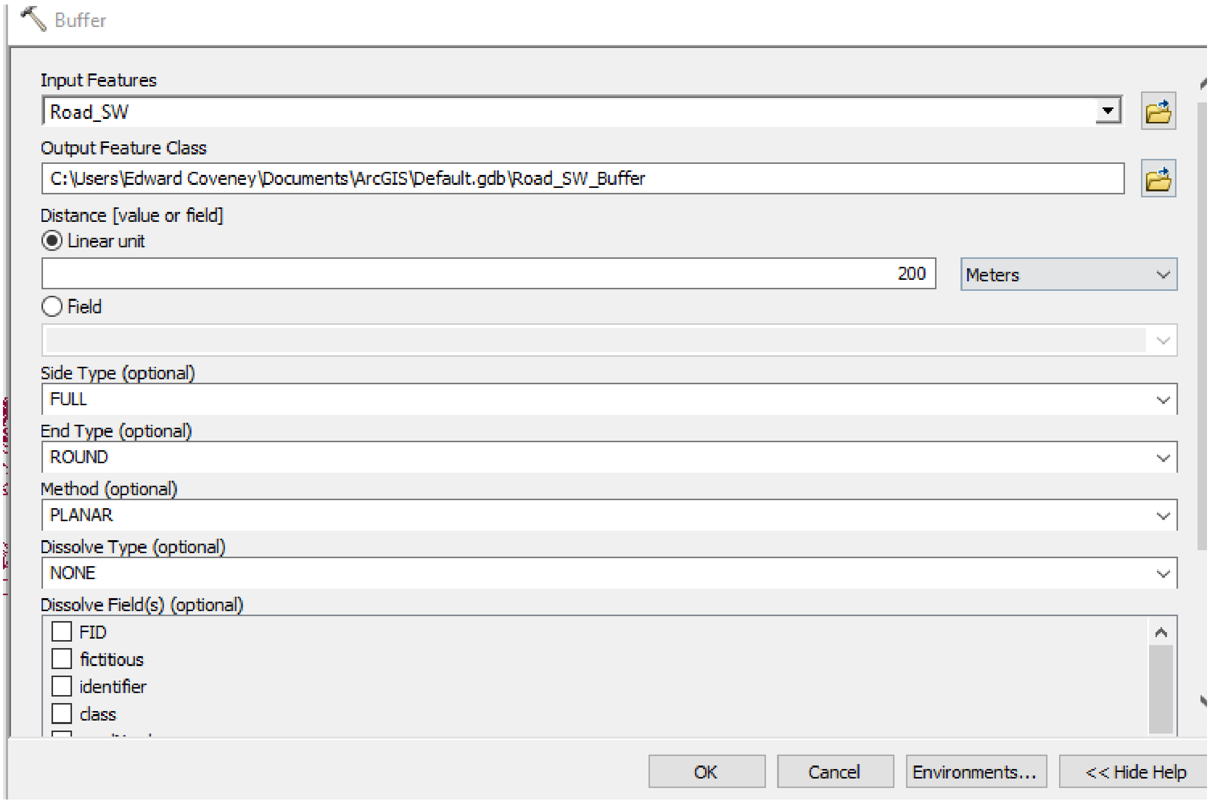


Figure 19 - Buffer Analysis tool used on road network

After completion, the next necessary step was to merge together all the individual polygon buffers in each individual shapefile to create one single record per shapefile. This was done in an editing session using both the *select features* button and *merge* tool located in the editing toolbar. This was obligatory as it removed any unnecessary overlapping and made the shapefile more manageable in size.

4.2.2 Environmentally Protected Areas

The Environmentally Protected Areas (EPAs) that have been included into this stage of the study are highlighted in Figure 09 and are as follows: SSSIs, SPAs, Ramsar Sites, NNRs, LNRs and SACs. Once these shapefiles had been added to the stage 1 map book there was no need to apply any buffers, as only the physical boundaries of these area would be used to eliminate land from the potential development of wind turbines. However, it was decided that for ease of handling, all 6 polygon layers would be combined into one single shapefile as there was no longer a need to manipulate individual EPAs. This was done by using geoprocessing tool *Merge*.

The Impact Risk Zones (IRZ) shapefile however could not be incorporated into the single layer, primarily for two reasons. Firstly, its purpose was not to completely rule out the land that falls within its boundaries like the other 6 EPAs but merely to warn the eventual user that a consultation with

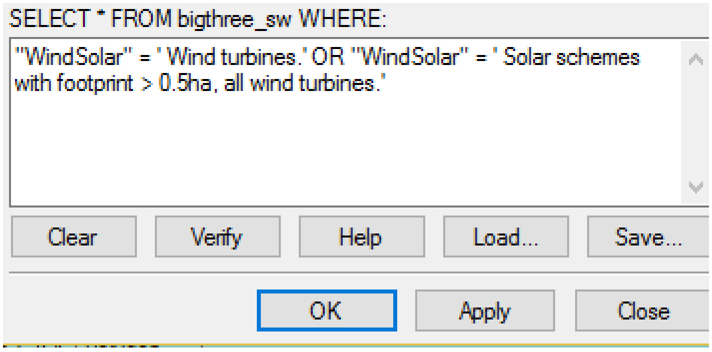


Figure 20 - Select by attribute query for wind development affected IRZs

Natural England will be necessary if the land is to be developed on. And secondly, as the shapefile was not only created with just the wind energy industry in mind, the IRZ layer needed to be vetted to keep only the areas that would need consultation specifically for wind energy development. To do this, *select by attributes* was used to highlight only the necessary IRZ records, which were then exported into their own shapefile. The full query used for extraction can be seen in Figure 20.

4.2.3Landscape Character Assessment (LCA) areas and Areas of Outstanding Natural Beauty (AONB)

In the March 2016 Cornish landscape sensitivity assessment, the Cornwall Council set out the strategy matrices for each Landscape Character Area – these matrices set out a detailed assessment of the sensitivity of the Cornish landscape to wind farms. In Section 2.2.4 it stresses the importance to this study of two specific measures when determining the sensitivity of a LCA to wind development. These were the Overall Sensitivity of LCAs to wind development and the recommended height limit of a wind turbines in a LCA. Both of which can be seen in Appendix 1 of the Cornish landscape sensitivity assessment.

After viewing appendix 1, it becomes clearly apparent that each LCA scores with regards to overall sensitivity and height restriction are deeply split dependent on which parts of LCA which fall within an Area of Outstanding Natural Beauty (AONB) and those which don't. This resulted in the need for AONBs to be included into Stage 1 of this assessment and for each LCA to be split along AONB bounds where applicable.

To start this in a practical sense, both the LCA and AONB shapefiles were loaded into a new map book. From here both layers were added into the geoprocessing tool *intersect*, with made sure that the 'JoinAttribute' input command was set to 'All'. By using the *Intersect* tool, the new output shapefile had the same extent as the AONB but was now split into individual muilti-polygon records in accordance to what LCA they fell in. And by ensuring 'JoinAttribute' equals 'All', each new record had metadata referencing which LCA they were a part of.

The areas of the LCA layer that now overlapped with the new AONB layer were now redundant. to remove these areas the erase analysis tool was used, with LCA layer acting as the input layer and the new OANB layer acting as the erasing layer. The resulting new LCA still kept the same metadata, which importantly meant that both new layers had metadata linking them to the original LCA areas. Figure 21 shows as screenshot of these two new non-overlapping layers.

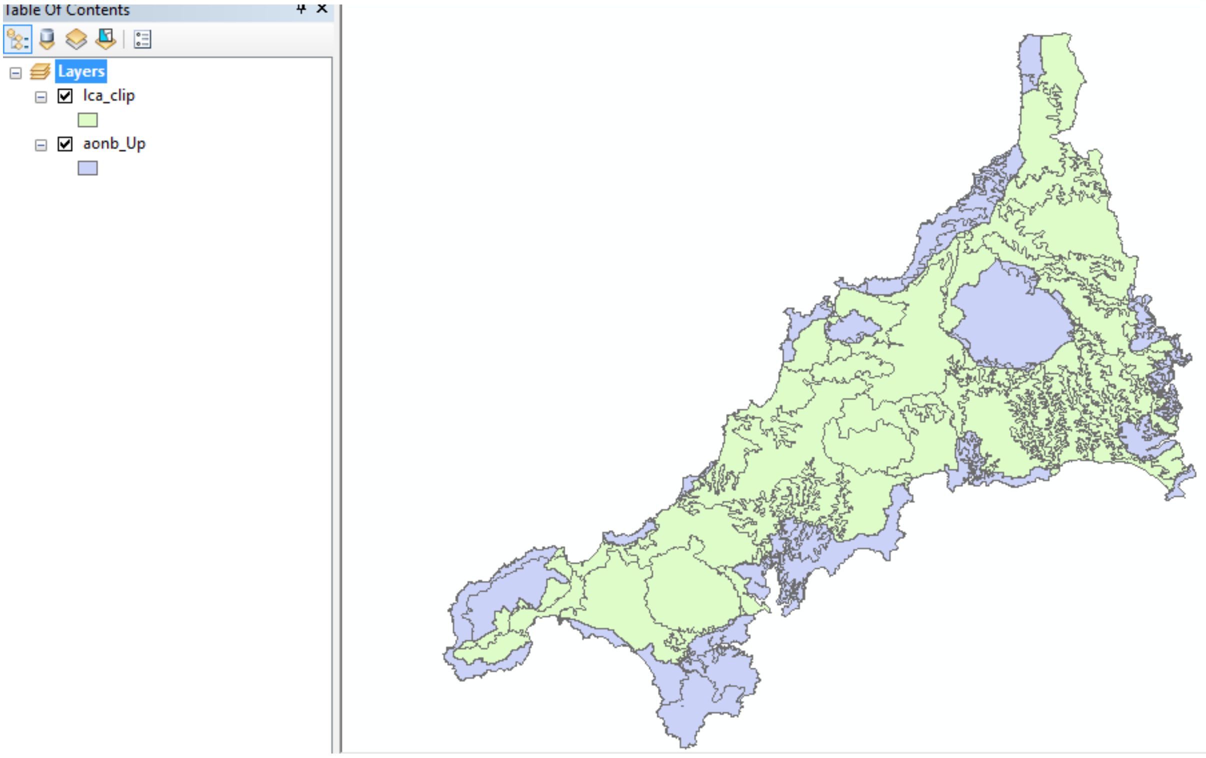


Figure 21 - ScreenShot of LCA areas divided by AONB sections and non-AONB section

It should be made clear at this point the information seen in Appendix 1 of the Cornish sensitivity study was never part of the GIS layers metadata. Therefore, the next step was to find a means of attaching this data to the metadata of the GIS Layer. After consideration, this was done in PostgreSQL, a free and open source object-relational database with backing from PostGIS, an open source software program that adds support for geographic objects to the PostgreSQL.

First the two shapefiles were uploaded into the database system. Next, two new columns were created for both tables to store sensitivity data, these were *Overall_Sensitivity* and *Band_Limit.* Both with a required datatype of Characters. Figure 22 shows the specific SQL query to create a new column. Next the new columns were populated in accordance to Appendix 1. *Overall_Sensitivity was populated on* a 5-classification based ranking, ranging from 'Low' to 'High' and *Band_Limit* was populated on a 4-classification based system, ranging from 'Band A (18-25m)' to 'Band D (100-150m)'. An Example SQL query to do this is seen in Figure 23.

```sql
ALTER TABLE lca_clip
 ADD COLUMN Overall_Sensitivity VARCHAR;
```

Figure 22 – Example of Add Column SQL query for the LCA table

```sql
Update lca_clip set Overall_Sensitivity = 'Moderate-High', Band_Limit = 'B'

 Where lca_clip.ca_ref = 'CA01';
```

Figure 23 - Example of SQL query updating LCA table with sensitivity data

Lastly the tables were exported back into shapefiles, where they could now be visually presented based on the newly contributed data.

Using both the LCA layer and OANB layer it was then possible to create 3 single shapefiles that ruled out the land for the three different desired categories of turbine. For category D turbines, i.e. turbines of a hub height between 100m - 150m, LCAs that had a height restriction of Band A, B or C were selected from LCA layer, using *select by attribute*, and then merged together with the AONB. This combined layer rules out all land in Cornwall that the Renewable Energy Planning Advice service deemed unsuitable for wind turbines of a hub height over 100m. This step was then also repeated for band B and C turbines, with the band C layer extracting LCAs with a max restriction of B and A and the band B layer extracting LCAs with a max restriction of A.

4.2.4 Slope Gradients

The elevation data that came from the EPA was in a Raster Tiff file; at a spatial resolution of 25m² per grid. With this elevation data, it was possible to use the spatial analyst tool *slope* to calculate the various slope gradients that permeate the Cornish landscape. The resulting raster file showed gradients ranging from 0 to 78 degrees' in steepness. For this part of the assessment, only the areas of 15 degrees and above are important in helping to rule out land unsuitable for wind development. To extract just the areas of land that fit this description, a few more tools had to be used in the slope map book. Firstly, the *reclassify* spatial analyst tool was used to create a new raster that was defined in respect to the older as the following '0 = < 15°, and 1 = 15° ≥'. From here, the reclassified raster file was then converted in to a polygon vector shapefile using the conversion tool *raster to polygon*. This was done to ensure uniformity in formatting for all data that would be used in Stage 1. It should also be stated that option to create simplified polygons when using the tool was checked to help create a smoother more natural shaping of the 15° ≥ areas. The next step was to export only the 15°

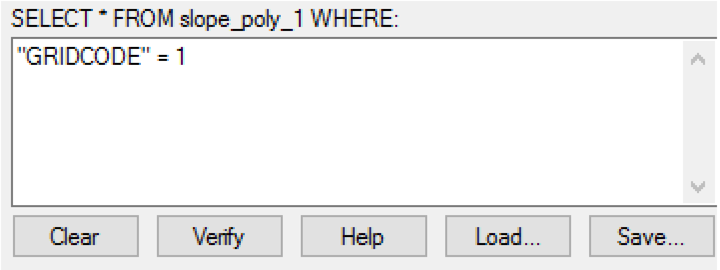


Figure 24 - Selection by Attributes SQL query for highlighting and exporting areas of land with a steepness gradient of 15° and over.

≥ areas into their own shapefile using the select by attributes tool and the SQL query seen in Figure 24.

The next step for the slope polygon layer was to filter out some of the smaller polygons. Smaller polygons were filtered out to ensure that 10,000 square metres plots of land are not excluded from the analysis because they hold within them small areas of land that have a slope gradient of over 15°. To do this, an additional field of data type *float* was added to the attribute table of the polygon layer, which was then in turn filled with area sizes using the *calculate geometry* option. The select by attribute was used again to select records with a size of over 3333m² and then these records were exported into their own shapefile.

4.2.5 Urban Area Buffers

Lastly, there were Urban Areas with a population of over 2000 that need protecting from wind development, and unlike roads, railways and airports this data came in raster format instead of vector data. The first step was to extract just the urban areas from the Corine Land cover raster layer. This meant a *select by attribute* query that targeted the following land types: Urban Continuous urban fabric, Discontinuous urban fabric, Industrial or commercial units, Road and rail networks and associated land, Ports, Construction sites and sports facilities. Once the query was run and the results exported into their own raster it was time to turn the date into vector data. This was done by using the *raster to polygon* tool, again simplifying the polygons to add smoothness. The last two steps were to again use the *buffer tool*, remembering to apply a 1000m buffer, and then merging the resulting polygons into a single record.

4.2.6 Layer Compilation for Stage 1

With all the individual layers created for ruling out land for their respective reasoning completed, the last step in stage 1 was to combine these layers into a final set of shapefiles that could be used effectively in the following stages of the assessment. The aim was to create 3 shapefiles; one for land excluded from turbines of a hub height of over 100m, one for land excluded from turbines of a hub height of between 60 - 100m and one for land excluded from turbines of a hub height of between 26 -60m.To do this the first step was to establish which shapefiles need to combined for each of the three different hub heights.

The roads, railways, airports and urban areas layers in combination with the slope gradient layer and environmentally protected areas layer are all completely restrictive regardless of turbine hub height. Therefore, they were *merged* together 3 times to form a basis for all 3 of the desired output shapefiles. Then, from the LCA analysis in section 4.2.3, the three shapefiles created for ruling out land for landscape sensitivity reasons were added, one for each the 3 base layers, to create the 3 desired shapefiles.

4.3 Stage 2

Map Book 6 in the Appendix shows the section of electrical included in the cost analysis. Map Book 7 in the Appendix shows the starting 10m above ground average yearly wind speed data. Map Books 8-10 in the Appendix show the 3 final data sets produced at the stage 2 of the analysis. For each turbine, there is an excluded layer and another layer showing the predicted annual energy output of the turbine.

4.3.1 Preparing Land Coverage dataset

The CORINE land cover raster had two uses in stage 2 of this wind assessment. It was need as part of the extrapolation of average wind speed data to different hub heights and was also needed to help calculate land clearance costs. Before the layer could be used for either of these purposes, it had to be converted from its original geographical co-ordinate system ETRS_1989_LAEA to the British National Grid co-ordinate system. This was because the British National Grid system was the chosen projection system for stage 2 of the analysis and it must be able to align with other rasters used in this stage. This was managed by using the data management tool *project raster*, a tool which only requires the original raster and the name of new co-ordinate system. It was possible to change the cell size during the transformation, but this was unnecessary as no resampling was needed for the CORINE raster. At this the dataset was ready to be used for the Wind Resource Mapping System

4.3.2 Wind Resource Mapping System

The average wind speed data for Cornwall came in raster format with a spatial resolution of 1000m x 1000m and was projected in the British National Grid co-ordinate system. There was no need to change this co-ordinate system as it was the decided co-ordinate system for all raster data in stage 2. There was however, a need to resample the spatial resolution to a lower resolution; but before this could be done there was a priority to delete unwanted data from the raster layer.

Figure 25 shows a screenshot of the average wind speed raster layer after it was first loaded into ArcMap. It clearly shows that sea areas around Cornwall, which are of no interest in this study, have an average wind speed of 0. This is incorrect and has merely been used as a substitute for a No-Data status. It was imperative then to remove this inaccurate data, especially as it would have had adverse effects on the next step, resampling. To remove the tiles that had a value of 0 the spatial analyst tool *Set Null* was used, with the input and conditional rasters set to the average wind speed layer and SQL expression as 'Value = 0'.

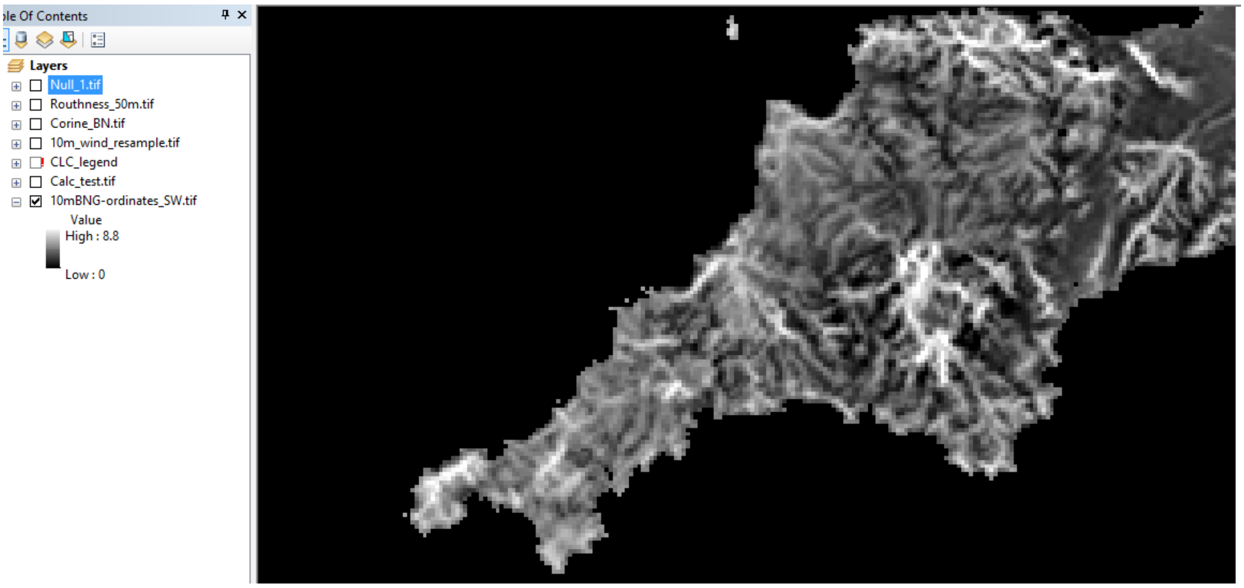


Figure 25 - ScreenShot of starting average wind speed raster

Resampling

There are two major decisions that have to be made when resampling and this remained the case for average wind speed raster. The first is, what will be the new agreed spatial resolution that is being resampled to? And the second is, what resampling technique will be used to carry out the resampling? To begin with we will look at the first question.

Ideally the 1000m x 1000m spatial resolution of the average wind speed layer should not be resampled to a lower resolution and instead any layers with lower resolution in stage 2 should be resampled to this resolution. This is because any time one resamples to a higher resolution the results will imply a much greater accuracy than the data on which they are based, introducing a false accuracy. It was however decided that this was an inevitability and that the average wind speed data could not remain at a resolution of 1000m x 1000m. This was because it is simply too large to be effective; being far too large to represent the area needed for a single turbine and significantly increases the chances that no full grid squares will be remaining after the land exclusion in Stage 1. It was therefore decided to resample to the same resolution as the CORINE land cover raster file, 100m x 100m, in order to counter the aforementioned worries.

The next key decision was the use of which resampling technique. In the data management *resample* tool, there were 4 choices of technique. A quick review of all 4 techniques can be seen below courtesy of the online ArcGIS website, (although the specific mathematical formulas are not published by ArcGIS):

*"There are four options for the **Resampling Technique** parameter:*

- ***Nearest****—Performs a nearest neighbor assignment and is the fastest of the interpolation methods. It is used primarily for discrete data, such as a land-use classification, since it will not change the values of the cells. The maximum spatial error will be one-half the cell size.*
- ***Majority****—Performs a majority algorithm and determines the new value of the cell based on the most popular values within the filter window. It is mainly used with discrete data just as the nearest neighbor method; Majority tends to give a smoother result than Nearest. The majority resampling method will find corresponding 4 by 4 cells in the input space that are closest to the center of the output cell and use the majority of the 4 by 4 neighbors.*
- ***Bilinear****—Performs a bilinear interpolation and determines the new value of a cell based on a weighted distance average of the four nearest input cell centers. It is useful for continuous data and will cause some smoothing of the data.*
- ***Cubic****—Performs a cubic convolution and determines the new value of a cell based on fitting a smooth curve through the 16 nearest input cell centers. It is appropriate for continuous data, although it may result in the output raster containing values outside the range of the input raster. It is geometrically less distorted than the raster achieved by running the nearest neighbor resampling algorithm. The disadvantage of the Cubic option is that it requires more processing time. In some cases, it can result in output cell values outside the range of input cell values. If this is unacceptable, use Bilinear instead."*

The continuous nature of the average wind speed data rules out the use of both the Nearest and Majority techniques, leaving only Bilinear and Cubic. The main differences between these two are that Cubic takes into account a greater number of nearest input cells (16 versus 4) and may produce values outside of the original datasets range. As neither of these points positively affect the aims of the resampling, and in conjunction to having a longer processing time, the Bilinear technique will be preferred on the resampling of average wind speed data to the resolution of 100m x 100m.

One last thing that had to be done before running the *resample* tool was to ensure that new average wind speed layer would be correctly aligned with the existing CORINE land cover layer. This was done by entering into the tools environments, selecting *processing extent* and then selecting the CORINE layer as the Snap raster option.

Data extrapolation

Once the average wind speed data had been resampled and the CORINE land cover dataset was in the correct projection system it was then possible to extrapolate the average wind speed data to the required hub heights, using the formula seen in section 1.2.3. To do this the spatial analyst tool *raster calculator* was used. It required a map algebra expression to run effectively, the full expression entered to produce the average wind speed at a 70m hub height is seen below:

‘Con("Corine_BN.tif" == 1, "10m_wind_resample.tif" * (Ln(70/1.2)/Ln(10/1.2)), Con(("Corine_BN.tif" >= 23) & ("Corine_BN.tif" <= 25), "10m_wind_resample.tif" * (Ln(70/0.75)/Ln(10/0.75)), Con(("Corine_BN.tif" == 10) | ("Corine_BN.tif" == 29), "10m_wind_resample.tif" * (Ln(70/0.6)/Ln(10/0.6)), Con(("Corine_BN.tif" == 2) | ("Corine_BN.tif" == 3) | ("Corine_BN.tif" == 5) | ("Corine_BN.tif" == 9) | ("Corine_BN.tif" == 11), "10m_wind_resample.tif" * (Ln(70/0.5)/Ln(10/0.5)), Con(("Corine_BN.tif" == 20) | ("Corine_BN.tif" == 21), "10m_wind_resample.tif" * (Ln(70/0.3)/Ln(10/0.3)), Con("Corine_BN.tif" == 16, "10m_wind_resample.tif" * (Ln(70/0.1)/Ln(10/0.1)), Con("Corine_BN.tif" == 4, "10m_wind_resample.tif" * (Ln(70/0.07)/Ln(10/0.07)), Con(("Corine_BN.tif" == 14) | ("Corine_BN.tif" == 37) | ("Corine_BN.tif" == 35) | ("Corine_BN.tif" == 12), "10m_wind_resample.tif" * (Ln(70/0.05)/Ln(10/0.05)), Con(("Corine_BN.tif" == 18) | ("Corine_BN.tif" == 26) | ("Corine_BN.tif" == 27), "10m_wind_resample.tif" * (Ln(70/0.03)/Ln(10/0.03)), Con(("Corine_BN.tif" == 6) | ("Corine_BN.tif" == 7) | ("Corine_BN.tif" == 8) | ("Corine_BN.tif" == 32) | ("Corine_BN.tif" == 31), "10m_wind_resample.tif" * (Ln(70/0.005)/Ln(10/0.005)), Con(("Corine_BN.tif" == 36) | ("Corine_BN.tif" == 39), "10m_wind_resample.tif" * (Ln(70/0.001)/Ln(10/0.001)), "10m_wind_resample.tif" * (Ln(70/0.0001)/Ln(10/0.0001))))))))))))’

It was run multiple times to extrapolate to the following hub heights: 50m ,70m 117m.

Converting from raster to polygon

Having the average wind speed data for the 3 chosen wind turbines, the next step was to use this data to calculate the potential energy output for each 100m x 100m grid cell in Cornwall. The first step in this process was to convert the average wind speed layers into vector shapefiles, this allows for easier attribute manipulation.

This was completed in a four-step process. The first was to create a fishnet that was the exact same size and in the exact same position as the raster layers. This was done with the *create fishnet* data management tool seen in figure 26, with the important requirements being the boundary box set to average wind speed raster, cell sell size equalling 100m x 100m and the snap raster, found in the environments tab, set to the average wind speed layer again. The resulting polygon layer occupied the same spatial location as the wind speed raster layer.

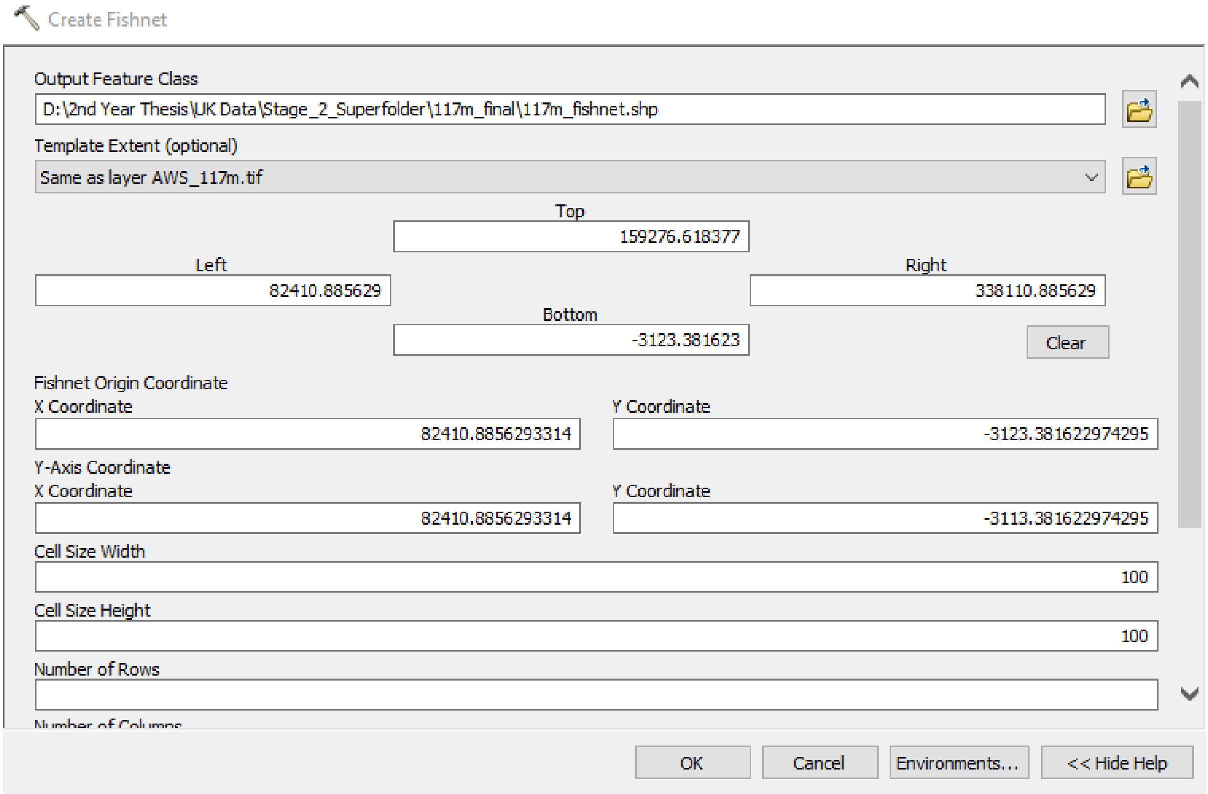


Figure 26 - Fishnet tool used for WRMS stage 2

The second part, was to extract the value data from the raster, i.e. the yearly average wind speed. This was done with the conversion tool *raster to point*. The tool creates a vector layer by generating a point in the exact centre of a cell of a chosen raster layer, these points also store in their attribute table any value the corresponding raster cell had, which in this case was the average wind speed.

With a polygon layer mimicking the shape and location of the average wind speed raster and a point layer storing the value of each raster grid cell, the last step in the raster to vector conversion was to transfer the value of the points to the polygons cells. This was done using a spatial join, available by right-clicking on a layer in the table of contents. The key part in the use of this tool was to select the 'join data from another layer based on spatial location'.

With the average wind speed data in polygon shapefiles, they could then be loaded into a Database Management System (DBMS), which in this case was a PostgreSQL DBMS with a PostGIS extension. The purpose of this was because from here, the average wind speed data could be manifested into potential energy output in a simpler manner.

Wind distribution and calculated energy output

To calculate the potential annual energy output of each of the three chosen wind turbines, a three-step process need to be completed.

The first was to round the average wind speed data to the nearest 0.5. This was necessary as to match the each of the wind turbines power curve parameters found at the https://en.wind-turbine-models.com/ website. To do this it required two SQL queries for each of the 3 new tables. They can be seen in figure 27, the first adding an addition column and the second calculating rounded figures from the existing average wind speed data.

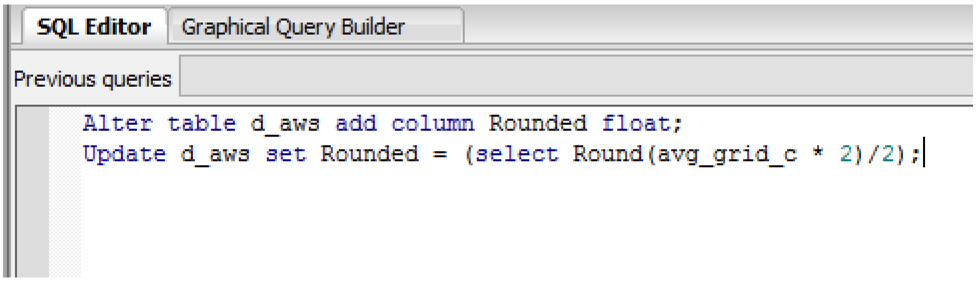


Figure 27 - SQL rounding average wind speeds

The next step was to try and find a way to incorporate the modified average wind speed Weibull distribution discussed in section 2.3.4. To start, each wind turbine needed additional columns of which wind speeds it could feasibly produce energy at, these wind speeds would therefore be whole digit m/s that fell between the turbines cut in speed and its cut off speed. For example, with the Vestas V-126, whose cut in speed is 3 m/s and whose cut out speed is 22.5 m/s, it need 20 additional columns (3m/s, 4m/s …. 22m/s) to account for all the potential wind speeds that it could produce energy. With these columns in place, it would then be possible to apply the Weibull distribution formula, seen in section 2.3.4, to each of the possible wind speeds for which a column had been created, this in turn would create a value that would be each specific wind speeds proportion of average yearly wind speed.

An example of the SQL Queries that were used to carry out this step is seen below (figure 28):

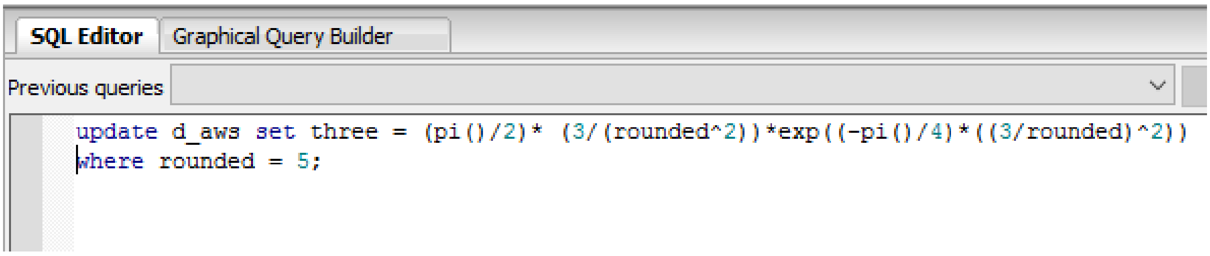


Figure 28 - Example SQL query to estimate proportion of time for each m/s wind speed

At this stage, it should be made clear that the wind speeds that are below the cut in speed (1m/s & 2m/s) and wind speeds above the cut off speed (+ 23m/s) are not excluded from the distribution equation but merely not recorded as they cannot result in energy production. Therefore, if we were to add all the proportion values recorded in the data columns of the table for a specific record it would not equate to a value of 1. It would be possible from here to establish what proportion of time the wind speed fell in between the cut-in cut-off speeds, but this value is not of specific interest for this study.

The last step entailed calculating the annual energy output for all the different possible wind speeds and then adding them together to calculate the final potential energy of a wind turbine in that 100m x 100m grid. The SQL query below (Figure 29), gives an example of how this was done for the wind speed of 14m/s column of the Vestas V126 table.

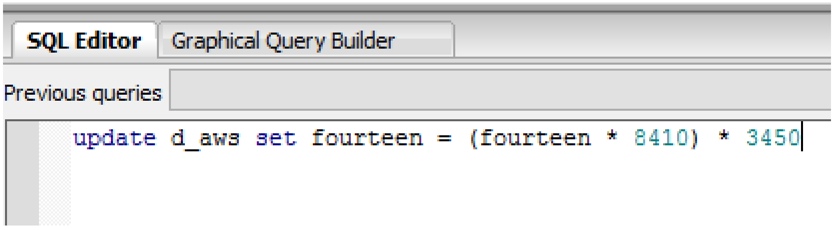


Figure 29 - Example SQL query to produce estimated energy output per m/s wind speed

There are two key values in this query that are important. The first is the value '8410', this is the calculated number of hours that a wind turbine is estimated to function per year. By multiplying this figure to the proportion value already calculated it results in the estimated number of hours a potential wind turbine would be subjugated to that specific wind turbines per year. The second important value is '3450'. This is the number of kW that would be produced by the Vestas V126 at a wind speed of 14m/s. Clearly this value changes with each wind speed and can be obtained by consulting the Vesta's power curve data. The '8410' value is however fixed for all wind speeds.

The final query that was need to complete this section was to create a column to store the total annual MWh output for each grid cell and then to populate that column by adding all the MWh calculated for all the specific wind speeds together (figure 30). Once this was done for all three tables (i.e. all three specified wind turbines) the result was that each square 100m x100m cell of Cornwall had a predicted annual energy output figure for three differently sized wind turbines. These three tables were then exported back into ArcMap as shapefiles using the DBF loader.

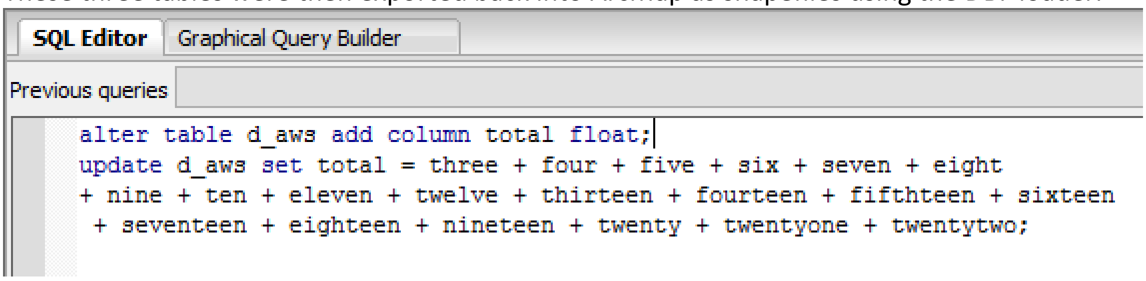


Figure 30 - SQL query to calculate total predicted energy output

Incorporating land exclusion shapefiles into stage 2 analysis

With the three shapefiles visualising the annual energy output of each wind turbine now in arc map, the last part of stage 2 was to disqualify areas within these shapefiles that were calculated to be inappropriate for wind energy development in stage 1. To remove these areas 7 layers needed to be added to a new map book: The Vestas, Nordex and Enercon annual MWh output layers from stage 2, the 3 layers excluding Cornish land from the wind assessment (for Band B, Band C and Band D wind turbines) from stage 1 and lastly the Cornish rivers dataset also to be used for land exclusion.

The tool used to remove the unsuitable 100m x 100m grid cells from the stage 2 polygon layer was the geoprocessing tool *symmetrical difference*. This tool takes features or portions of features from two input layers and creates a new layer comprised of features that do not overlap between the two input layers. For each turbine, both the annual energy output layer and matching exclusion layer from stage 1 needed to be used in the *symmetrical difference* analysis.

The next step in isolating only the suitable 100m x 100m cells for each turbine, was to exclude any cells that intersected with any of the Cornish rivers. The river data was not incorporated into the overall polygon layers in stage one as it was in a polyline shapefile. This was done using the *select by location* tool. using the new layers created by the symmetrical difference as the target layer and rivers dataset as the source layer. Once the grid cells intersecting the rivers had been selected they were then deleted in an editing session.

To complete stage two of the wind energy assessment, a few more of the grid cells had to be removed from contention. When using the Symmetrical difference tool many of the grid cells had been reshaped and lessened in area size. This was because the tool didn't clip out a whole polygon if it intersected with the other layer but only removed the section of the polygon that was in contact with the other layer. This resulted in many grid cells remaining despite the fact they had now become to smaller areas in which to host a wind turbine. To remove these cells an addition field was created in the layer's attribute table (setting the data type to numeric), then, by right clicking on the new field, the calculate geometry function was triggered to produce the m^2 area of each cell. After the cells were populated with their geometry, a SQL query was run in the *select by attribute* tool. It only selected the cells that had 75% or above of their original area size left. These selected cell polygons where then exported into their own shapefile.

4.3.3 Calculating Spatial cost

There were three spatial costs that needed to be calculated for each 100m x 100m grid cell. These were: Land clearance costs, Access roads costs and Grid connectivity costs. To calculate these, a new map book was needed in ArcMap along with the three final datasets calculated in sections 4.3.2. To recap, these were the datasets showing the predicted annual energy output on suitable land for Enercon e-48, Nordex N-90 and Vestas V-126 wind turbines.

The first step of the cost analysis was to convert these polygon datasets into point data, this was because it would prove to be easier to extract values from raster datasets to points rather than to polygons. It was done using the *feature to point* tool, making sure to centre the point in the middle of the polygons.

The next step of the cost analysis was to calculate the distances the points were now away from the amenities a potential wind turbine would need to connect to. The first one of these amenities was road access, the same road shapefile used in stage 1 was added to map book and then *Euclidean Distance* tool (figure 31) was used to produce a raster that's value was the direct distance from the cells to the nearest polyline/road. The *Euclidean Distance* tool was used again to calculate distances away from the Cornish electrical grid. The only difference this time being that the tool was run twice, once to find the distances away from the electrical substations and the other to find the distances away from the electrical lines themselves, be it overhead lines or underground cables. The last spatial cost, land clearance, did not require distance calculations.

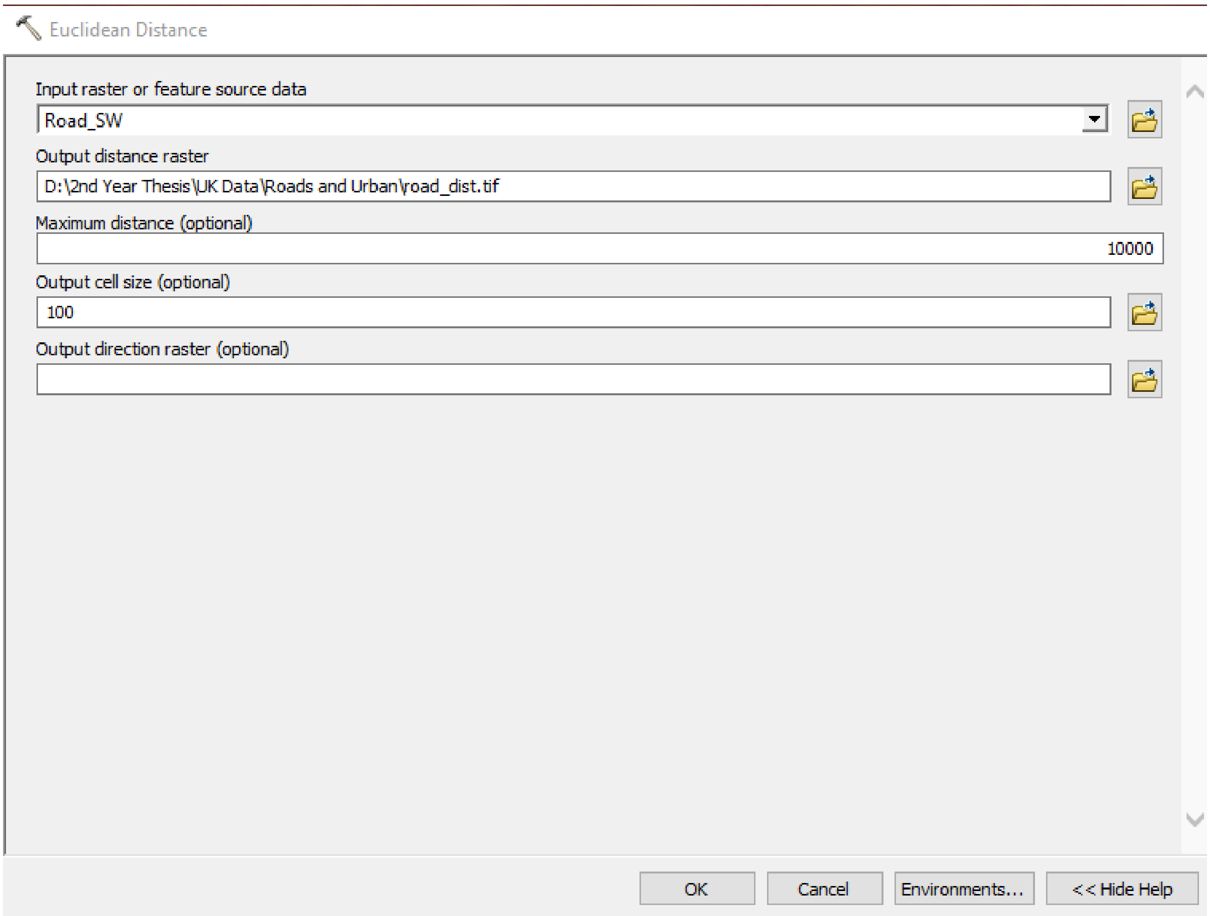


Figure 31 - Euclidean distance tool used in the cost analysis of Stage 2

At this stage, there were four raster datasets that had values that needed to be attributed to point datasets marking the available land for each wind turbine, one holding distance data from roads, two holding distance data from the electrical grid and one was the Corine land cover raster. To absorb these raster values into the point data, the spatial analyst tool extract multi values to point was used (figure 32). This tool was run three times to add the data to all three wind turbine point layers. Next, using a spatial join, the attributes from the point data were incorporated back into their 100m x 100m polygon grid cells from where the point data came.

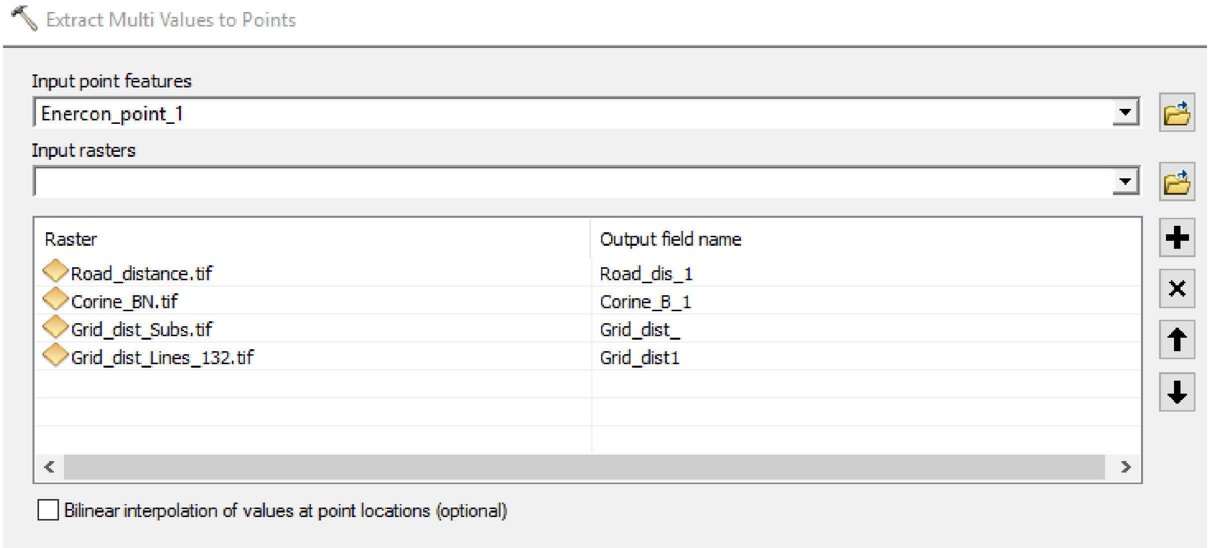


Figure 32 - Extract Multi Value to Point tool used in Cost analysis

Once the geometry calculation had been completed in ArcMap, the three final shapefiles were then transferred in the PostgreSQL DBMS where the associated costs of the spatial components could be applied to the geometry. The following description on how that was done will be exemplified by using the Vestas V-126 data/table, however all SQL queries seen, were applied to all three wind turbine tables.

To calculate the estimated cost of building an access road to each of the available 100m x 100m parcels of available land the first step was to add an additional column to the Vestas table. Then the SQL in figure 33 was run to populate the column with the complete cost of any potential access road.

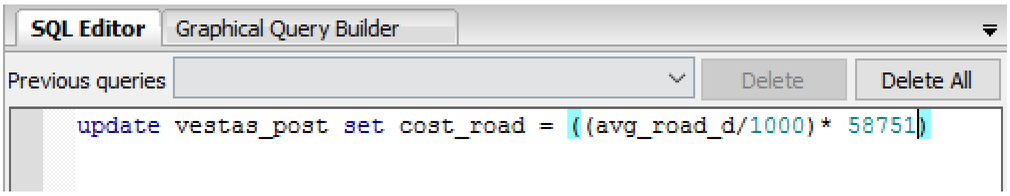


Figure 33 - SQL query to calculate access road costs

In this query, the '*avg_road_d*' is the distance calculated in ArcMap. It is divided by 1000 to convert the units from metres to km and then multiplied by the average cost of an access road per km, £58751.

For grid connection, an additional two columns were added to Vestas table. They were then populated using the queries seen in figures 34 and 35, with one giving the estimated cost of connecting to the electrical grid via an existing substation and the other giving the estimated cost of connecting to the electrical grid via a new substation on the existing grid network.

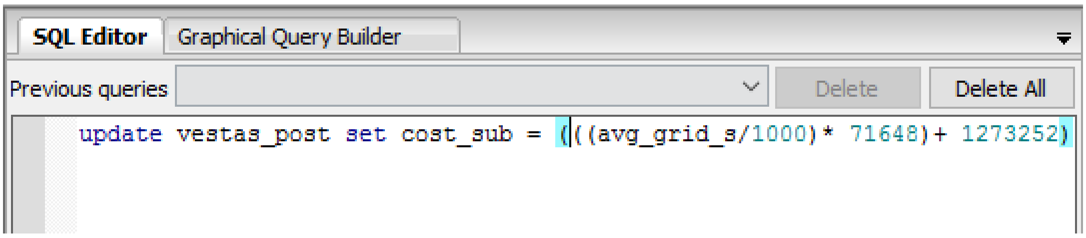


Figure 35 - SQL query to calculate the cost of connecting to an existing electrical substation

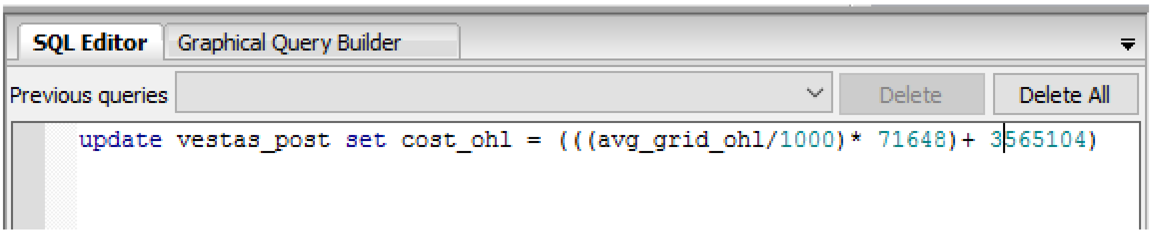


Figure 34 - SQL query to calculate the cost of connecting to a newly built electrical substation

For both calculations, the distance geometries are multiplied by the cost of the average connecting electrical cables per km, £71648. The difference between the two queries lie in the fixed costs associated with the required substation. Wanting to connect to an existing substation would mean having to upgrade said station at an estimated average cost of £1,273,252. Whereas building a new substation on the electrical grid would result in a higher up front cost of £3,565,104.

One additional column was made for the Vestas table to store the cost of which ever means of connecting to the grid was cheapest. Figure 36 shows that query.

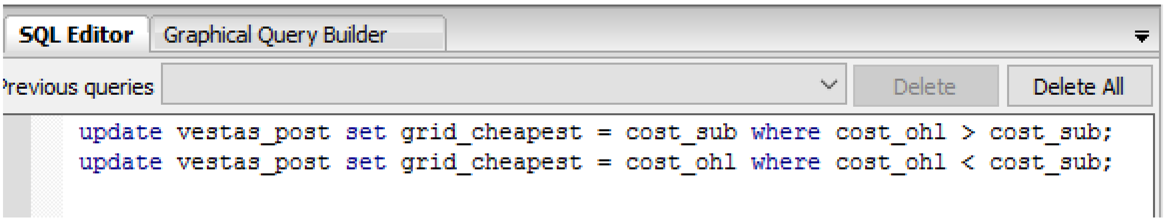


Figure 36 - SQL query to selected the cheapest means of grid connection

One last column was made to the vestas table to give an estimate to the land clearance cost of each 100m x 100m grid cell. Variations the SQL query in figure 37 were run multiple times to ensure that all land types were given their appropriate land clearance cost, set out in figure 14.

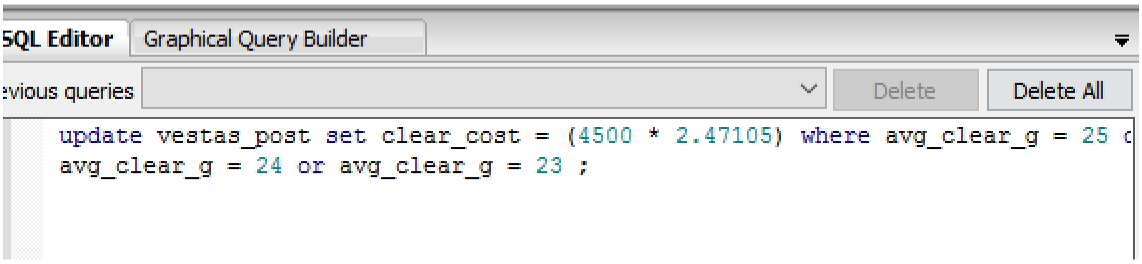


Figure 37 - Example SQL query of calculating land clearance costs

'avg_clear_g' values were the original id numbers of the Corine land cover raster, they are unique to each land type and a good means of identifying them (figure 37). The clearance costs were multiplied by 2.47105 as a mean of converting the cost from per acre to per hectare. Once these SQL queries had been completed on the Nordex and Enercon tables, all three tables were ready for stage 4.

4.4 Stage 3 – Visibility analysis

Stage 3 of the Cornish wind energy assessment was designed to map where a potential wind turbine would be visible from, this information is very import to developers as the visual impacts of wind turbines can prove to be a big obstacle in approving potential sites. Unfortunately, the technical resources available for the assessment made doing a visibility analysis for every available 100m x 100m parcel of land impossible. It was therefore decided to carry out a visibility analysis for only the most promising of sites, 5 potential sites for each differently sized turbine, 15 sites in total.

Choosing these sites became the first part of the analysis. Site selections were based around 3 primary requirements, the first being the most obvious, was a high average estimated annual energy output. The other two were that the sites would be larger than 50 hectares and at the same time relatively uniform in shape. The selection ultimately was however at the author's discretion. The methodology following, will focus solely on how sites from the Vestas V-126 GIS layer were incorporated into the visibility analysis, however the same methodology was used for both the Nordex and Enercon layers.

Once the sites were identified from the Vestas polygon grid shapefile created at the end of stage two, the 100m x 100m grid cells making up the site were exported into their own shapefile. At this point, statistics were taken from each site (using the statistics tool opened by right clicking on the attribute table), including average estimated yearly energy output, average estimated yearly wind speed and total area size. Once recorded, all the polygons responsible for making up a site were merged together in an editing session, leaving just a polygon per site marking the overall area.

Switching back to the Vestas polygon grid shapefile, centre 100m x 100m grid cells from each of the five sites were selected and then the *feature to point* tool was run on those five squares. This left 5 points in their own layer at the centre of each site, those central squares that were selected were then also exported into the own shapefile. At this point, each identified Vestas V-126 site should have a polygon layer covering its entire area, a polygon layer of the sites most central grid cell and a point layer at the centre of site.

The point layer is necessary to finally run the visibility analysis. The spatial analyst tool *visibility* performs this analysis by taking the points or 'observers' and calculating where they are visible from. It requires two input layers, the first being the observer layer i.e. the point of interests, which in our case was a potential wind turbine and the second being a Digital Elevation Model, to act a geography on which the tool can work. For this analysis, the same DEM was used as the one used in stage one of this assessment to calculate slope gradients, the EEA's EU-DEM. Apart from input datasets the other important variables to control in the tool were to select *'Use NoData for non-visible cells'* and

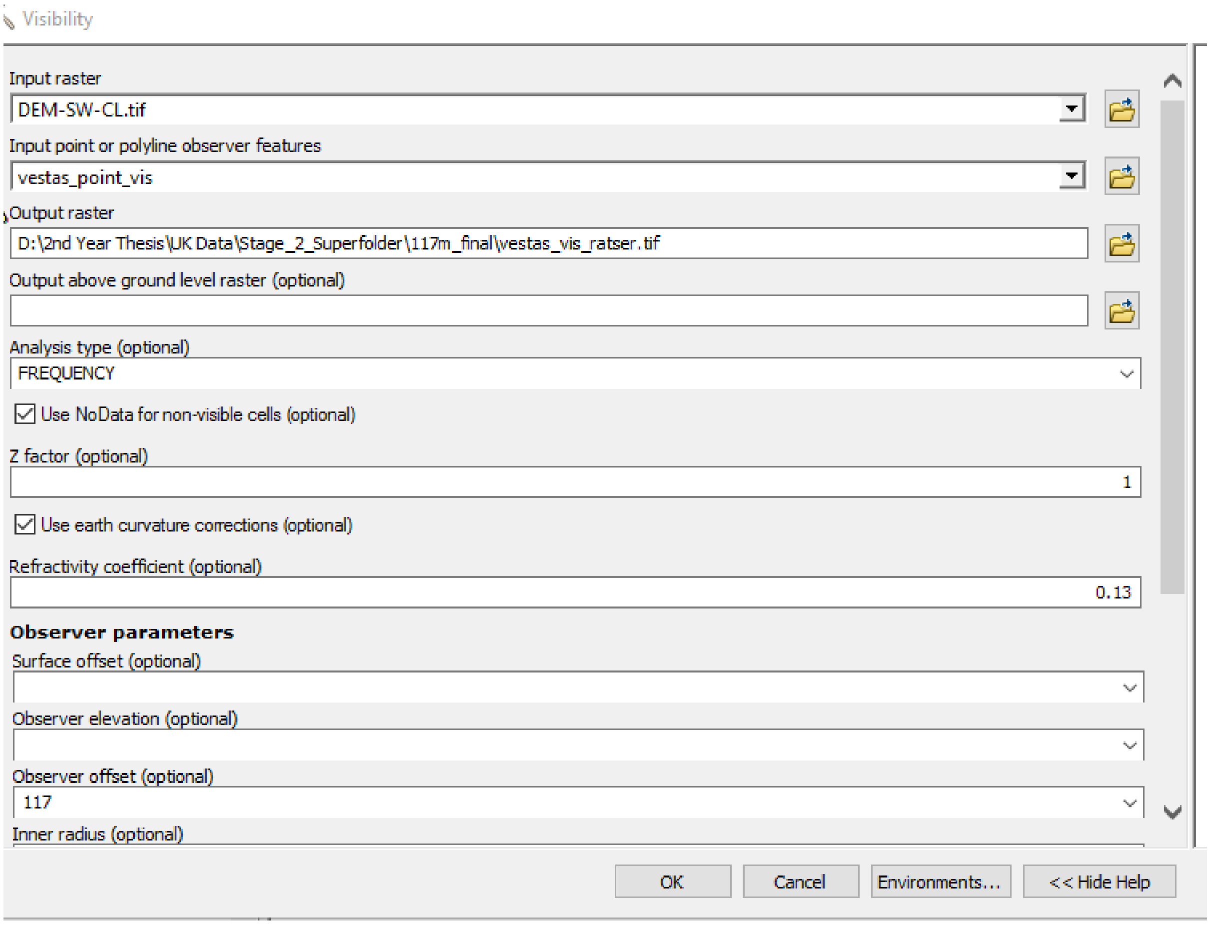


Figure 38 - Visibility tool used in stage 3

'*Use earth curvature corrections*' and then to specify an Observer offset of 117m (figure 38). 117m being the hub height of the Vestas V-126.

Once this tool has been run, the output is raster image showing what parts of Cornwall the Vestas turbine is visible from. The raster is then converted into a multi-polygon shapefile using the *raster to polygon* tool.

Finally, all three polygon layers (the layer showing visibility, the layer showing the site its self and the layer showing the central grid cell) are merged together into one single shapefile, using the geoprocessing tool *merge* and then split again into 5 shapefiles one for each site. Leaving each site with a polygon displaying its area, a polygon displaying its origin of the visibility analysis and a polygon displaying from what parts of the county it can be viewed from. 15 shapefiles in total were then ready to be incorporated into stage 4 of the assessment.

4.5 Stage 4 – Web application design

Stage 4 of the Cornwall wind energy assessment focuses on the development of a web application, its main aim, being to visualise the outputs of stages 1-3 to any interested parties via the world-wide web. This part of the methodology/implementation phase will lay out how the web application was created and also what tools of the information technology world were used in that process.

4.5.1 Infrastructure Overview

The infrastructure of the web application installed onto an external server has been visualised below in figure 39. It can offer itself as a visual guide to the following section of implementation.

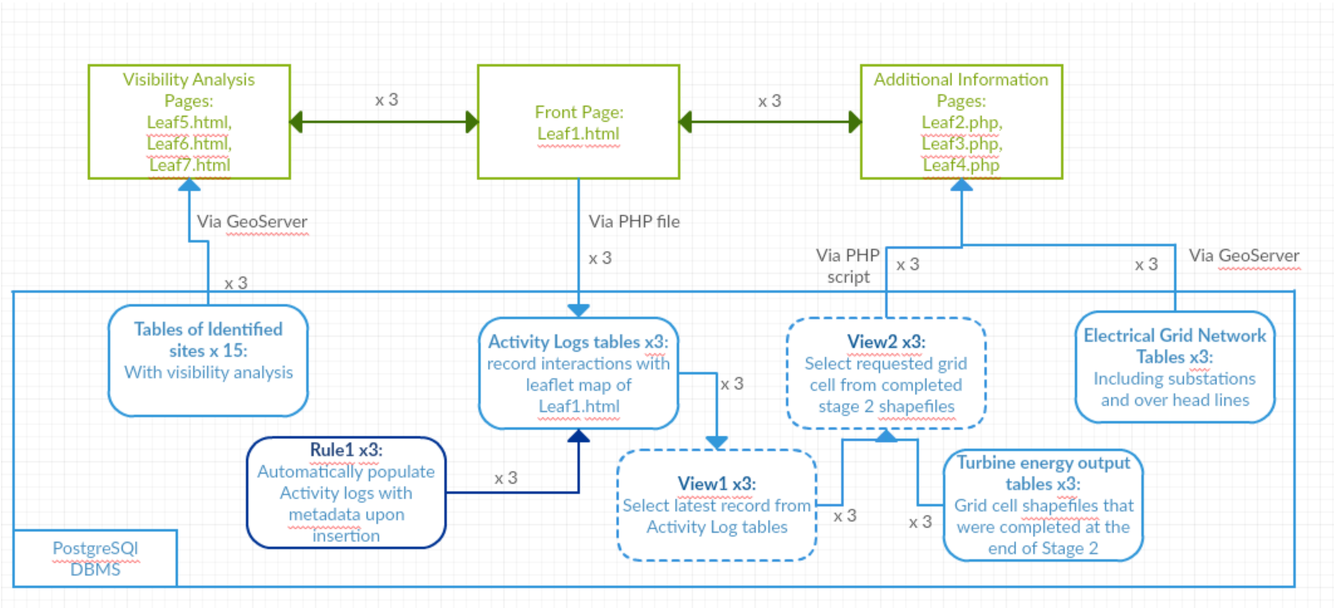


Figure 39 - Flow diagram of infrastructure of the web application

4.5.2 Server and software

The web application was developed on an Amazon EC2 instance. This instance is a virtual server in Amazon's Elastic Compute Cloud (EC2), which in turn is a platform to access all of Amazon's web services. There were an array of different instances available to help with web application development, but the one used in this assessment was a t2 Medium instance with Windows OS.

Once the remote desktop file was downloaded and the corresponding security key safely stored, the next step was to download Bitnami's WAPP development environment. This environment consisted of, among other things: PHP, PostgreSQL and Apache, all of which were fully-integrated. To see a full list of used software that was installed on the server and what they were used for, see Figure 40.

Installed Software	Source	Use
Apache	(Part of WAPP Package) https://bitnami.com/stack/wapp/installer	Web server software
PostgreSQL	(Part of WAPP Package) https://bitnami.com/stack/wapp/installer	Database management system
PHP	(Part of WAPP Package) https://bitnami.com/stack/wapp/installer	Hypertext Pre-processor

PGAdmin III	https://www.pgadmin.org/download/	Desktop software used to interface with PostgreSQL databases
Notepad ++	https://notepad-plus-plus.org/download/v7.4.1.html	Code editor
QGIS desktop	http://www.qgis.org/en/site/forusers/download.html	Primarily used for data type conversion
Geoserver	http://geoserver.org/download/	Server for sharing geospatial data

Figure 40 - List of Installed software used for web development

4.5.3 Front page of the web application

'Leaf1.html' is the html script for the opening page of the web application (it can be found in Appendix 1). This web page has two aims, one, to visualise the available space for wind development in Cornwall and two, to show the estimated MWh outage potential of that available land. This information is stored within the final 3 GeoJson files created at the end of stage 3. This page will not attempt to convey any of the spatial costs nor the visibility analysis.

The open source JavaScript library that was used to create maps on the web application was Leaflet 1.0.3. Leaflet is a small basic JavaScript library weighing just about 38 KB of JS. The library holds core basic scrips to help produce maps, but there is also a wide array of additional plugins available to customise and ensure interactivity.

Leaflet Basics

The first step was to produce the map itself, which was to be the focal point of the opening. The JavaScript code used to do this is seen in figure 41. The CSS styling, DIV creation and JavaScript library referencing of the leaflet map, can all be viewed in Appendix 1.

```
// initialise the map
var map = L.map('map', {
 center: [50.54, -4.86],
 zoom: 12,
 layers: [OpenR]
});
```

Figure 41 - Initialisation of Leaflet map - Leaf1.html script

The '*centre*' and '*zoom*' variables are used to give the map a focal point when it is first initialised. For this assessment, the variables were used to focus in on Cornwall county specifically. The other variable, '*layers*', is refence to the map's base layer. Figure 42 shows how that base layer was created.

```
// loading a base map tile layer
var OpenR = L.tileLayer('http://korona.geog.uni-heidelberg.de/tiles/roads/x={x}&y={y}&z={z}', {
  maxZoom: 20,
  minZoom: 10,
  attribution: 'Imagery from <a href="http://giscience.uni-hd.de/">GIScience Research Group @ U
  });
```

Figure 42 - Base map creation - Leaf1.html script

The base layer for this assessment was taken from an online source at Heidelberg University. The max and min Zoom attributes were used to restrict the user in their ability to view the map at too close and too far resolutions. The limits however do not conflict with the intended use of the web application.

Other basic functions that were added to the Leaflet map include a scale bar and layer control manager. The script used to add these to the map is seen below in figure 43.

```
// Adding OpenR to baseMaps variable
var baseMaps = {
 "BaseMap": OpenR
 };

// Creating layer control manager
 L.control.layers(baseMaps, overlayMaps).addTo(map);
// Creating a scale bar
 L.control.scale().addTo(map);
```

Figure 43 - Scale bar and layer control manager creation - Leaf1.html script

The layer control manger splits the layers' present on the map into two categories; base maps and overlays. The variable for overlays is currently useless as there are none present, but it is a variable that will be used later when then geographic data created in Stage 1 and 2 is added to the map.

Custom Information Control

An addition control was added to the map, with the purpose of displaying information unique to each feature in an overlay. Once the GeoJsons from the end of Stage 2 are added to the maps, these features will be the individual grid cells and the unique information will be the average wind speed and potential energy output of each grid cell. The script to add this custom control to the map is seen in figure 44. The styling of said control can be seen in the full 'Leaf1.html' (Appendix 1).

```
// creating custom control
 var info = L.control();

  info.onAdd = function (map) {
     this._div = L.DomUtil.create('div', 'info'); // create a div with a class "info"
     this.update();
     return this._div;
 };

 // method that we will use to update the control based on feature properties passed on from GeoJSON
 info.update = function (props) {
    this._div.innerHTML = '<h4>Click on a square for addition Information</h4>' +  (props ?
     '<b>' + props.TOTAL_MWH + '</b>' + ' Estimated annual MWh outage' + '<br />' + '<b>'
     + props.AVG_GRID_C + '</b>' +' Average wind speed (m/s)'
     : 'Hover over a square');
 };
 info.addTo(map);
```

Figure 44 - Custom information control creation - Leaf1.html script

The key parts of the script that links the GeoJson files to the custom control are 'props.TOTAL_MWH' and 'props.AVG_GRID_C', as both TOTAL_MWH and AVG_GRID_C are field headers in the GeoJson files (for predicted annual MWh outage and average wind speed respectively).

Styling of GeoJson data

Each wind turbine had a different estimated energy output and a different calculated average wind speed for the same 100m x 100m grid cell. This meant that the styling of the GeoJson data had to be unique to each of the 3 GeoJsons. Figure 45 shows the styling attributed to Enercon E-48 800kW overlay.

```
// Colour styling for Enercon GeoJSON
function getColour(d) {
 return d > 4112 ? '#900C3F' :
        d > 3732.67  ? '#C70039' :
        d > 3284.40  ? '#FF5733' :
        d > 2767.28  ? '#FFC300' :
        d > 2188.60  ? '#EDE238' :
        d > 1575.31  ? '#F1F94B' :
                       '#FFEDA0';
 }
// Overall styling for Enercon GeoJSON
function styleEner(feature) {
 return {
     fillColor: getColour(feature.properties.TOTAL_MWH),
     weight: 1,
     opacity: 1,
     color: 'white',
     dashArray: '3',
     fillOpacity: 0.7
 };
 };
```

Figure 45 - Styling for the Enercon E-48 800kW overlay – Leaf1.html script

The first function is setting a colour scheme based on numeric limits. These limits were determined from when the GeoJson was present in the ArcMap software and displayed in 6 classification. The colour classification function is then recalled in a second function and is used to determine the fill colour of a grid cell. In this second function, all over styling characterises are determined, including opacity, perimeter colour, perimeter weight and dash array. Similar styling attributes were then given to the other two GeoJson.

Feature interaction

Feature interaction was an important part of the websites interactivity. Three manners of 'action' or interaction were identified to be important for each overlay's features. These were: mouse hover over feature, mouse hover off feature and clicking on feature. Each of these required a specific defined function to be embedded into the script. Figure 46 shows the functions defined to control hovering over and off a specific feature on the Enercon overlay.

```
 // styling for when a feature has a mouse hovering over it
function highlightFeature(e) {
 var layer = e.target;

 layer.setStyle({
     weight: 4,
     color: '#666',
     dashArray: '',
     fillOpacity: 0.7
 });

 if (!L.Browser.ie && !L.Browser.opera && !L.Browser.edge) {
     layer.bringToFront();
   }
  info.update(layer.feature.properties)
 };
 // styling for when mouse moves off a feature
 function resetHighlight(e) {
 Enercon.resetStyle(e.target);
 info.update();
 };
```

Figure 46 - Hovering on/off a feature - Leaf1.html script

The function *'highlightFeature()'* is triggered when a mouse hovers over any of the feature in an overlay. It changes the style of that feature to make it obvious that that feature is highlighted. It also updates the custom control layer '*info*' so that that features metadata can be displayed in the custom control. When the mouse leaves that feature, that features should return back to its original style and the information sent to '*info*' should be removed. This is exactly what the second function, '*resetHighlight()*',in figure 46 does, it resets the feature back to default.

The last action for feature interaction is clicking, the function 'submitting()' in figure 47 is what happens when this action is triggered.

```
// transfering co-ordinates to hidden form and triggering the submission of two hidden forms
function submitting(e) {
        var lat = e.latlng.lat
        var lon = e.latlng.lng
        document.getElementById('latitude').value = lat;
        document.getElementById('longitude').value = lon;
        $('#enercon_php').submit();
        $('#enercon_leaf2').submit();
       }

// creating a single function to hold all three feature triggering fuctions
function onEachFeature(feature, layer) {
layer.on({
    mouseover: highlightFeature,
    mouseout: resetHighlight,
    click: submitting
})};
```

Figure 47 - Clicking on feature - Leaf1.html script

The first four lines of code in the function are responsible for taking the geographic co-ordinates of the location clicked upon and then adding them in to two labels ('*latitude*' and '*longitude*') of a form called '*enercon_php*'. The last two lines of code are then responsible for triggering the two forms seen in figure 48, one of which is '*enercon_php*' and the other is '*enercon_leaf2'*. Triggering '*enercon_php*' results in the posting of php script designed to insert the gathered co-ordinates into a PostgreSQL DBMS and triggering '*enercon_leaf2'* results in a change of web page (Leaf2.html). Both scripts will be looked at in further detail later on in this stage. The forms mentioned can be seen in figure 48. The line of script also in figure 48 has also been included as it is responsible for making the forms invisible when the html file is read by the browser.

```
<div id="enercon_div">
      <form action="database_con.php" id="enercon_php" method="POST">
          <label>Latitude : <input type="text" name="latitude" id="latitude"  /></label>
          <label>Longitude : <input type="text" name="longitude" id="longitude"  /></label>
          <input type="submit" :>
      </form>
      <form action="Leaf2.html" id="enercon_leaf2" method="POST">
          <input type="submit" :>
      </form>
  </div>

<div id="map"></div>

<script>
// makes the div "div1" unseen on the web page
document.getElementById("enercon_div").style.display = "none";
```

Figure 48 - Enercon div creation - Leaf1.html script

Like the styling, all functions and forms responsible for interactivity were used three times, to fit with the three different overlays/wind turbine layers.

Legends

Legends were also needed for all three overlays, the colour categorisation of predicted annual MWh outage needed to be explained to any user of the website. Figure 49 shows how a legend was produced for the Enercon e-48 overlay.

```
    // Creating legend variable
var legend = L.control({position: 'bottomleft'});

legend.onAdd = function (map) {
// Creating div
var div = L.DomUtil.create('div', 'info legend'),
    grades = [0, 1575, 2188, 2767, 3284, 3732, 4112],
    labels = [];

// loop through the density intervals and generate a label with a coloured square for each interval
for (var i = 0; i < grades.length; i++) {
    div.innerHTML +=
        '<i style="background:' + getColour(grades[i] + 1) + '"></i> ' +
        grades[i] + (grades[i + 1] ? '&ndash;' + grades[i + 1] + ' (MWh)' + '<br>' : '+' + ' (MWh)');
}

return div;
};
```

Figure 49 - Creating legend - Leaf1.html script

The first line of the figure is creating the variable that will holds the legend; it also holds the positioning of the legend. The next section is responsible for creating the div for the legend, including the MWh limits for each category and the last section adds the colour scheme created in the get colour function used earlier in the script for styling.

With the legend completed, there was still a need to ensure that it materialised at the correct time. Each legend only need to be present when that respective overlay was on the map. To do this, the code in figure 50 was added to the script, the first section is programmed to make the legend appear when then overlay equals Enercon E-48 800kW and the second section removes that legend when that is not the case.

```
// adding enercon_e48 lengend when the overlay is selected
 map.on('overlayadd', function (eventLayer) {
    if (eventLayer.name === "Enercon E-48 800kW") {
     legend.addTo(map);
     }
     });
 // removing enercon_e48 lengend when the overlay is deselected
map.on('overlayremove', function (ffd) {
    if (ffd.name === "Enercon E-48 800kW") {
     map.removeControl(legend);
    }
    });
```

Figure 50 - Legend layer control - Leaf1.html script

4.4.4 PHP script to input data into the database management system

The PHP scripts called Enercon_connection, Nordex_connection and Vestas_connection are all virtually the same. They are designed to run after a feature has been clicked on the main page' s map i.e. Leaf1.hmtl. Once activated they connect to the database and then run an SQL query. This query inputs the longitude and latitude of the where the mouse was clicked, into the specified table within the DBMS. The full script can be seen in Appendix 2.

4.4.5 PostgreSQL database management system

PgAdmin III was the interface to control The PhpPgAdmin DBMS. Upon creating a new database in PgAdmin III, the first step was to turn on the extension 'PostGIS'. This extension allows for the database to handle geographic data and is a necessity for this web application.

The 3 polygon grid shapefiles created at the end of stage two, that contained all the finished data from stage one and stage two, had to be loaded into the DBMS. To do this the DBF-loader was used, it takes shapefiles are downloads them into table format, automatically creating a geometry column storing the files geometry.

The next step was to create some new tables that will store incoming information inputted in by the applications user on the opening page of the website. The information will be the co-ordinates of the location selected on the opening map, these co-ordinates are then in putted via a php script containing a SQL query. The tables each had 5 columns: Id – a unique identification number, longitude and latitude – to store the co-ordinates, time stamp – to store the time and data of an entry in the log, and a geometry column to store the co-ordinates in uniform format that allows for interaction with other geometries in the database.

When then the SQL query in the php script is triggered only the numeric co-ordinates are added to the table (in columns latitude and longitude). This means the at this point the three other columns are empty and have to be populated correctly in another manner. The ID column can be populated automatically by setting its data type to serial. This ensures a unique id number is generated whenever a new record is opened up in the table. For both the geometry column and the time stamp column a function known as a rule was needed to populate these columns automatically after a data entry. The SQL query used to create that rule is seen in figure 51, the update part of the SQL query is run every time there is an "INSERT INTO" the log table.

```sql
CREATE OR REPLACE RULE r_enercon AS
    ON INSERT TO enercon_al DO  UPDATE enercon_al
    SET geom = st_transform(st_geomfromtext(((('POINT('::text || enercon_al.longitude) || ' '::text)
     || enercon_al.latitude) || ')'::text, 4326), 27700),
     time_stamp = now();
```

Figure 51 - SQL query to create Rule upon insertion into log table

Once the data inputted by the user is into the table and all columns have the accurate associated information, the attention of the database can turn to replying to the user the data associated with the grid cell they clicked on. The first part of this is separating the latest entry into the log table so that it's in its own view. A view being a kind of virtual pseudo-table, that re-manifests itself by running the SQL query used for its creation every time it is called upon. Using a view in this context will always guarantee that the latest entry is in a table of its own. The query used to create the view can be seen figure 52.

```sql
CREATE OR REPLACE VIEW public.enercon_view AS
 SELECT enercon_al.gid,
    enercon_al.latitude,
    enercon_al.longitude,
    enercon_al.geom
   FROM enercon_al
  ORDER BY enercon_al.gid DESC
 LIMIT 1;
```

Figure 52 - SQL query to create view of latest entry in log table

Once the desired point location was in its own view, the next important part of the DBMS was to use this set of co-ordinates to highlight which of the 100m x 100m grid cells the user had intend to select. To do this, another view was created based around the ST_intersect() command, this is a spatial query that requires to geometry columns and returns true if the two geometries are in anyway intersecting each other. Figure 53 shows the SQL query used to create a view that selected the correct grid cell from the downloaded stage 2 shapefile tables. The '*WHERE st_intersects(enercon_view.geom, enercon_post.geom)*;' ensures the grid cell that contained the co-ordinates of the first view would be returned in the second view. From the second view, the necessary data was then ready to be accessed from the 'Leaf2-4.php' scripts.

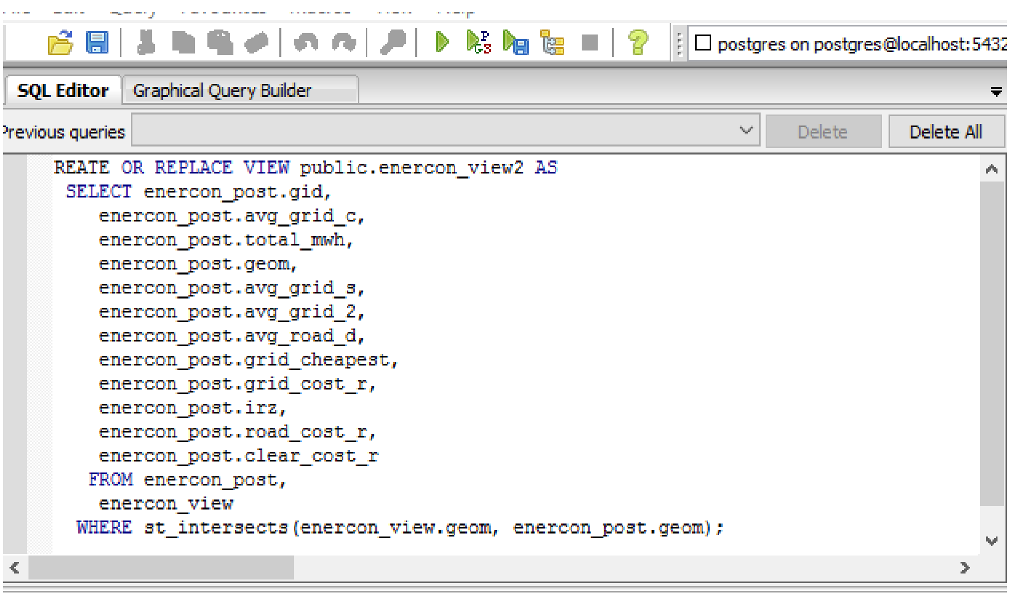


Figure 53 - SQL query to create view of selected grid cell

To complete the data base system on the server, a few more shapefiles had to be loaded into the database. First there were 15 shapefiles from the stage 3 visibility study, 5 sites per example wind turbine. And secondly 2 shapefiles containing electrical grid data that would be shown on the cost analysis webpages as a visual aid. Once they were included into the database the DBMS on the server was complete.

4.4.6 Web page to display additional information, including cost analysis

When the user clicks on a grid cell on the map centring the front page of the web application (leaf1.html), one of the two PHP files triggered is 'Leaf2.php' (presuming a cell is clicked on the Enercon E-48 overlay, if clicked on the Nordex N-90 or Vestas V-126 overlays then all but identical php files are triggered. Leaf3.php and Leaf4.php respectively). In this part of the methodology/ implementation phase the focus on the Leaf2.php file and how it was designed to show the requested additional information.

The general format of the web page is similar to that of the main page with a map taking up a significant portion and then the rest by a div dedicated to allowing written communication. The map on this page is a leaflet map and has the same basics as the one on 'Leaf1.html', including a layer control manager, zoom slider and a scale bar. The full php file can be viewed in appendix 3.

At the start of the file there is a section of php script which has the purpose of connecting to the DBMS and running a SQL query that selects all the data in the 'enercon _view2' view. At this point nothing is done with the data in this view, but the connection has been made and it makes it easier later on the get access to data in the view. Figure 54 shows how the interaction with the DBMS was created.

```
<?php
        $host = "localhost";
        $port = "5432";
        $database = "postgres";
        $user = "postgres";
        $password = "pgadmin";


    $connection = "host=".$host." port=".$port." dbname=".$database." user=".$user." password=".$password;
        //echo $connection;
        $dbh = pg_connect($connection) or die("Connection impossible");
        //echo $dbh;

    $query = "SELECT * FROM enercon_view2";

    $result = pg_query($dbh, $query);


    ?>
```

Figure 54 - Leaf2.php - connecting to DBMS

Next a div was created on the right-hand side of the web page to store information on the selected grid cell. First there was text in the form of headings and sub headings, then more php tags containing php code. In this section of code variables are created that are set to specific value within the view, for example '$val_i' is the variable set equal to 'pg_fetch_result($result,0,1);'. The function 'pg_fetch_result' is the command to get data from a table, which is in this case in the view 'enercon _view2' that is held in the variable $result. The numbers 0 and 1 specify the row and column number of the desired piece of data, with 0 equalling the first row and 1 equalling the second column. The value $val_i is then referred to in the echo of text that is laid out after the variables. This echoed text is fixed with any specific values unique to the grid cell that need to be displayed having to be stored as a variable first. Figure 55 is a section of this div that shows how this works in practice.

```
<div class="fixed">
  <h1>Information on the selected location </h1>
  <h2>Wind Speed and Energy Output</h2>
  <?php
  $val_i = pg_fetch_result($result,0,1);
  $val_j = pg_fetch_result($result,0,2);
  echo "This location has an estimated annual average wind speed of  ", $val_i,
  " m/s at a height of 50m above ground. The Enercon E-48 would produce roughly ", $val_j,
  " MWh worth of energy per year at this location." ;
          ?>
  <h2>Spatial Costs</h2>
  <?php
  $val_a = pg_fetch_result($result,0,4);
  $val_b = pg_fetch_result($result,0,5);
  echo "This location is ", $val_a, " km away from the nearest exsisting substation (132+ kV) and
  ", $val_b, " km away from the exsising electical grid network (132+ kV)." ;
          ?>
```

Figure 55 - leaf2.php - displaying data from DBMS

With the specific values of interest being displayed by text in the side div, the map on the web page takes a more secondary role. Some layers however are added to this map to help the user visuals the figures given. The first overlay of the map is the 'enercon_view2' grid cell itself, the one that was clicked on from the front page will be shown again, to reiterate the location selected by the user. In addition to this layer, electrical grid data was to be added as overlays to map, including both substation data and over-head cable data. Roads and land types are already displayed in the OpenStreetMap base map, but there is no visualisation of the electrical grid on this base map, so that is why electrical grid data was added. Figure 56 shows all the layers that were added to this map.

```
var cell = L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
 layers: 'thesis:enercon_view2',
 transparent: "true",
 format: "image/png"
  }).addTo(map);
 var WPD = L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
 layers: 'thesis:cornwall_total_132kv',
 transparent: "true",
 format: "image/png"
  }).addTo(map);
 var ohl = L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
 layers: 'thesis:ohl_sw',
 transparent: "true",
 format: "image/png"
  }).addTo(map);
 var subs = L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
 layers: 'thesis:cornwall_total_subs',
 transparent: "true",
 format: "image/png"
  }).addTo(map);
```

Figure 56 - leaf2.php - added layers to map

Once additional div was created for this web pages and was located in the bottom right corner of the page. The div contained a form with a button that triggered the return to the main page of the application. The code for this is in figure 57.

```
       <div class="absolute">
<form action="Leaf1.html" id="back" method="POST">
           <input type="submit" value="Click to go back to the front page" :>
       </form>
       </div>

  <div id="map"></div>
```

Figure 57 - leaf2.php - back button

5 – Results section of the Web application

Unfortunately, due to technical difficulties the Web application is not currently on the WWW, instead a screenshot series of the application working on the server's localhost will have to suffice for the results section.

'Leaf1.html' is the front page of the application, on the right-hand side of the page, a div of written information about the assessment sis present along with links to the Visibility analysis. The map on the page has an overlay of the Enercon E-48 energy output layer and details of the of the grid cell the curser is hovered over appear in the custom control at the top-right of the map (figure 58).

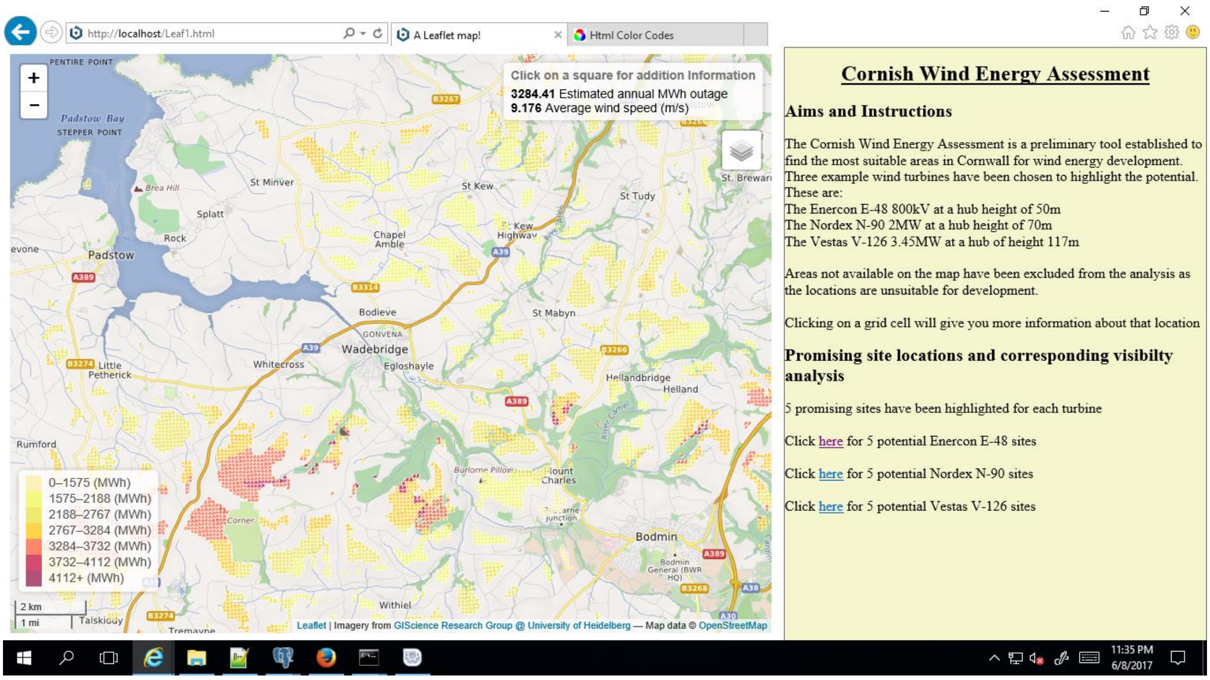


Figure 58 - Screen-Shot of Leaf1.html

Once a grid is clicked on, it appears in 'Leaf2.php' along with all the collected information made available by the assessment, including all the spatial costs and whether it falls within a IRZ. There is a back button in the bottom-right of the page (figure 59).

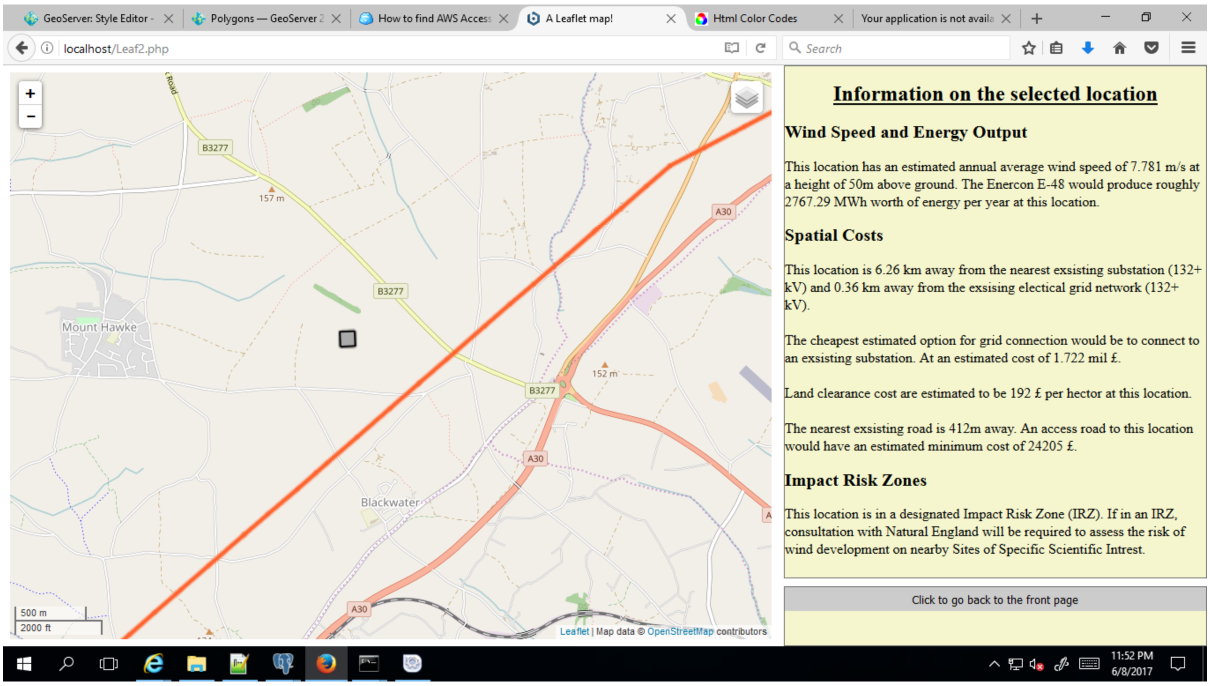


Figure 59 - Screen-Shot of Leaf2.php

Assessing the visibility analysis triggers 'Leaf5.html'. on the right hand-side information about the 5 chosen sites is made available (figure 60). On the map, a site can be selected via the layer control manager and the visibility layer appears.

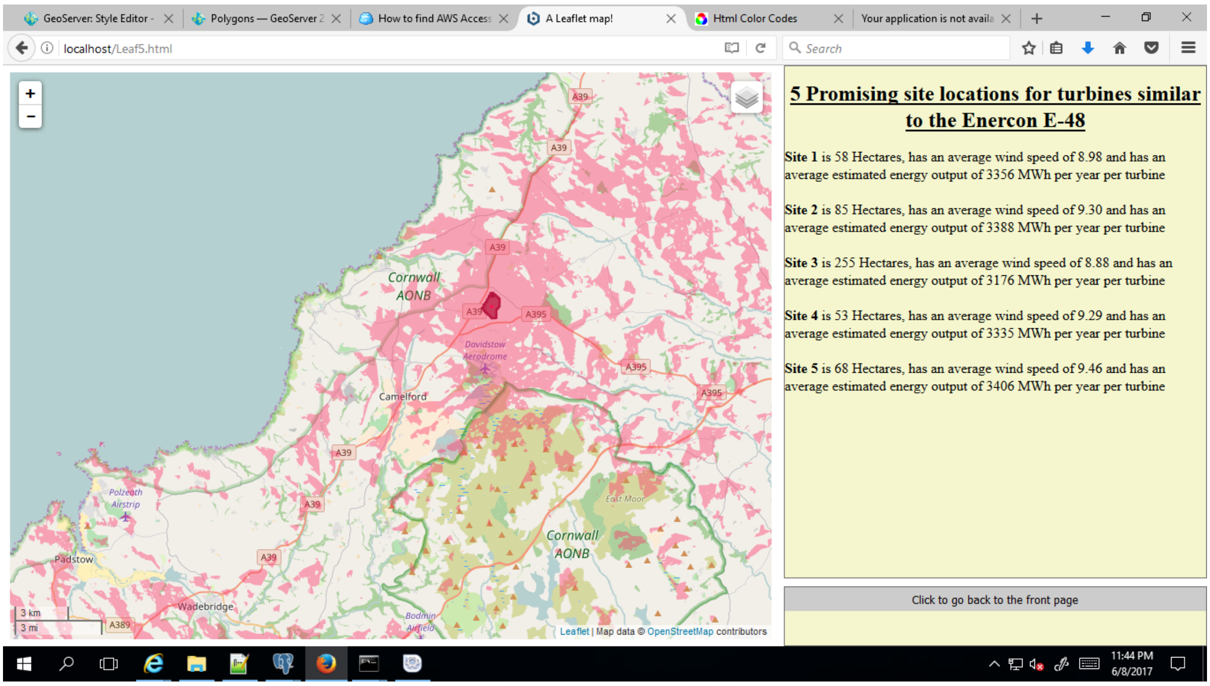


Figure 60 - Screen-Shot of Leaf5.html

6 – Discussion

6.1 Research Question 1 - Has the most accurately available and relevant geodata been incorporated into this wind energy assessment? And if not, why?

Data quality is a key pillar in any GIS assessment as reliable data is indispensable in obtaining meaningful results. This is especially true in assessments which do not include the collecting of raw geodata but rely on other third party sources for collection and maintenance. In these cases, it is essential to assess the sources of the data that will be incorporated into the assessment, as well as the methodology of collection. In additional to the importance of data sources and collection methodologies, it is equally imperative to assess how geodata is manipulated to become practical to a specific assessment. Sometimes data in an assessment can be originally created for an alternate purpose and for that data to be of useful in another assessment it needs to be altered. The techniques used to make data relevant to an assessment need also to be scrutinised as they are often responsible for reducing data reliability. Another important proponent of assessing data quality is making sure to compare the data used in an assessment to other sources of similar data available. It is not always possible to use the highest quality data in every assessment, but it is nonetheless important to identify these sources of data and understand why it cannot be used.

In stage one of this assessment an array of different geographical features had to be mapped to help minimise the effects of wind turbines on the surrounding human population. The sources of these datasets, that contained these geographical features, tended to be governmental or a least in some ways, have governmental connections, albeit not under direct oversight. The Land Character Assessment GIS data was maintained by Cornwall Council, Environmentally Protected Areas were maintained by Natural England and datasets such roads, railways and rivers were preserved by the Ordnance Survey (OS). All of these sources are widely regarded as top tier sources in the UK for geographic data. OS is the UK's mapping agency, it owns and updates the National Geographic Database (which holds 500 million geographic features), using a team 250 field surveyors to collect geodata (Ordnance Survey, 2017). Natural England and Cornwall council may not have direct field surveyors like OS but are still responsible for the GIS data they publish, both publish GIS for non-commercial and commercial use (Natural England, 2017). Overall the data published by these organisations are regarded as highly reliable and with no alternative source offering equal or better reassurances, confidence in the data should be high.

Not all data used in Stage one of the Wind Energy Assessment however came from governmental sources. The geographic data of airports, needed to locate the presence of ATC radars systems, came from OpenStreetMap. OpenStreetMap is Volunteered Geographic Information (VGI), relying on the general public to submit geographic data collected using any device that sustains GPS. Using VGI in an assessment always brings into question the reliability of said data being used, quality assurance that other centralised sources of data can offer may not be present for VGI projects (Haklay, 2010). With this being stated however, OpenStreetMap does have some characteristics that make it a more reputable VGI project than others. First, it has the largest and most complete database of geographic data worldwide and second there has been numerous academic studies into the reliability of its data. The quality of data in OSM is not uniform world-wide, but generally the UK is seen to have some of the highest quality data in comparison to its countries mapping agency (OS) (Girres & Touya, 2010) (Haklay, 2010). Taking airport data from OSM may not have been ideal for this wind energy assessment, but the regard the UK' OSM data has within VGI community coupled with un-contentiousness of airport locations make its use acceptable.

The last two major datasets that have not been discussed yet are Karst landscapes and the Digital Elevation Model. Karst landscapes can disrupt construction projects, which is why the issue is discussed in the Background/Theory of this assessment. However, no data about karst or other dissolution hazards has been included into the land exclusion stage of this assessment. This is not because there is a lack of this data in the UK, but simply that it is seen as a commercial product and one that is not freely available for academic use. This data set is owned by the British Geological Survey and known as the GeoSure dataset (British Geological Survey , 2017). Not having access to this dataset does compromise the quality of stage one of this assessment too an extent.

Another example of not being able to use the best GIS data available to accurately exclude un-suitable land in stage 1 was in using the EEA's EU-wide digital elevation model. The DEM was used in stage 1 to help discard areas of land with excessively steep gradients and in stage 3 to assess visibility parameters for some of the most promising potential sites. Although the EEA's DEM was adequately used for these purposes, it was not the initially intended dataset to be included into the assessment. That would be the Environmental Information Data Centres (EIDC) South-West DEM (Centre for Ecology & Hydrology, 2017). The EIDC is a Data Centre hosted by the Centre for Ecology & Hydrology (CEH) who is responsible for managing nationally-important datasets concerned with the terrestrial and freshwater sciences (Envioronment Infomation Data Centre, 2017). The reason for initially favouring the CEH's south west DEM was that it had a higher spatial resolution, it was 1m x 1m grid compared to the EEA's DEM's 25m x 25m grid spatial resolution. A higher resolution DEM would have enabled a higher level of detail and a more spatially accurate analysis, however as a result of this, using the more detailed DEM put excessive strain on the CPU used to carry out the ArcMap operations on the data set. Unfortunately tools necessary to produce slope gradient and visibility areas were unable to run correctly on the IT systems used in this assessment. Overall having to use the EEA's DEM was a minor drawback in data quality terms, but the dataset was still from a reliable source and had sufficient resolution to produce creditable results. It therefore is not a significant factor in compromising the credibility of stage 1 or stage 3 in this assessment.

The reliability and quality of the raw data to be used in the Wind Resource Mapping System (WRMS) section of this assessment was of vital importance. The WRMS would be the most essential dataset in cementing the overall success of the Cornish wind energy assessment. The raw geodata that was used in the WRMS came from the Department of Energy and Climate Change (DECC). Its geodatabase was created '*some time before 2001*' and gives estimates of annual mean wind speeds (Department of Energy and Climate Change, 2017). Although the governmental body is a reputable source, its user guidance that accompanies the database casts some doubt into the quality of said data. It mentions that '*the data that was used to build up the database dates from the period approximately mid-1970s to mid-1980s*' and that it '*should not be considered to be measured data or to be up to date'* (Department of Energy and Climate Change, 2017). The methodology of creating this geodatabase would also be a factor to assess to determine data reliability but unfortunately the methodology is relatively unknown, with user guidance summarising it uses an '*air flow model'* to estimate wind speed (Department of Energy and Climate Change, 2017). Meaning more trust must be held in the source of the data.

One the purposes of the wind speed database was to offer wind speed data to aid in the decision making of constructing small scale wind turbines across the UK. Although this aim is close to ideal source of data for the Cornish wind energy assessment aim, there are two main aspects of that purpose that are unideal for this assessment. The first being that the data is for small wind turbines. The DECC's modelling of wind speeds only goes to 45m, whereas for this assessment, mean wind speed data had to be at much higher heights. The second is the 'UK wide' part, as this meant that the spatial resolution would not be as detailed as would be required for the county wide WRMS. The additional steps that had to be taken to alter the data to counter these two conflictions would only continue to dilute the quality of data. Despite the shortcomings of DECC mean wind speed's geodatabase, it presented itself as the only suitable non-commercial raw data for the Cornish WRMS.

Most datasets incorporated into the Cornish wind energy assessment have proven to be high quality datasets from reputable source. They have tended to be the best datasets available, requiring as little pre-data manipulation as possible to be of use in this assessment. There have however been a few exceptions to this. The reliance of VGI for datasets marking the location of airports was not ideal, unavailability of the karst dataset was a set back and insufficient processing power to utilise the most accurate DEM was an unseen complication. The biggest exception though was wind speed data used for the WRMS, the questionable reliability of the data and method calculations surpass the reputable nature of the DECC and additional data manipulation to make the WRMS applicable to this assessment further puts into question the reliably of the data. Overall however despite this concern, the datasets incorporated into this assessment from third party sources have generally been excellent and give testament to effectiveness of the Cornish wind energy assessment.

6.2 How to justify the steps taken to create a Cornish Wind Resource Mapping System (WRMS)? and what effect they had on the overall confidence in the WRMS?

As was previously mentioned in Research Question 1, there was considerable amount of data manipulation needed to turn the annual mean wind speeds geodatabase from the DECC into a functioning WRMS that would meet the needs of this Cornish wind energy assessment. This research question will analyse the steps that were taken to complete this process and decide what effect those steps had on the amount of trust that can be placed in the results the WRMS produced.

With the spatial resolution of the original DECC geodata being 1000m x 1000m, the first step that was taken was to resample this data to a smaller spatial resolution (100m x100m). This decision was taken for two primary reasons, one being to keep all rasters used in stage 2 of the wind assessment the same resolution and snapped to each other. The other, was to smooth the data and reduce abruptness between grid cells in an attempt to more closely model the nature of wind speeds. Using the bilinear method of resampling was testament to this second aim. It was the resampling technique that was designed for the smoothing of continuous data and also ensure that it would not produce values outside of the original datasets range. By resampling the average wind speed data to a higher resolution, the resultant data is implying a much greater accuracy than there really is, introducing some false confidence in the data. This is something that should be acknowledged when looking at overall quality of results produced by the WRMS. However, it was deemed a necessary consequence of a needed step in developing a Cornish WRMS.

The next step in creating the Cornish WRMS was to extrapolate the annual average wind speed data to higher altitudes. To be of use for this assessment, the average wind speeds needed to be calculated for 50m and above ground level, this was important as the majority of modern day of commercial grid connecting turbines have a hub height higher than 50m. As this was not done for the original DECC geodatabase, it had to be done as part of this assessment to ensure its relevancy. The formula used to extrapolate the wind speed data has often been chosen while considering heights exceeding 60m above ground and was found in a published paper in a similar wind energy potential assessment. The formula allows for this WRMS to produce the desired average wind speed data and allows for a much more accurate calculations of potential energy outputs from the wind turbines than using wind speed data at ground level. With that being stated however, it is still a rather simplistic formula and pale in comparison to the complex modelling commercial WRMS utilise.

The DECC geodatabase made available to the public only holds the mean average annual wind speeds of the UK, it does not give the data to which that mean was calculated from or give any details into the distribution of wind speeds for each grid cell. These datasets would have been extremely beneficial to the WRMS because the relationship between wind speed and energy output is not a linear relationship. Simply using the average wind speed to calculate energy output would not have accounted for the non-normal distribution of the wind resource. As a result of this, a form of the Weibull distribution formula was applied to all of the average wind speed grid cells, producing a uniformly shaped distribution curve that was then attributed to each average wind speed in a cell. Doing this was also vital for estimating the proportion of time wind speeds were lower than the cut-limit and higher than the cut-off limit of the turbines (and therefore not producing energy); another important factor in giving confidence the results of the Cornish wind energy assessment. Overall, using an academically approved formula for wind distributions undeniably improved the accuracy of the WRMS. The only additional step that could have further improved the results was creating unique distribution models for each individual grid cell, however with a lack of raw data this was impossible.

The last step in creating the WRMS was to round the average wind speeds to the nearest .5m/s. This was not a desired step but one of necessity. By rounding the wind speed datasets, there was a loss of precision in the data and therefore a reduction in quality. It was done due to problems in calculating the potential energy output of the designated wind turbines. The turbines' power curves used in this assessment only had calculated energy output figures for wind speeds at every .5m/s precision. The assessment did not have access to the equation of each power curve, if it had, there would have been no reason to round the wind speed averages to meet the .5 increments of the power curve data.

It is clear at this point that the DECC's annual average wind speed geodatabase was not the ideal data to base the WRMS off of for wind energy assessment. Having to resample the data to a higher resolution, lack of distribution data and it not being at the correct height, all made significant dents in the confidence of results produced by this study. With that being stated, in the authours opinion, the DECC's data was the best freely available source to use for the WMRS. Also, the GIS analysis to manage the geodata into a WRMS for this study had a sound methodology; making use of peer-reviewed academic formula on wind extrapolation and wind distribution and using suitable GIS tools that minimised unnecessary data manipulation. This should count when accessing the overall confidence in the Cornish WRMS.

6.3 Research Question 3 – Do the results of the cost analysis sufficiently help the Cornish wind energy assessments meets its principle aims?

The cost analysis of this wind assessment came in stage two and focused on estimating just the varying spatial cost that would be unique to each potential site. Stage two of the assessment would include costs in connecting to the electrical grid, costs in building an access road to the potential site and land clearance costs. Assessing the inclusion and estimation of these spatial costs in relation to how they help the assessment fulfil its design purpose, is an important part of this discussion. To reiterate, the design purpose was as follows:

'to estimate and visualise the achievable onshore wind energy resource potential of Cornwall, in order to provide itself as a decision support system for wind energy related policies and plans in the county…. This assessment cannot make completely accurate predictions on the cost and potential energy output of each conceivable part of available land and should not be an alternative to a full site analysis on a potential site for wind development'

To break this down further, a full cost analysis of turbine construction was never the intended purpose of this project. The focus was on finding areas of Cornwall best suitable to wind energy. Analysing spatial costs was just one way in which to do that, albeit an important one.

Figure 61 shows the breakup of cost for the average wind turbine in Europe. There are four spatial dependent components of that break up and they add up to between 5% - 29% of the total cost. The only one of these spatial costs not included in the cost analysis was foundations, although this was to be included in stage one of the assessment by trying to prohibit wind turbine on dissolution hazards. A lack of data made this impossible however. The other three components however were all included and had access to reliable and accurate GIS data as base data for the analysis (as previously discussed in RQ1). Reliable and accurate source GIS data is a vital element in the analysis and helps cement confidence in its results.

Component	Cost range (% of total)	Spatially dependent
Grid connection	2–10	Yes
Foundation	1–9	Yes
Land/clearing	1–5	Yes
Road construction	1–5	Yes
Wind turbines	68–84	No
Electric installation	1–9	No
Financial costs	1–5	No
Consultancy	1–5	No

Figure 61 - Breakdown of the capital cost components for a typical onshore wind farm in Europe (European Wind Energy Association , 2009)

The GIS ArcMap tool '*Euclidean Distance'* was the tool used to calculate distances from roads and the electrical grid network to new potential sites. This tool was perfect for this assessment, in that in produced a raster (snapped to other rasters in stage 2) covering the whole of Cornwall and produced distances based on a direct A to B measurement. This tool in combinations with accurate source data allows for a high degree of trust in the distances a potential site is away from the amenities it needs connecting to, I.e. Roads and electricity.

Ideally, the costing of the spatial components should be up-to-date and calculated for the country that they are needed. Unfortunately, in this assessment the costing data used was neither of these. There was a struggle in trying to find reliable source of cost, that were calculated relatively not long ago and explicitly with the UK industry in mind. As a result, the costs associated with access roads and grid connection, where taken from American academic papers, with the actual sums of money in US dollars. Land clearance cost were derived from both American and UK sources. Clearly this is not ideal for an assessment based in the UK and reduces the quality of the cost analysis aspect of the Cornish wind energy assessment.

A few steps were taken however to try and make the costs taken from American sources more relevant to this study. First the figures were transferred into pounds using the exchange rates between the currencies at the time of publishing, then secondly applying the applicable inflation rate to the sum. This way the cost figures would be at least be in the correct currency. This process however, should not mask the fact that the figures were not intended for the current UK market and that in general they may not be accurate costs.

The cost calculations created as part of the cost analysis may then not be 100% accurate or trustworthy. They do still however, act as a good basis to show the spatial differences in costs. With the reality that spatial measurement can be trusted a lot more than the costs associated with them, a decision was made to include both values to any user of the web application. Originally only the total estimated cost of the spatially dependent components was to be made available, however this changed after the realisations were made.

6.4 How best to tailor the web application so that it visualises the results of the wind energy assessment to the correct target audience?

When designing and developing a web application, all decisions made in the process should bear in mind who the application is designed for. This makes understanding the target audience a vital component of web design and an issue that can greatly affect the overall success of an application. In this part of the discussion, there will be a focus on who is the target audience for the Cornish wind energy assessment and how that affected the application development in stage 4 of this project.

The primary target audiences of the Cornish wind energy assessment were always the major stakeholders in the Cornish and UK's wind energy industry, with major players being the companies who own and operate wind farms and Cornwall Council, the local governmental body. Both these parties have an active interest in trying to utilize the Cornish landscape for wind energy development. With these target audience, we can expect a relatively high understating of the wind energy terminology and the processes that are part of the wind farm development. These parties being the primary target audience is way the assessment has been tailored to medium or large grid-connecting wind energy developments. There was however a desire to have a secondary target audience for the assessment, this was to be the general public. The idea being that any member of the public could view the application to find if an area of interest to them could be subject to wind energy development or if an area of interest to them could be in the line of site of a wind turbine if development happens to any of the potential site identified in stage 3. With this is mind the web application still needs to be interpretable to an average member of the public.

The opening page of the web application focuses on displaying the results of land exclusion part of the assessment and the results of the WRMS. Each exemplary turbine has an overlay on the map showing which areas are unsuitable and for those are suitable that are suitable, both the average wind speed and potential yearly energy output. This specific information was displayed on the front page as it was deemed to be the core information of the assessment and important to all of the target audiences identified. Trying to display all the results of all the different parts of the assessment on one front page was deemed to be untidy and overly confusing, especially for a user from the general public. This way the front page is hopefully understandable for all users and then for additional information on cost or visibility the user can be directed to another page.

The cost analysis and visibility analysis are then split per turbine into two additional web pages. The visibility analysis web page is accessed via a link in the front page and the cost analysis is accessed by an interactive click on the main map on the front page. For the cost analysis web page, the economic information is then displayed in written form and only for the grid cell selected, again this is an attempt to simplify and clarify the data. There are over 10 values that are displayed on the page for each grid cell, to display them in map form would to be much visual information to account for. However, in the map on this page road and grid data is displayed in its raw form to be a visual aid accompanying the addition information. As the visibility study was only for specific identified sites with great potential, it belonged on a different web map. The link to the pages holding the study were clearly linked on the front page. The maps on these pages have an overlay for each site as once again however simplicity was in mind.

In conclusion, a balance was needed for the web application. Conveying all the necessary data to the user in one web page was unnecessarily complicated, splitting up the assessment into separate analyses on different webpages was a means of tackling this issue. At the same time, divulging the assessment into many different webpages and sources of information would make the navigation of the web application unnecessarily complex. Three different web pages was a good compromise, with the front page showing the core information of the assessment, which is relevant to all target audiences.

7 – Conclusion

The aim of this assessment was to conduct a Cornish wind energy assessment that highlighted the area's best suitable for wind energy development in Cornwall, UK. The addition of a web application was also included to give interested parties access to the results of the assessment via the web.

Stage one of the assessment to exclude land from the study which was unsuitable for wind development was a great success. The analysis was built of sound restrictions parament, coming from official government policies when applicable and other academic GIS wind energy studies when lacking governmental guidance. Local considerations were also taken into account, optimised by the inclusion of the Cornwall Council's Renewable Energy Planning Advice service. Not all desired GIS data was available however, Karst datasets were not able to be incorporated into stage 1. The GIS data management tools also allowed for swift implementation of the restriction and a simple way of combining the individual issue to create shapefiles containing the total land area withdrawn from the assessment.

Stage two of the assessment, to produce a Cornish Wind Resource Mapping System and accompanying cost analysis was a tougher process. Average yearly wind speed data that came from the Department of Energy and Climate Change was not up-to-date and was not at the desired heights for this assessment. Distribution data on the average wind speeds was also missed. However, using sound data management techniques and academically published formulae's, a fully working WRMS was manufactured and specified for the assessment which worked well for unlocking areas of Cornwall most suitable to wind energy assessment. The cost analysis came off of sound GIS data for the amenities that a wind turbine would have to connect to; land cover type, electrical grid network and road network data all had reputable sources. The costs however were not so reliable, a lack of UK relevant costings hurt the quality of the analysis and was one of the biggest failings of this study.

Technical limitations of the resources used for this assessment unfortunately changed the scope of stage three of the wind assessment, original planning was set about to give every available hectare of suitable land for wind energy assessment its visibility analysis. This resulted in the change of identifying 15 potential sites across the county and finding from what areas of Cornwall would the turbine be visible from. Although narrowing the scoop of stage 3 it did allow for the analysis to highlight some of the most promising wind energy site for the county.

Stage four of the assessment was the development of a web application that would portray the results of the first three stages to all interested parties. Target audiences were the major players in the UK's wind energy industry and also to the general public, albeit to a slightly lesser extent. These target audiences were kept in mind during the design process and were they major concern in how the varying results of the assessment were split up and displayed in the application. All of the results produced in the first three stage were incorporated into the application smoothly, this in combination with the simplicity of the web application make the application a useful addition to the GIS wind energy assessment.

At a time in which the UK continues to need new clean energy solution to meet renewable energy targets, the cheapness and reliability of on-shore wind energy will ensure that the industry will continue to play a major role in the wider UK energy industry. The contentiousness over Cornish land use makes expanding the industry into the county difficult, but with a high natural resource of wind and a committed local council to pushing renewable energy, there will continue to be a market from wind energy in the county. Although the limitations of the Cornish wind energy assessment have been made clear throughout the study, it does succeed in identifying the best areas in Cornwall for future wind energy developments and perhaps could be of use in the future.

8 - References

Aberystwyth, L. B., & Rudd, A. (2015). Energy Bill [HL]. *Energy Act 2016 c.20*.

Alenia Marconi Systems Limited. (2003). *Feasibility of Mitigating the effects of wind farms on primary radar.* London: Crown Copyright.

AWS. (2011). *WINDNAVIGATOR: Methods and validtion.*

Aydin, N. Y., Kentel, E., & Duzgun, S. (2010). GIS-based environmental assessment of wind energy systems for spatial planning: A case study from Western Turkey. *Renewable and Sustainable Energy Reviews 14*, 364–373.

Barclay, C. (2010). *Wind Farms - Distance from housing.* House of Commons Library.

Bassi, S., Bowen, A., & Fankhauser, S. (2012). *The case for and against onshore wind energy in the UK.* Grantham Research Institute.

Bowen, A., & Rydge, J. (2011). *Climate change policy in the United Kingdom.* Centre for Climate Change Policy Economics and Policy, Grantham Institution Research on Climate Change and the Environment .

Boyle, G. (2012). *Renewable energy: Power for a sustainable future (third edition).* Oxford: Oxford University Press.

British Geological Survey . (2017). *GeoSure Dataset*. Retrieved 04 2017, from British Geological Survey : http://www.bgs.ac.uk/products/geoSure/geosureDataset.html

Bureau of Land Management. (2005). *Wind energy development programmatic environmental impact statement: Volume 1.* FES 05-11, US Department of Interior .

Cave, S. (2013). *Wind Turbines: Planning and Separation Distances.* Northern Ireland Assembly.

Centre for Ecology & Hydrology. (2017). *LiDAR based Digital Terrain Model (DTM) data for South West England*. (Centre for Ecology & Hydrology) Retrieved 05 2017, from data.gov.uk: https://data.gov.uk/dataset/lidar-based-digital-terrain-model-dtm-data-for-south-west-england

Copernicus. (2017). *Overview*. Retrieved 02 2017, from copernicus.eu: http://www.copernicus.eu/main/overview

Cornwall Council. (2011). *Cornwall Landscape Assessment* . Truro. Retrieved from www.cornwall.gov.uk/cornwall_landscape

Cornwall Council. (2016). *Cornwall Renewable Energy Planning Advice - Annex 1: An assessment of the landscape sensitivity to on-shore wind energy & large-scale photovoltaic development in Cornwall.* London: LUC Services.

Cornwall Council. (2016b). *Cornwall Renewable Energy Planning Advice Appendix 1: Landscape Sensitivity and Strategy Matrices for each Landscape Character Area.* London: LUC Services.

Cornwall.gov. (2016, 06 07). *Cornwalls Landscape*. Retrieved Jan 2017, from Cornwall.gov.uk: https://www.cornwall.gov.uk/environment-and-planning/cornwalls-landscape/

costhelper.com. (2017). *land-clearing*. Retrieved 02 2017, from costhelper.com: http://home.costhelper.com/land-clearing.html

Department for Business, Energy & Industrial Strategy. (2016b). *Wave 19 summary tables - Findings from the nineteenth quarterly wave of the Public Attitudes Tracking survey.* Energy and Climate Change Public Attitudes Tracking Survey.

Department for Business, Energy and Industry Strategy. (2016). *Energy Trends section 6: renewables.*

Department of Business, Energy and Industry Strategy . (2016b). *Renewable energy capasity and generation (ET 6.1).*

Department of Energy and Climate Change. (2015). *Towards a Smart Energy.*

Department of Energy and Climate Change. (2016). *Third Progress Report on the promotion and use of energy from renewable sources for the United Kingdom.* Ref. Ares(2016)319237.

Department of Energy and Climate Change. (2017). *Windspeed database: information sheet.*

Department of Trade and Industry. (2003). *Energy White Report: Our Energy Future.* London: The Staionary Office.

Deutsches Windenergie-Institut GmbH. (2001). *Wind Turbine Grid Connection and Interaction.* Energie publication by European Commision.

Drechsler, M., Masurawski , F., & Frank, K. (2016). A spatially explicit assessment of the wind energy potential in response to an increased distance between wind turbines and settlements in Germany. *Energy Policy, 97*, 343-350.

Energy Network Assocsiation . (2014). *Distribution generation connection guide.* London: Energy Network Assocsiation .

Envioronment Infomation Data Centre. (2017). *Main page*. Retrieved 05 2017, from Envioronment Infomation Data Centre: http://eidc.ceh.ac.uk/

European Environmental Agency. (2009). *Europe's onshore and offshore wind energy potential. Final Report.* Copenhagen: European Environmental Agency.

European Wind Energy Association . (2009). *The Economics of Wind Energy.* Brussles.

Evans-Pritchard, A. (2016). *Britain abandons onshore wind just as new technology makes it cheap*. Retrieved 11 2016, from Daily Telegraph: http://www.telegraph.co.uk/finance/economics/12090394/Britain-abandons-onshore-wind-just-as-new-technology-makes-it-cheap.html

Girres, J., & Touya, G. (2010). Quality Assessment of the French OpenStreetMap Dataset. *Transactions in GIS, 14*(4), 435-459. doi:10.1111/j.1467-9671.2010.01203.x

Green, J., Bowen, A., Fingersh, L. J., & Wan, Y. (2007). *Electrical Collection and Transmission Systems for Offshore Wind Power.* NREL/CP-500-41135.

Haklay, M. (2010). How good is Volunteered Geographic Information? A comparitive study of OpenStreetMap and Ordnance Survey datasets. *Enivornment and Planning B: Planning and Design, 37*, 682-703. doi:10.1068/b35097

Hollnaicher, S., McKenna, R., & Fichtner, W. (2014). Cost-potential curves for onshore wind energy: A high-resolution analysis for Germany. *Applied Energy, 115*(ISSN 0306-2619), 103-115.

Intergovernmental Panel on Climate Change. (2014). *Climate Change 2014: A Summary for Policymakers.* Cambridge University Press.

Katsigiannis , Y., & Stavrakakis , G. (2013). Estimation of wind energy production in various sites in Australia for different wind turbine classes: a comparative technical and economic. *Renew Energy, 67*, 1-7.

Knopper, L., & Ollson, C. (2011). Health effects and wind turbines: A review of the Literature. *Environmental Health, 78*, 1-10.

Landscapes for life. (2017). *Further information about AONBs*. Retrieved Jan 2017, from Landscapes for Life: http://www.landscapesforlife.org.uk/further-information-about-aonbs.html

Latinopoulos, D., & Kechagia, K. (2015). A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application in Greece. *Renewable Energy, 78*, 550-560.

Lemmon, J. J., Carroll, J. E., Sanders, F. H., & Turner, D. (2008). *Assessment of the Effects of Wind Turbines on Air Traffic Control Radars.* U.S. DEPARTMENT OF COMMERCE. U.S. DEPARTMENT OF COMMERCE.

Leung, D., & Yang, Y. (2012). Wind energy development and its environmental impact: A review. *Renewable and Sustainable Energy Reviews, 16*, 1031– 1039.

Mari, R., Bottai, L., Busillo, C., Calastrini, F., Gozzini, B., & Gualtieri, G. (2011). A GIS-based interactive web decision support system for planning wind farms in Tuscany (Italy). *Renewable Energy 36*, 754-763.

Miceli, F. (2012, Aug 20). *wind farm substation an overview*. Retrieved Jan 2017, from Windfarmbop: http://www.windfarmbop.com/wind-farm-substation-an-overview/

Miceli, F. (2015, December 15). *Karst problems in wind farms: use of Ground Penetrating Radar (GPR)*. Retrieved November 2016, from Windfarmbop: http://www.windfarmbop.com/tag/karst/

Natioanal Grid. (2009). *Embedded and Renewable Generation: GB Seven Year Statement (Introduction to Chapter 4).* Natioanal Grid.

National Grid. (2012). *Small Embedded Generation and National Grid.*

Natural England. (2016). *Impact Risk Zones for Sites of Specific Scientific Interest - User Guidance.* v2.5.

Natural England. (2017). *Gis-More*. Retrieved 03 2017, from Natual England: http://www.gis.naturalengland.org.uk/pubs/gis/more.htm

Natural England and Department for Environment, Food & Rural Affairs. (2015). *Wild birds: surveys and monitoring for onshore wind farms*. Retrieved 02 2017, from Gov.uk: https://www.gov.uk/guidance/wild-birds-surveys-and-monitoring-for-onshore-wind-farms

Nedaei , M., Assareh, E., & Biglari, M. (2014). An extensive evaluation of wind resource using new methods and strategies for development and utilizing wind power in Mah-shahr station in Iran. *Energy Conservation and Management, 81*, 475-503.

Office of National Statistics. (2016). *2011 Census aggregate data.* UK Data Service (Edition: June 2016). doi:DOI: http://dx.doi.org/10.5257/census/aggregate-2011-1

OFGEM. (2016). *Renewable Obligation closure*. Retrieved 11 2016, from https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro/ro-closure

Onyango, V., Illsley, B., & Radfar, M. (2013). *Review of the 2Km separation distance between areas of search for onshore wind farms and the edge of cities, towns and villages.* Prepared for Scottish Government.

Ordnance Survey. (2017). *data collection management*. Retrieved 03 2017, from Ordnance Survey: https://www.ordnancesurvey.co.uk/international/knowledge/data-collection-management.html

Pearson, P., & Watson, J. (2012). *UK energy policy 1980-2010: A history and lessons to be learnt.* The Institution of Engineering and Technology. London: The Parlimentary Group for Energy Studies.

Røkenes, K. (2009). *Investigation of terrain effects with respect to wind farm siting.* PhD Thesis, Norwegian University of Science and Technology, Department of Energy and Process Engineering.

Royal Commission on Environmental Pollution. (2000). *Summary Report: Energy - The Changing Climate .* London: The Stationary Office.

Saidur, R., Solangi, K., Rahim, N., & Islam, M. (2011). Environmental impact of wind energy. *Renewable and Sustainable Energy Reviews, 15*, 2423-2430.

Siyal, S. H., Mortenberg, U., Mentis, D., Welsch, M., Babelon, I., & Howells, M. (2015). Wind energy assessment considering geographic and environmental restrictions in Sweden: A GIS approach. *Energy, 83*, 447-461.

Sliz-Szkliniarz, B., & Vogt, J. (2011). GIS-based approach for the evaluation of wind energy potential: A case study for the Kujawsko–Pomorskie Voivodeship. *Renewable and Sustainable Energy Reviews, 15*, 1696–1707.

Sorensen, B. (1991). A history of renewable energy technology. (Elsevier, Ed.) *Energy Policy, 19*(1), 8-12.

Sorensen, B. (2000). *Renewable Energy (Second Edition).* Academic Press.

Sorensen, B. (2004). *Renewable Energy: Physics, Engineering, Environmental Imapcts Econmics and Planning* (3rd ed.). Elsevier.

Tsoutsos, T., Tsitoura, I., Kokologos, D., & Kalaitzakis, K. (2015). Sustainable siting process in large wind farms case study in Crete. *Renewable Energy, 75*, 474-480.

Twidell, J., & Weir, A. (1986). *Renewable Energy Resources .* London: E & FN Spon.

United States Geological Survey. (2007). *National land cover data (NLCD).* Retrieved from http://landcover.usgs.gov/natllandcover.php

van Haaren, R., & Fthenakis, V. (2011). GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): Evaluating the case for New York State. *Renewable and Sustainable Energy Reviews, 15*, 3332-3340.

Vestas. (2017). *3MW Platform: Brochure*. Retrieved 02 2017, from www.vestas.com: http://nozebra.ipapercms.dk/Vestas/Communication/Productbrochure/3MWbrochure/3MWProductBrochure/

Weart, S. (2008). *The Discovery of Global Warming .* Cambridge, USA: Harvard University Press.

West Devon Borough Council . (2013). *On Shore Wind Turbines in West Devon.*

Western Power. (2017). *Our Network*. Retrieved 2017 Jan, from Western Power: https://www.westernpower.co.uk/About-us/Our-Business/Our-network.aspx

White, W. (1990). Surface and near surface karst landforms. In C. Higgins, & D. Coates, *Groundwater geomorphology.* The geological society of America.

Zindler, E. (2015). *H2 2015 LCOE: WIND AND SOLAR BOOST COST-COMPETITIVENESS VERSUS FOSSIL FUELS*. Retrieved from Bloomberg New Energy Finance : https://about.bnef.com/press-releases/wind-solar-boost-cost-competitiveness-versus-fossil-fuels/

9 – Appendix

9.1 Appendix 1 – Leaf1.html

```
<html>
<head>
  <title>A Leaflet map!</title>
  <meta http-equiv="content-type" content="text/html; charset=utf-8" />
  <link rel="stylesheet" href="leaflet.css"/>
<script src="leaflet.js"></script>
<script type='text/javascript' src='leaflet-src.js'></script>
 <script type='text/javascript' src='leaflet.ajax.js'></script>
<script type='text/javascript' src='jquery-3.2.1.min.js'></script>
<script src='Enercon_4326.geojson' type='text/javascript'></script>
<script src='Vestas_4326.geojson' type='text/javascript'></script>
<script src='Nordex_4326.geojson' type='text/javascript'></script>


<style>
    #map{ height:100%; width:64%;}.info {
    padding: 6px 8px;
    font: 14px/16px Arial, Helvetica, sans-serif;
    background: white;
    background: rgba(255,255,255,0.8);
    box-shadow: 0 0 15px rgba(0,0,0,0.2);
    border-radius: 5px;
    }.info h4 {
    margin: 0 0 5px;
    color: #777;
    }.legend { text-align: left; line-height: 18px;
    color: #555; } .legend i { width: 18px; height:
    18px; float: left; margin-right: 8px; opacity: 0.7; }

</style>
<style>

div.fixed {
    position: fixed;
    top: 0;
    right: 0;
    width: 35%;
    height: 100%;
    border: 1px solid #6E6E6E;
    background-color: #F5F6CE;

}
h1 {
    color: black;
    text-align: center;
    font-size: 150%;
    text-decoration: underline;
}
h2 {
    color: black;
    text-align: left;
    font-size: 125%;
}
</style>
</head>
<body>
  <div id="div1">
```

```
        <form action="Enercon_connection.php" id="enercon_php"
method="POST">
            <label>Latitude : <input type="text" name="latitude"
id="e_latitude"  /></label>
            <label>Longitude : <input type="text" name="longitude"
id="e_longitude"  /></label>
            <input type="submit" :>
        </form>
        <form action="Leaf2.php" id="enercon_leaf2" method="POST">
            <input type="submit" :>
        </form>
        <form action="Nordex_connection.php" id="nordex_php" method="POST">
            <label>Latitude : <input type="text" name="latitude"
id="n_latitude"  /></label>
            <label>Longitude : <input type="text" name="longitude"
id="n_longitude"  /></label>
            <input type="submit" :>
        </form>
        <form action="Leaf3.php" id="nordex_leaf3" method="POST">
            <input type="submit" :>
        </form>
        <form action="Vestas_connection.php" id="vestas_php" method="POST">
            <label>Latitude : <input type="text" name="latitude"
id="v_latitude"  /></label>
            <label>Longitude : <input type="text" name="longitude"
id="v_longitude"  /></label>
            <input type="submit" :>
        </form>
        <form action="Leaf4.php" id="vestas_leaf4" method="POST">
            <input type="submit" :>
        </form>
    </div>

  <div id="map"></div>
 <div class="fixed">
    <h1>Cornish Wind Energy Assessment  </h1>
    <h2>Aims and Instructions</h2>
     The Cornish Wind Energy Assessment is a preliminary tool established
to find the most suitable
     areas in Cornwall for wind energy development.
     </br>
     Three example wind turbines have been chosen to highlight the
potential. These are:
     </br>
     The Enercon E-48 800kV at a hub height of 50m
     </br>
     The Nordex N-90 2MW at a hub height of 70m
     </br>
     The Vestas V-126 3.45MW at a hub of height 117m
     </br></br>
     Areas not available on the map have been excluded from the analysis as
the locations are unsuitable for development.
    </br></br>
    Clicking on a grid cell will give you more information about that
location
    <h2>Promising site locations and corresponding visibilty analysis</h2>
    5 promising sites have been highlighted for each turbine
    </br></br>
    Click <a href="Leaf5.html">here</a> for 5 potential Enercon E-48 sites
    </br></br>
    Click <a href="Leaf6.html">here</a> for 5 potential Nordex N-90 sites
```

```
    </br></br>
    Click <a href="Leaf7.html">here</a> for 5 potential Vestas V-126 sites
</div>
<script>

  document.getElementById("div1").style.display = "none";
// loading a base map tile layer
var OpenR = L.tileLayer('http://korona.geog.uni-heidelberg.de/tiles/roads/x={x}&y={y}&z={z}', {
      maxZoom: 20,
      minZoom: 10,
      attribution: 'Imagery from <a href="http://giscience.uni-hd.de/">GIScience Research Group @ University of Heidelberg</a> &mdash; Map data &copy; <a href="http://www.openstreetmap.org/copyright">OpenStreetMap</a>'
    });

// initialise the map
   var map = L.map('map', {
    center: [50.54, -4.86],
    zoom: 12,
    layers: [OpenR]
   });

  // creating custom control
    var info = L.control();

     info.onAdd = function (map) {
        this._div = L.DomUtil.create('div', 'info'); // create a div with a class "info"
        this.update();
        return this._div;
    };

// method that we will use to update the control based on feature properties passed on from GeoJSON
    info.update = function (props) {
       this._div.innerHTML = '<h4>Click on a square for addition Information</h4>' +  (props ?
        '<b>' + props.TOTAL_MWH + '</b>' + ' Estimated annual MWh outage' + '<br />' + '<b>' + props.AVG_GRID_C + '</b>' +' Average wind speed (m/s)'
        : 'Hover over a square');
    };
    info.addTo(map);

   // Colour styling for Enercon GeoJSON
   function getColour(d) {
    return d > 4112 ? '#900C3F' :
           d > 3732.67  ? '#C70039' :
           d > 3284.40  ? '#FF5733' :
           d > 2767.28  ? '#FFC300' :
           d > 2188.60  ? '#EDE238' :
           d > 1575.31  ? '#F1F94B' :
                          '#FFEDA0';
    }
    function getColourV(d) {
    return d > 17908.18  ? '#900C3F' :
           d > 16383.52  ? '#C70039' :
           d > 15433.49  ? '#FF5733' :
           d > 14361.04  ? '#FFC300' :
           d > 11872.66  ? '#EDE238' :
```

```
            d > 7491.98  ? '#F1F94B' :
                            '#FFEDA0';
    }
    function getColourN(d) {
    return d > 11103.98  ? '#900C3F' :
            d > 9683.29  ? '#C70039' :
            d > 8873.47  ? '#FF5733' :
            d > 8005.71  ? '#FFC300' :
            d > 7089.38  ? '#EDE238' :
            d > 5168.75  ? '#F1F94B' :
                            '#FFEDA0';
    }
    // Overall styling for Enercon GeoJSON
   function styleEner(feature) {
    return {
        fillColor: getColour(feature.properties.TOTAL_MWH),
        weight: 1,
        opacity: 1,
        color: 'white',
        dashArray: '3',
        fillOpacity: 0.7
    };
    };

    function styleVest(feature) {
    return {
        fillColor: getColourV(feature.properties.TOTAL_MWH),
        weight: 1,
        opacity: 1,
        color: 'white',
        dashArray: '3',
        fillOpacity: 0.7
    };
    };

    function styleNord(feature) {
    return {
        fillColor: getColourN(feature.properties.TOTAL_MWH),
        weight: 1,
        opacity: 1,
        color: 'white',
        dashArray: '3',
        fillOpacity: 0.7
    };
    };
    // styling for when a feature has a mouse hovering over it
   function highlightFeature(e) {
    var layer = e.target;

    layer.setStyle({
        weight: 5,
        color: '#666',
        dashArray: '',
        fillOpacity: 0.7
    });

    if (!L.Browser.ie && !L.Browser.opera && !L.Browser.edge) {
        layer.bringToFront();
       }
     info.update(layer.feature.properties)
    };
```

```
    // styling for when mouse moves off a feature
    function resetHighlight(e) {
    Enercon.resetStyle(e.target);
    info.update();
    };

     function resetHighlightV(e) {
    Vestas.resetStyle(e.target);
    info.update();
    };

    function resetHighlightN(e) {
    Nordex.resetStyle(e.target);
    info.update();
    };
    // transfering co-ordinates to hidden form and triggering the
submission of two hidden forms
    function submitting(e) {
             var lat = e.latlng.lat
             var lon = e.latlng.lng
             document.getElementById('e_latitude').value = lat;
             document.getElementById('e_longitude').value = lon;
             $('#enercon_php').submit();
             $('#enercon_leaf2').submit();
            }
    function n_submitting(e) {
             var lat = e.latlng.lat
             var lon = e.latlng.lng
             document.getElementById('n_latitude').value = lat;
             document.getElementById('n_longitude').value = lon;
             $('#nordex_php').submit();
             $('#nordex_leaf3').submit();
            }
    function v_submitting(e) {
             var lat = e.latlng.lat
             var lon = e.latlng.lng
             document.getElementById('v_latitude').value = lat;
             document.getElementById('v_longitude').value = lon;
             $('#vestas_php').submit();
             $('#vestas_leaf4').submit();
            }
    // creating a single function to hold all three feature triggering
fuctions
    function onEachFeature(feature, layer) {
    layer.on({
        mouseover: highlightFeature,
        mouseout: resetHighlight,
        click: submitting
    })};

    function onEachFeatureV(feature, layer) {
    layer.on({
        mouseover: highlightFeature,
        mouseout: resetHighlightV,
        click: v_submitting
    })};

    function onEachFeatureN(feature, layer) {
    layer.on({
        mouseover: highlightFeature,
        mouseout: resetHighlightN,
```

```
        click: n_submitting
    })};
    // Creating legend variable
    var legend = L.control({position: 'bottomleft'});

    legend.onAdd = function (map) {
    // Creating div
    var div = L.DomUtil.create('div', 'info legend'),
        grades = [0, 1575, 2188, 2767, 3284, 3732, 4112],
        labels = [];

    // loop through the density intervals and generate a label with a
coloured square for each interval
    for (var i = 0; i < grades.length; i++) {
        div.innerHTML +=
            '<i style="background:' + getColour(grades[i] + 1) + '"></i> '
+
            grades[i] + (grades[i + 1] ? '&ndash;' + grades[i + 1] + '
(MWh)' + '<br>' : '+' + ' (MWh)');
    }

    return div;
    };

    var legendV = L.control({position: 'bottomleft'});

    legendV.onAdd = function (map) {

    var div = L.DomUtil.create('div', 'info legend'),
        grades = [0, 7491, 11872, 14361, 15433, 16383, 17908],
        labels = [];

    // loop through our density intervals and generate a label with a
colored square for each interval
    for (var i = 0; i < grades.length; i++) {
        div.innerHTML +=
            '<i style="background:' + getColourV(grades[i] + 1) + '"></i> '
+
            grades[i] + (grades[i + 1] ? '&ndash;' + grades[i + 1] + '
(MWh)'+'<br>' : '+' + ' (MWh)');
    }

    return div;
    };

var legendN = L.control({position: 'bottomleft'});

    legendN.onAdd = function (map) {

    var div = L.DomUtil.create('div', 'info legend'),
        grades = [0, 5168, 7089, 8005, 8873, 9683, 11103],
        labels = [];

    // loop through our density intervals and generate a label with a
colored square for each interval
    for (var i = 0; i < grades.length; i++) {
        div.innerHTML +=
            '<i style="background:' + getColourN(grades[i] + 1) + '"></i> '
+
            grades[i] + (grades[i + 1] ? '&ndash;' + grades[i + 1] + '
(MWh)' +'<br>' : '+' + ' (MWh)');
```

```
    }

    return div;
    };




    var Enercon = new L.GeoJSON.AJAX('Enercon_4326.geojson',{
     style: styleEner,
     onEachFeature: onEachFeature
    });
      // Create new geojson layer



     var Vestas = new L.GeoJSON.AJAX('Vestas_4326.geojson',{
     style: styleVest,
     onEachFeature: onEachFeatureV
    });

    var Nordex = new L.GeoJSON.AJAX('Nordex_4326.geojson',{
     style: styleNord,
     onEachFeature: onEachFeatureN
    });


    // Adding OpenR to baseMaps variable
   var baseMaps = {
    "BaseMap": OpenR
    };

   var overlayMaps = {
    "Enercon E-48 800kW": Enercon,
    "Vestas V-126 3.45MW": Vestas,
    "Nordex N-90 2.00MW": Nordex
    };

  // Creating layer control manager
   L.control.layers(baseMaps, overlayMaps).addTo(map);
  // Creating a scale bar
   L.control.scale().addTo(map);

  map.on('overlayadd', function (eventLayer) {
       if (eventLayer.name === "Vestas V-126 3.45MW") {
        legendV.addTo(map);
        }
        });
   map.on('overlayremove', function (ffd) {
       if (ffd.name === "Vestas V-126 3.45MW") {
        map.removeControl(legendV);
       }
       });
    // adding enercon_e48 lengend when the overlay is selected
    map.on('overlayadd', function (eventLayer) {
       if (eventLayer.name === "Enercon E-48 800kW") {
        legend.addTo(map);
        }
        });
    // removing enercon_e48 lengend when the overlay is deselected
```

```
   map.on('overlayremove', function (ffd) {
        if (ffd.name === "Enercon E-48 800kW") {
         map.removeControl(legend);
        }
        });

    map.on('overlayadd', function (eventLayer) {
        if (eventLayer.name === "Nordex N-90 2.00MW") {
         legendN.addTo(map);
         }
         });
   map.on('overlayremove', function (ffd) {
        if (ffd.name === "Nordex N-90 2.00MW") {
         map.removeControl(legendN);
        }
        });
  </script>
</body>
</html>
```

9.2 Appendix 2 - enercon_connection.php

```
<!DOCTYPE html>
<html>
    <head>
        <title>Adding data</title>
        <meta charset="utf-8" />
        <title>test</title>
    </head>

    <body>


            <?php
            // connection
            $host = "localhost";
            $port = "5432";
            $database = "postgres";
            $user = "postgres";
            $password = "pgadmin";

            $connection = "host=".$host." port=".$port."
dbname=".$database." user=".$user." password=".$password;
            //echo $connection;
            $dbh = pg_connect($connection) or die("Connection impossible");
            //echo $dbh;
            ?>

            <?php
            //perform the insert using pg_query
                    $sql = "INSERT INTO enercon_al (Latitude, Longitude)
VALUES ('".$_POST['e_latitude']."', '".$_POST['e_longitude']."')";
                    $result = pg_query($dbh, $sql);
            ?>


            <?php
            pg_close($dbh);
            ?>
```

```
    </body>
</html>
```

9.3 Appendix 3 - Leaf2.php

```
<?php
            $host = "localhost";
            $port = "5432";
            $database = "postgres";
            $user = "postgres";
            $password = "pgadmin";


        $connection = "host=".$host." port=".$port." dbname=".$database."
user=".$user." password=".$password;
            //echo $connection;
            $dbh = pg_connect($connection) or die("Connection impossible");
            //echo $dbh;

        $query = "SELECT * FROM enercon_view2";

        $result = pg_query($dbh, $query);



        ?>

<html>
<head>
  <title>A Leaflet map!</title>
  <meta http-equiv="content-type" content="text/html; charset=utf-8" />
  <link rel="stylesheet" href="leaflet.css"/>
<script src="leaflet.js"></script>

<script type='text/javascript' src='jquery-3.2.1.min.js'></script>

<style>

div.fixed {
    position: fixed;
    top: 0;
    right: 0;
    width: 35%;
    height: 88%;
    border: 2px solid #7DD1CD;
    background-color: #C1EAE8;

}
h1 {
    color: black;
    text-align: center;
    font-size: 150%;
    text-decoration: underline;
}
h2 {
    color: black;
    text-align: left;
    font-size: 125%;
}
</style>
```

```
<style>
div.absolute {
    position: absolute;
    bottom: 0;
    right: 0;
    width: 35%;
    height: 10%;
    border: 2px solid #7DD1CD;
    background-color: #C1EAE8;
}

input[type=submit] {padding:5px 15px; background:#ccc; border:0 none;
    cursor:pointer;
    width: 100%;
    bottom: 0;
    -webkit-border-radius:
</style>


  <style>
    #map{ height: 100%;
          width: 64%;

         }
  </style>
</head>
<body>


  <div class="fixed">
    <h1>Information on the selected location </h1>
    <h2>Wind Speed and Energy Output</h2>
    <?php
    $val_i = pg_fetch_result($result,0,1);
    $val_j = pg_fetch_result($result,0,2);
    echo "This location has an estimated annual average wind speed of  ",
$val_i, " m/s at a height of 50m above ground. The Enercon E-48 would
produce roughly ", $val_j, " MWh worth of energy per year at this
location." ;
            ?>
    <h2>Spatial Costs</h2>
    <?php
    $val_a = pg_fetch_result($result,0,4);
    $val_b = pg_fetch_result($result,0,5);
    echo "This location is ", $val_a, " km away from the nearest exsisting
substation (132+ kV) and ", $val_b, " km away from the exsising electical
grid network (132+ kV)." ;
            ?>
    </br></br>
    <?php
    $val_c = pg_fetch_result($result,0,7);
    $val_d = pg_fetch_result($result,0,8);
    echo "The cheapest estimated option for grid connection would be ",
$val_c, ". At an estimated cost of ", $val_d, " mil £.";
            ?>
    </br></br>
    <?php
    $val_e = pg_fetch_result($result,0,11);
    echo "Land clearance cost are estimated to be ", $val_e," £ per hector
at this location." ;
            ?>
```

```
    </br></br>
    <?php
    $val_f = pg_fetch_result($result,0,6);
    $val_g = pg_fetch_result($result,0,10);
    echo "The nearest exsisting road is ", $val_f, "m away. An access road
to this location would have an estimated minimum cost of ", $val_g, " £.";
            ?>

    <h2>Impact Risk Zones</h2>
    <?php
    $val_h = pg_fetch_result($result,0,9);
    echo "This location is ", $val_h," a designated Impact Risk Zone (IRZ).
If in an IRZ, consultation with Natural England will be required to assess
the risk of wind development on nearby Sites of Specific Scientific
Intrest." ;
    pg_close($dbh);
            ?>


</div>

<div class="absolute">
<form action="Leaf1.html" id="back" method="POST">
            <input type="submit" value="Click to go back to the front page"
:>
        </form>
        </div>

  <div id="map"></div>

  <script>

  // initialize the map



  // load a tile layer
  var baseosm =
L.tileLayer('http://{s}.tile.openstreetmap.org/{z}/{x}/{y}.png',
    {
      attribution: 'Map data © <a
href="http://openstreetmap.org">OpenStreetMap</a> contributors',
      maxZoom: 17,
      minZoom: 11
    });
   // test for geoserver layer




   // initialize the map
   var map = L.map('map', {
    zoom: 12,
    layers: [baseosm],
    center: [50.54, -4.86]

   });

    L.control.scale().addTo(map);
```

```
   var cell =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:enercon_view2',
    transparent: "true",
    format: "image/png"
     }).addTo(map);
    var WPD =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:cornwall_total_132kv',
    transparent: "true",
    format: "image/png"
     }).addTo(map);
    var ohl =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:ohl_sw',
    transparent: "true",
    format: "image/png"
     }).addTo(map);
    var subs =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:cornwall_total_subs',
    transparent: "true",
    format: "image/png"
     }).addTo(map);



   var baseMaps = {
    "OSM": baseosm
    };

   var overlayMaps = {
    "Selected location": cell


   };


   L.control.layers(baseMaps, overlayMaps).addTo(map);
  </script>
</body>
</html>
```

9.4 Appendix 4 – Web page showing visibility study

```
<html>
<head>
  <title>A Leaflet map!</title>
  <meta http-equiv="content-type" content="text/html; charset=utf-8" />
  <link rel="stylesheet" href="leaflet.css"/>
<script src="leaflet.js"></script>

<script type='text/javascript' src='jquery-3.2.1.min.js'></script>

<style>
```

```
div.fixed {
    position: fixed;
    top: 0;
    right: 0;
    width: 35%;
    height: 88%;
    border: 1px solid #6E6E6E;
    background-color: #F5F6CE;

}
h1 {
    color: black;
    text-align: center;
    font-size: 150%;
    text-decoration: underline;
}
h2 {
    color: black;
    text-align: left;
    font-size: 125%;
}
</style>
<style>
div.absolute {
    position: absolute;
    bottom: 0;
    right: 0;
    width: 35%;
    height: 10%;
    border: 1px solid #6E6E6E;
    background-color: #F5F6CE;
}

input[type=submit] {padding:5px 15px; background:#ccc; border:0 none;
    cursor:pointer;
    width: 100%;
    bottom: 0;
    -webkit-border-radius:
</style>


  <style>
    #map{ height: 100%;
          width: 64%;

         }
  </style>
</head>
<body>


  <div class="fixed">
    <h1>5 Promising site locations for turbines similar to the Enercon E-48
</h1>
    <b>Site 1 </b>is 58 Hectares, has an average wind speed of 8.98 and has
an average estimated energy output of 3356 MWh per year per turbine
    </br></br>
    <b>Site 2 </b>is 85 Hectares, has an average wind speed of 9.30 and has
an average estimated energy output of 3388 MWh per year per turbine
    </br></br>
```

```
    <b>Site 3 </b>is 255 Hectares, has an average wind speed of 8.88 and
has an average estimated energy output of 3176 MWh per year per turbine
    </br></br>
    <b>Site 4 </b>is 53 Hectares, has an average wind speed of 9.29 and has
an average estimated energy output of 3335 MWh per year per turbine
    </br></br>
    <b>Site 5 </b>is 68 Hectares, has an average wind speed of 9.46 and has
an average estimated energy output of 3406 MWh per year per turbine
    </br></br>




</div>

<div class="absolute">
<form action="Leaf1.html" id="back" method="POST">
            <input type="submit" value="Click to go back to the front page"
:>
        </form>
        </div>

  <div id="map"></div>

  <script>

var baseosm =
L.tileLayer('http://{s}.tile.openstreetmap.org/{z}/{x}/{y}.png',
    {
      attribution: 'Map data © <a
href="http://openstreetmap.org">OpenStreetMap</a> contributors',
      maxZoom: 17,
      minZoom: 9
    });

   // initialize the map
   var map = L.map('map', {
    zoom: 11,
    layers: [baseosm],
    center: [50.54, -4.86]

   });

    L.control.scale().addTo(map);



var site_1 = L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?',
{
    layers: 'thesis:vestas_super_site1',
      transparent: "true",
    format: "image/png"
       });
       var site_2 =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:vestas_super_site2',
      transparent: "true",
    format: "image/png"
       });
       var site_3 =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
```

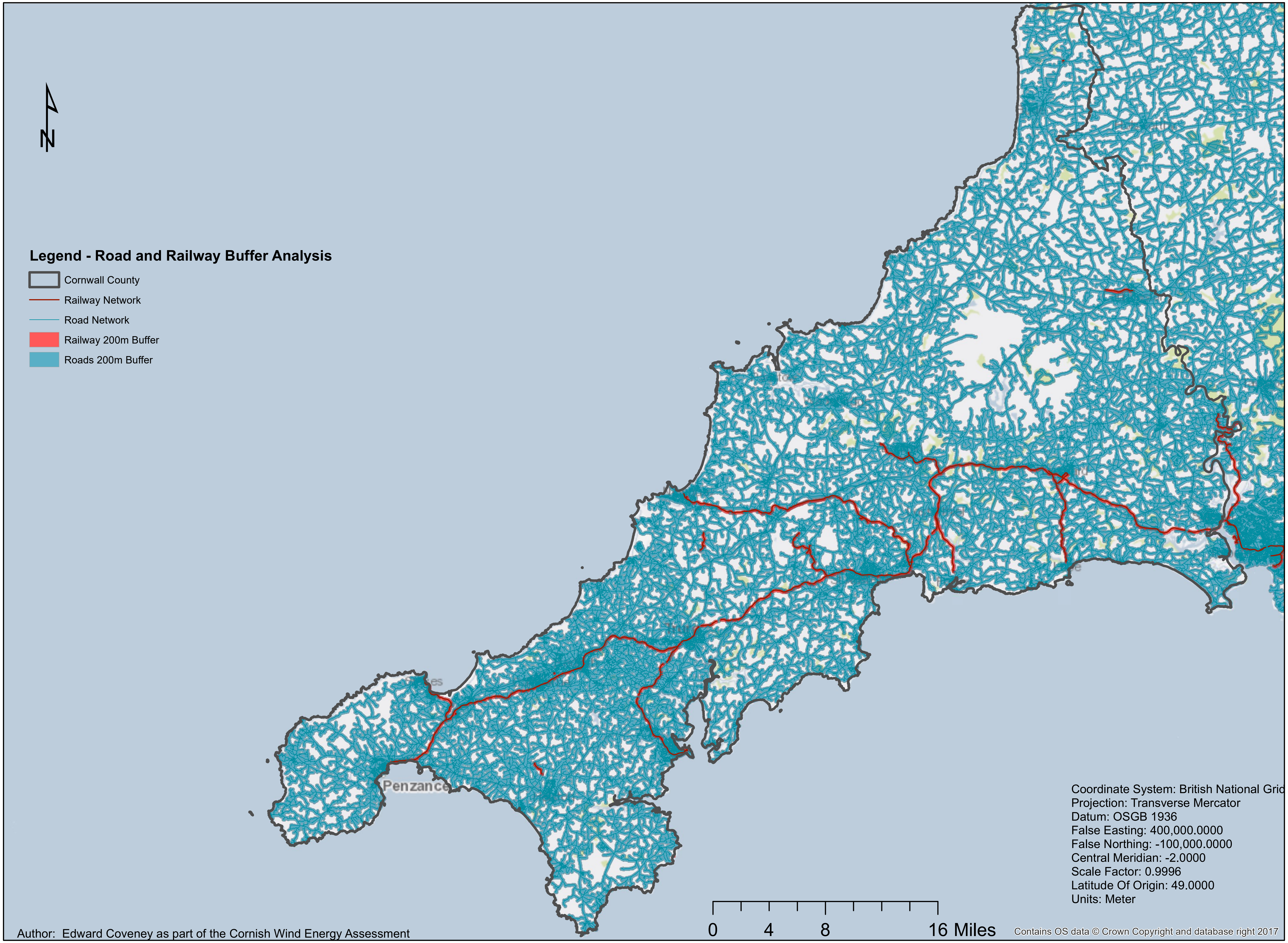
```
    layers: 'thesis:vestas_super_site3',
      transparent: "true",
    format: "image/png"
       });
       var site_4 =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:vestas_super_site4',
      transparent: "true",
    format: "image/png"
       });
       var site_5 =
L.tileLayer.wms('http://localhost:8090/geoserver/wms/thesis?', {
    layers: 'thesis:enercon_super_site1',
      transparent: "true",
    format: "image/png"
       });

var baseMaps = {
    "OSM": baseosm
    };

   var overlayMaps = {
    "Identified Site 1": site_1,
    "Identified Site 2": site_2,
    "Identified Site 3": site_3,
    "Identified Site 4": site_4,
    "Identified Site 5": site_5
    };


   L.control.layers(baseMaps, overlayMaps).addTo(map);
  </script>
</body>
</html>
```

9.5 Appendix 5 – Geoserver style example for site selection

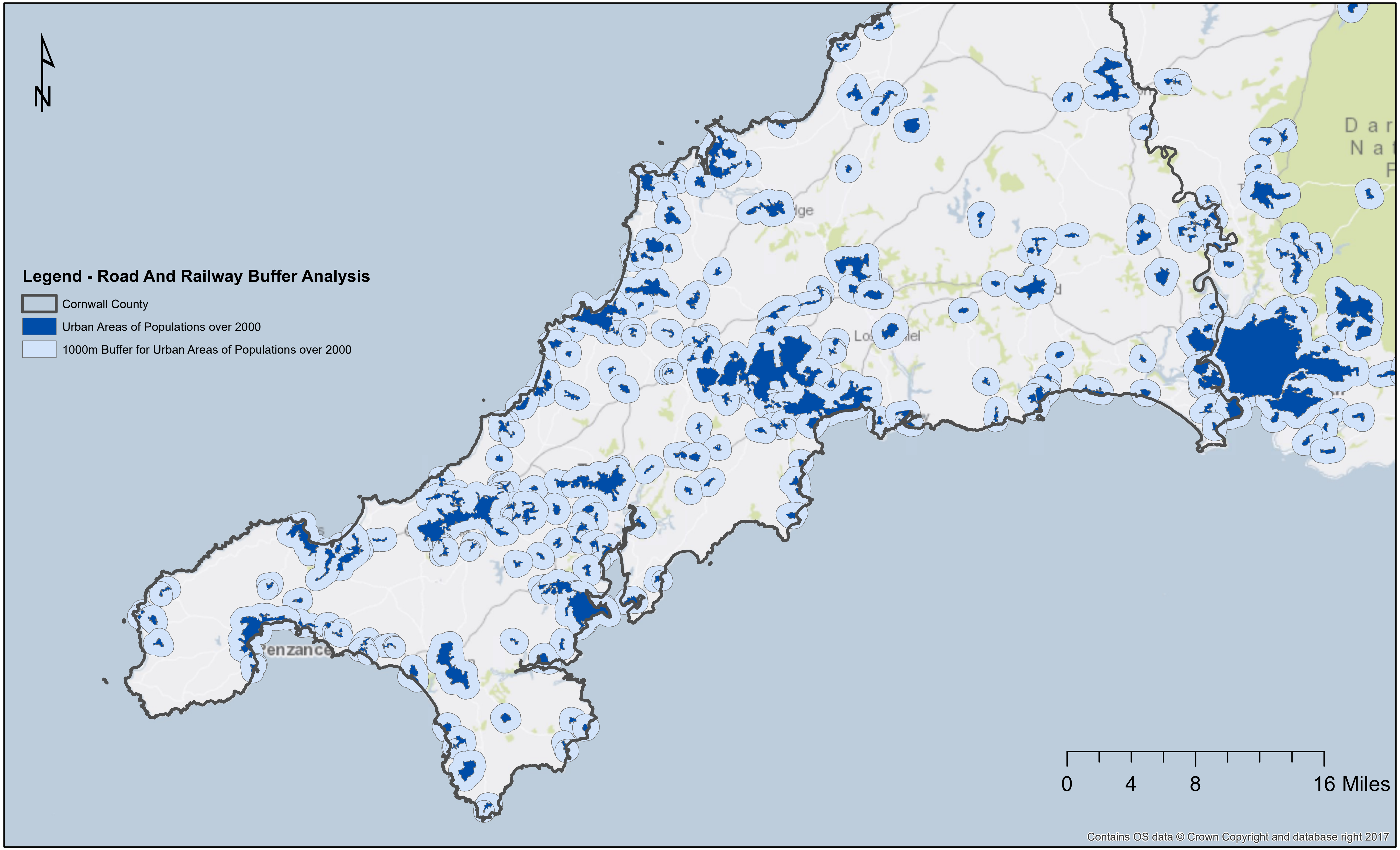
```
<?xml version="1.0" encoding="UTF-8"?>
<StyledLayerDescriptor version="1.0.0" xmlns="http://www.opengis.net/sld"
xmlns:ogc="http://www.opengis.net/ogc"
  xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://www.opengis.net/sld
http://schemas.opengis.net/sld/1.0.0/StyledLayerDescriptor.xsd">
  <NamedLayer>
    <Name>site 3</Name>
    <UserStyle>
    <Title>Site 3</Title>
    <Abstract>Polygons of interest for site 3</Abstract>
      <FeatureTypeStyle>
      <Rule>
       <Name>Point of Turbine</Name>
       <Title>Site 3- point of turbine</Title>
       <ogc:Filter>
         <ogc:PropertyIsEqualTo>
           <ogc:PropertyName>ident</ogc:PropertyName>
           <ogc:Literal>1</ogc:Literal>
         </ogc:PropertyIsEqualTo>
       </ogc:Filter>
```

```xml
        <PolygonSymbolizer>
          <Fill>
            <CssParameter name="fill">#29088A</CssParameter>
            <CssParameter name="fill-opacity">0.75</CssParameter>
          </Fill>
          <Stroke>
            <CssParameter name="stroke">#29088A</CssParameter>
            <CssParameter name="stroke-width">2</CssParameter>
          </Stroke>
        </PolygonSymbolizer>
        </Rule>
         <Rule>
        <Name>Full Extent of Site</Name>
        <Title>Site 3-site bounderies</Title>
        <ogc:Filter>
          <ogc:PropertyIsEqualTo>
            <ogc:PropertyName>ident</ogc:PropertyName>
            <ogc:Literal>2</ogc:Literal>
          </ogc:PropertyIsEqualTo>
        </ogc:Filter>
        <PolygonSymbolizer>
          <Fill>
            <CssParameter name="fill">#3A01DF</CssParameter>
            <CssParameter name="fill-opacity">0.5</CssParameter>
          </Fill>
          <Stroke>
            <CssParameter name="stroke">#3A01DF</CssParameter>
            <CssParameter name="stroke-width">1</CssParameter>
          </Stroke>
        </PolygonSymbolizer>
        </Rule>
         <Rule>
        <Name>Visbility</Name>
        <Title>Site 3- Where the turbine would  visible from</Title>
        <ogc:Filter>
          <ogc:PropertyIsEqualTo>
            <ogc:PropertyName>ident</ogc:PropertyName>
            <ogc:Literal>3</ogc:Literal>
          </ogc:PropertyIsEqualTo>
        </ogc:Filter>
        <PolygonSymbolizer>
          <Fill>
            <CssParameter name="fill">#642EFE</CssParameter>
            <CssParameter name="fill-opacity">0.4</CssParameter>
          </Fill>
        </PolygonSymbolizer>
        </Rule>
       </FeatureTypeStyle>
     </UserStyle>
   </NamedLayer>
</StyledLayerDescriptor>
```

Map Book Figure 1 - Road and Railway 200m Buffer Analysis



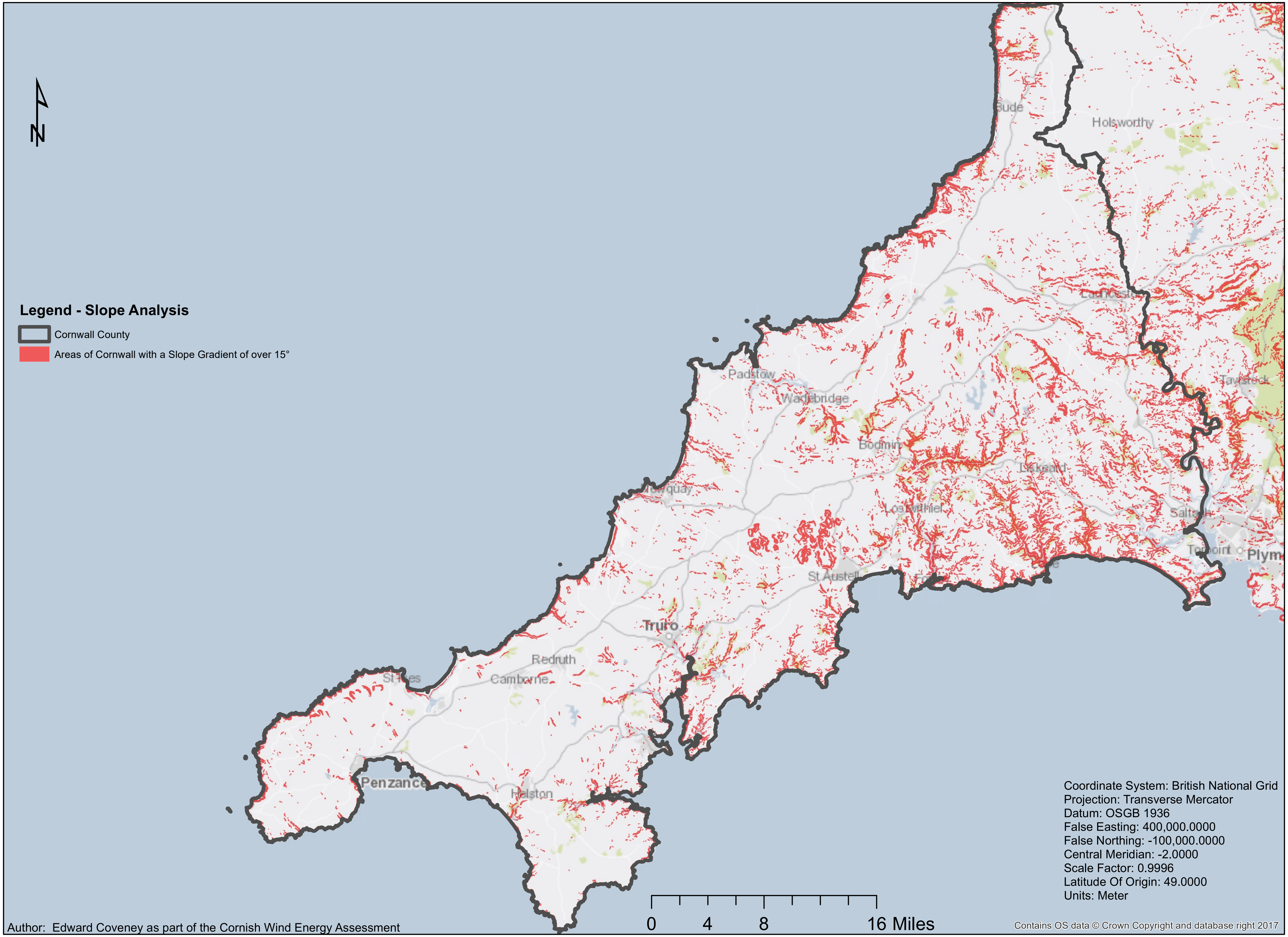
Map Book Figure 2 - Urban Areas of Populations over 2000 and Buffer Analysis



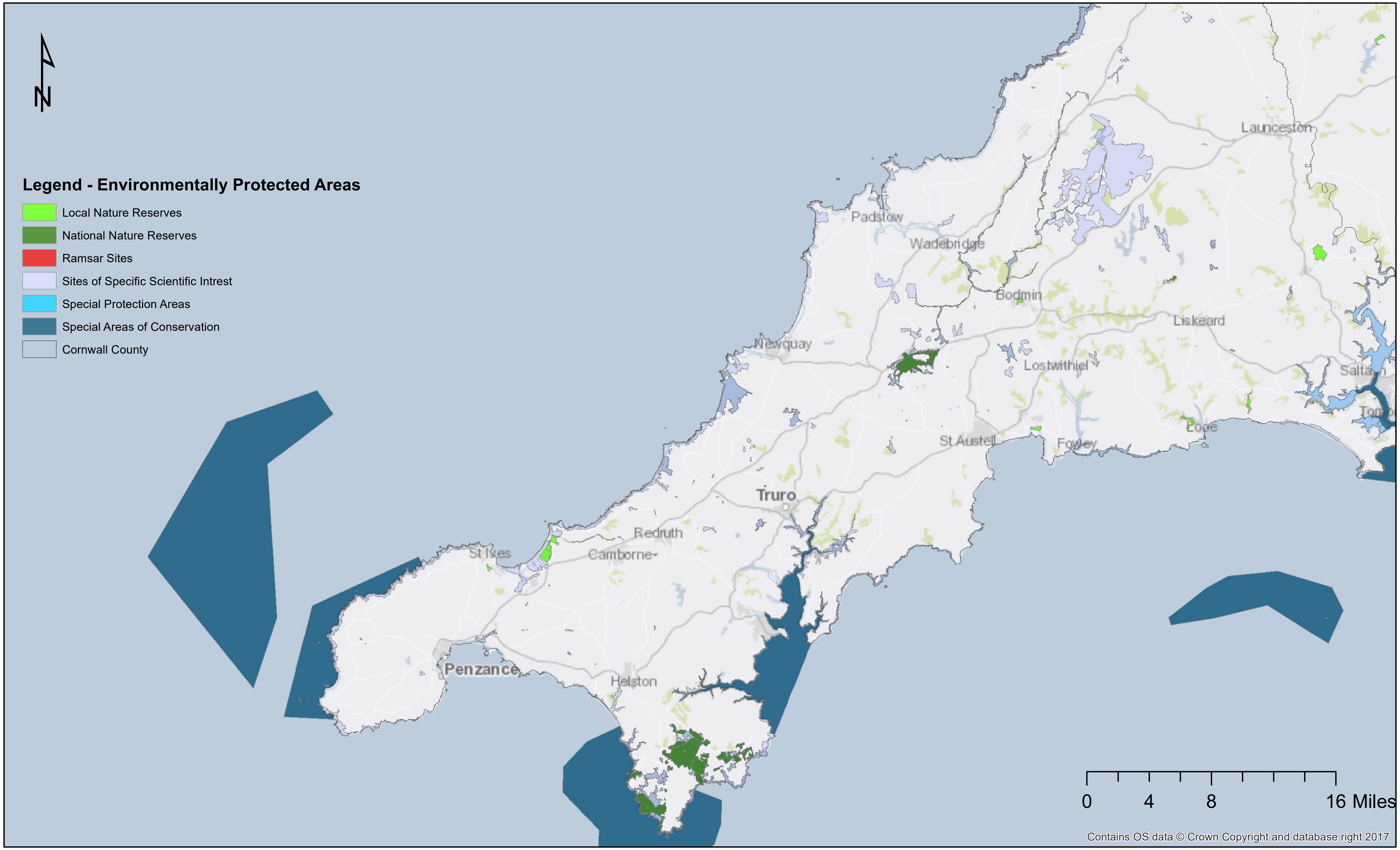
Coordinate System: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
False Easting: 400,000.0000
False Northing: -100,000.0000
Central Meridian: -2.0000
Scale Factor: 0.9996
Latitude Of Origin: 49.0000
Units: Meter

Author: Edward Coveney as part of the Cornish Wind Energy Assessment

Map Book Figure 3 - Slope Analysis



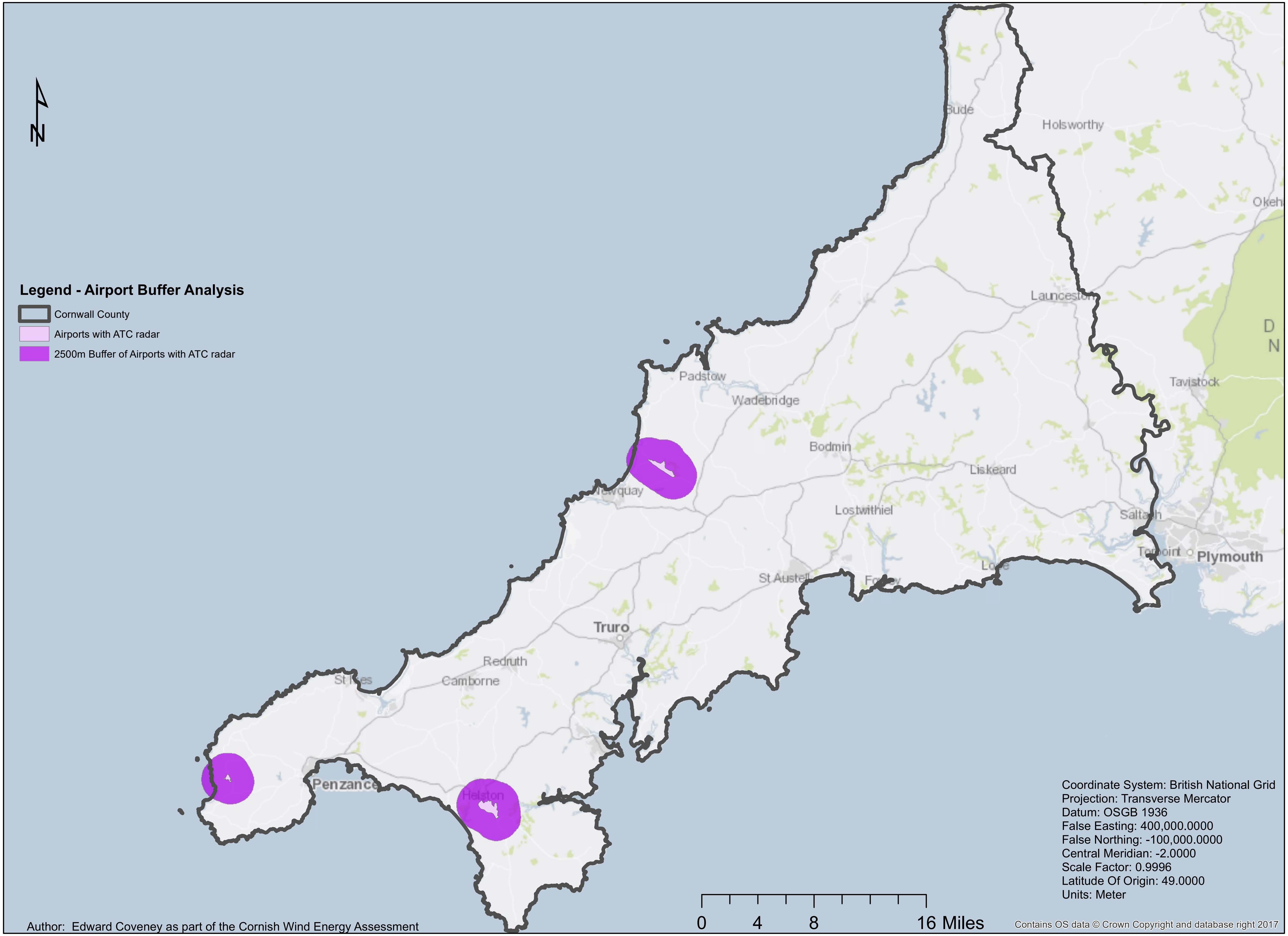
Environmentally Protected Areas in Cornwall



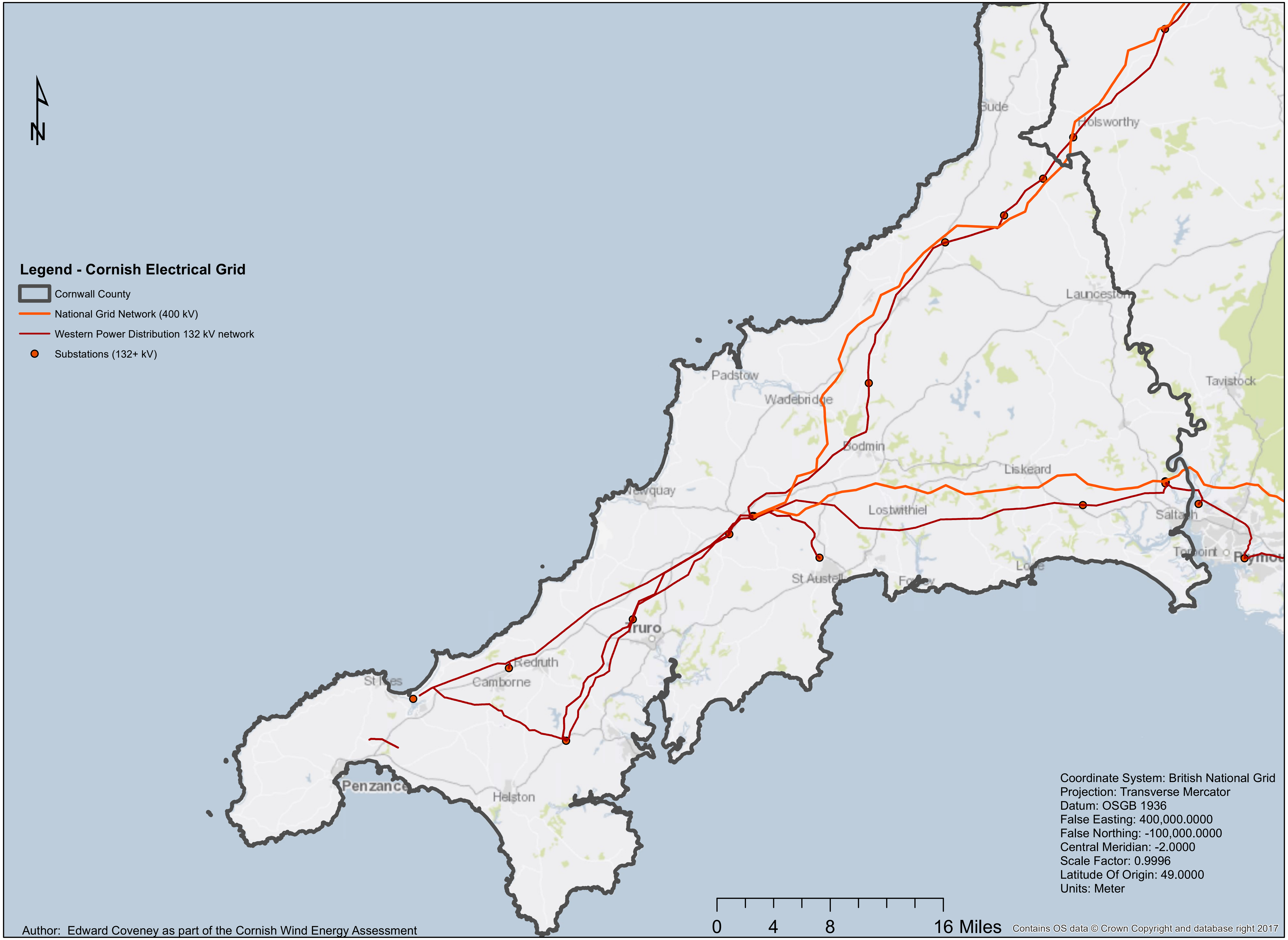
Coordinate System: British National Grid
Projection: Transverse Mercator
Datum: OSGB 1936
False Easting: 400,000.0000
False Northing: -100,000.0000
Central Meridian: -2.0000
Scale Factor: 0.9996
Latitude Of Origin: 49.0000
Units: Meter

Author: Edward Coveney as part of the Cornish Wind Energy Assessment

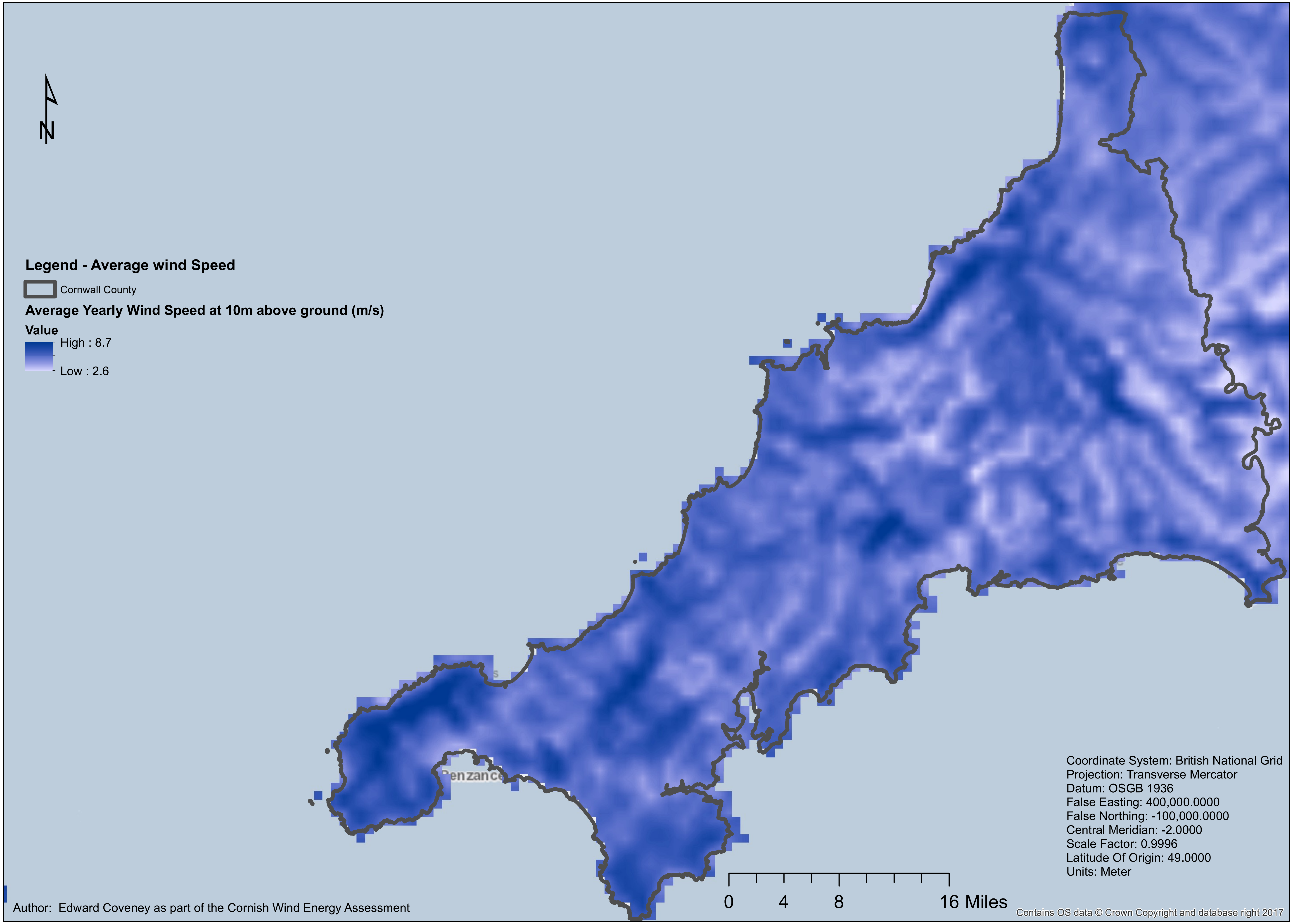
Map Book Figure 5 - ATC Radar Buffer Analysis



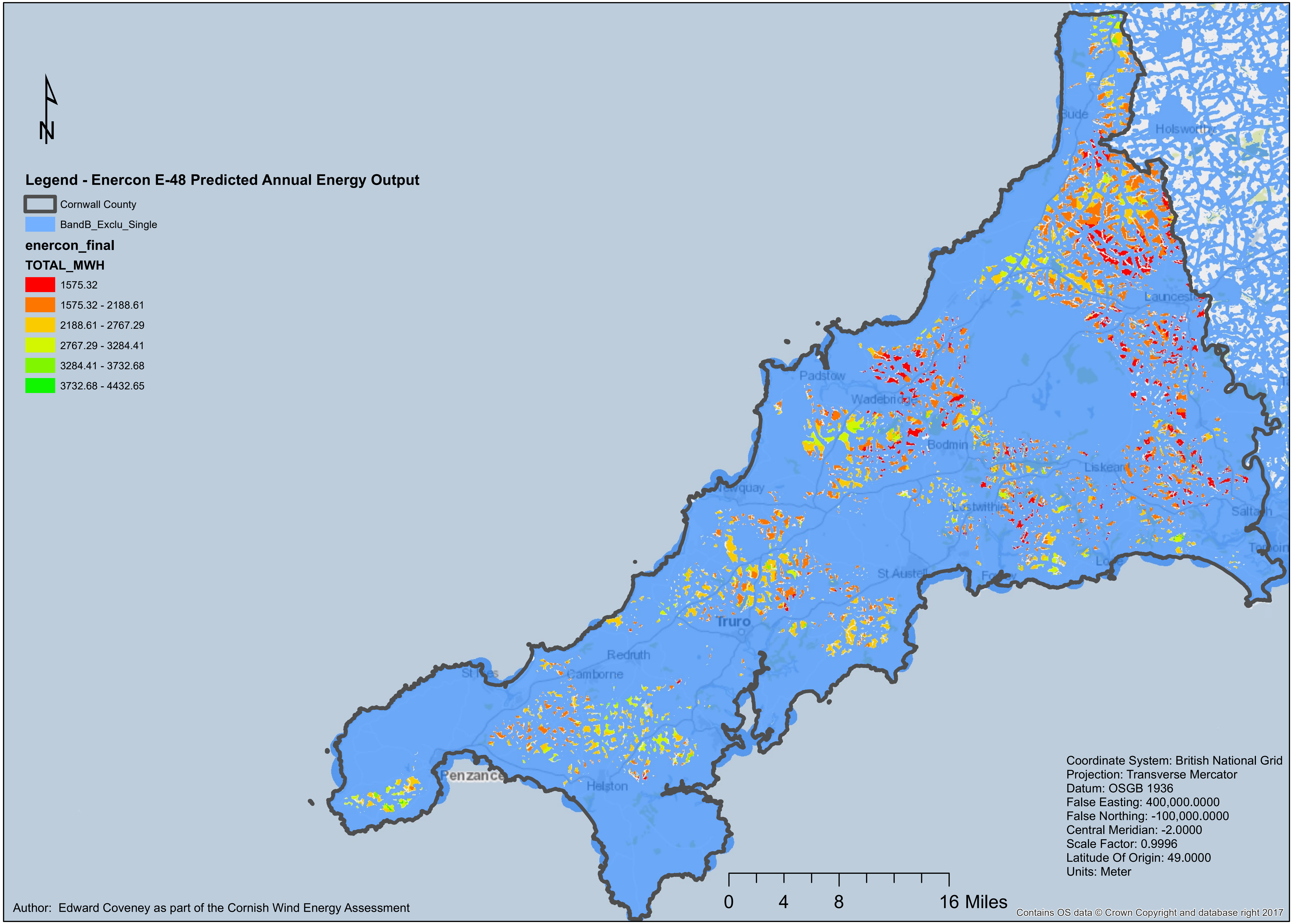
Map Book Figure 6 - Cornwalls 132+ kV Electrical Grid Network



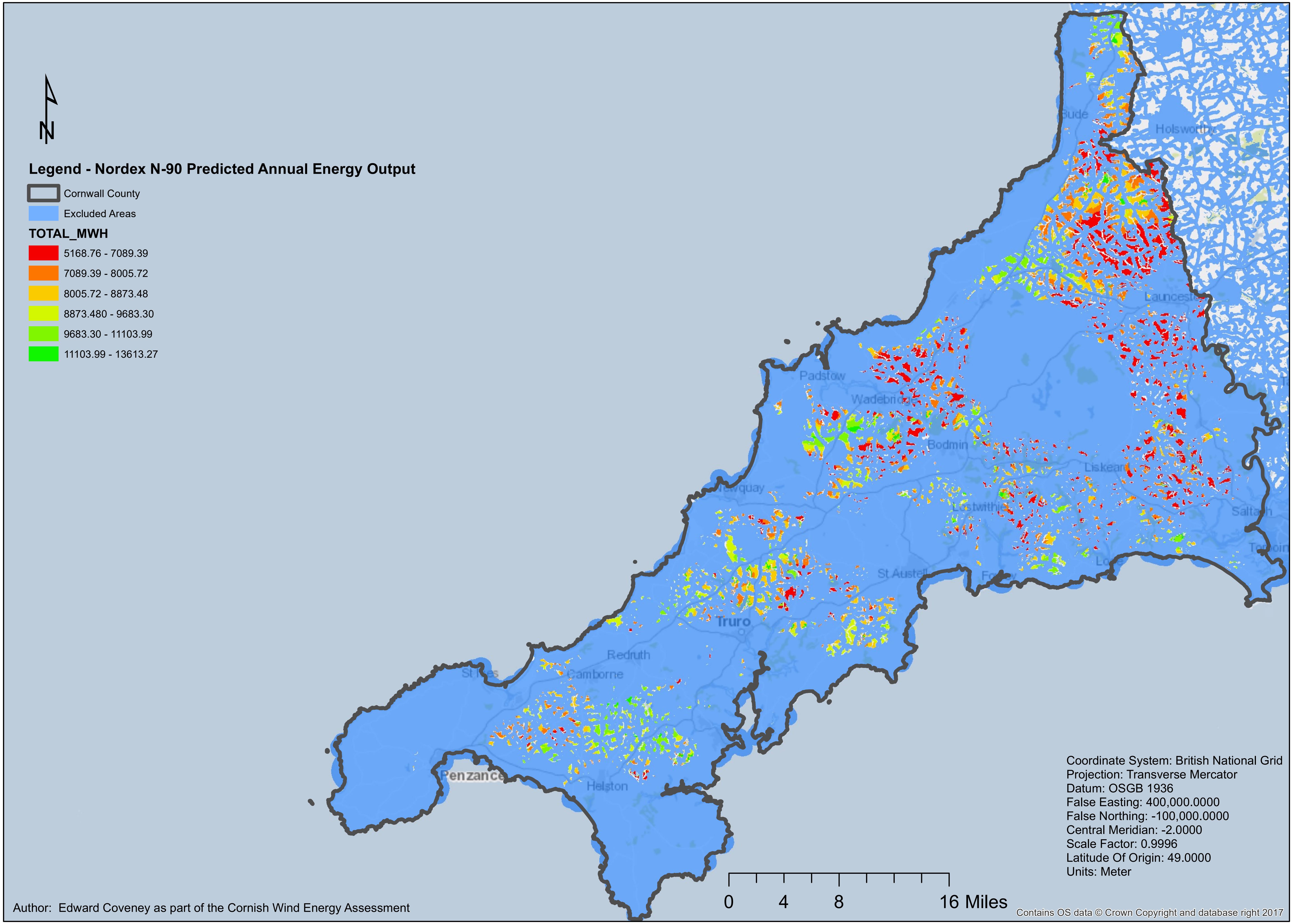
Map Book Figure 7 - Average Yearly Wind Speed at 10m above ground (m/s)



Map Book Figure 8 - Enercon E-48 Predcted Annual Energy Output (MWh)



Map Book Figure 9 - Nordex N-90 Predcted Annual Energy Output (MWh)



Map Book Figure 10 - Vestas V-126 Predcted Annual Energy Output (MWh)