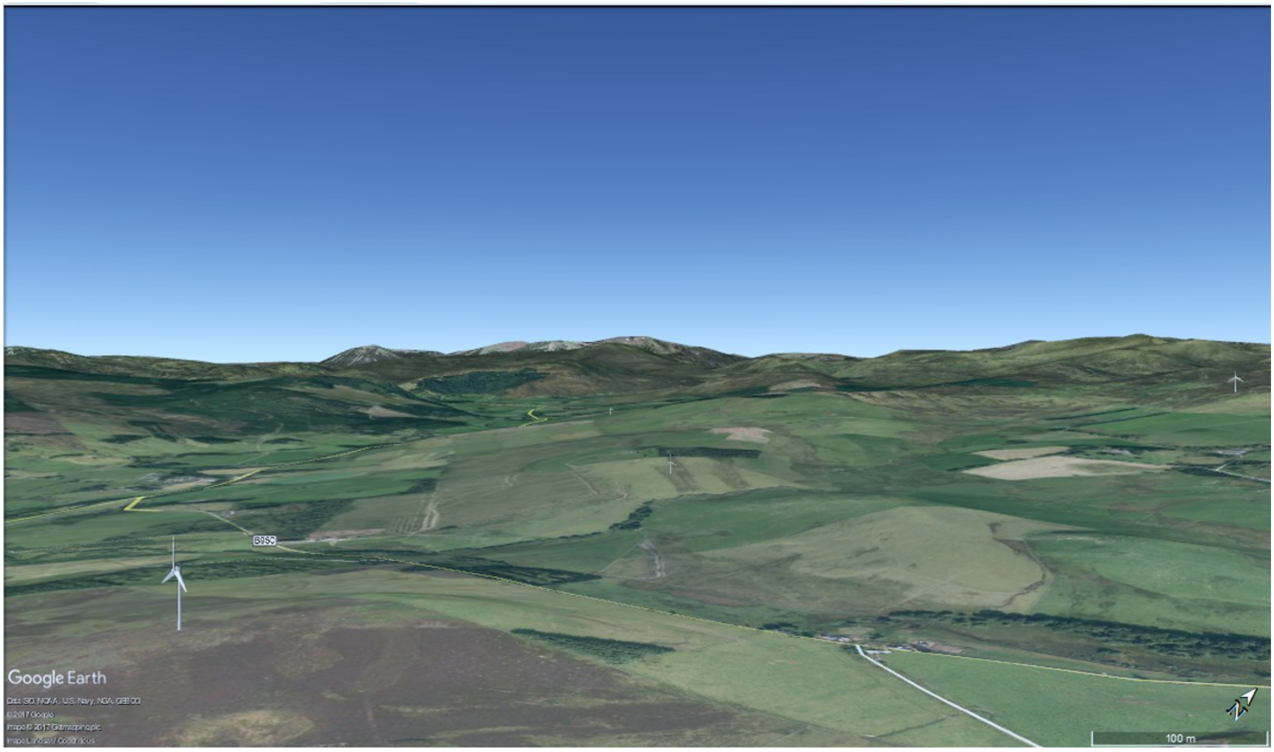
Identifying Suitable Sites for Single Medium-Scale Wind Turbines around Kindrogan using GIS and Field Techniques



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Executive Summary

Suitable areas have been selected for medium-scale wind turbines east of Kindrogan Field Centre, Blairgowrie using ArcGIS. Within these areas, four suitable wind turbine sites are located that avoid buildings, forests, and environmental and cultural designations; and include areas where wind speed is >6ms^{-1} at 25m height; and where existing electricity grid and access roads are < 1km.

Viewshed analyses and photomontages at the turbine locations establish the visibility and visual impact of the sites in the local area, respectively, and are used to select two example wind turbine sizes: WTN 250kW 30m hub height and WTN 500kW 50m hub height.

The financial viability of the sites is mostly dependent on wind speed, turbine size, and length of access and electricity grid infrastructure. The larger turbine sites provide higher returns, but at the expense of visual impact and difficult access. The smaller turbine sites provide negative or small returns, but have a lesser visual impact.

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Acknowledgement

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1. Introduction

Scotland is home to one of the best wind resources in Europe making it an ideal location for wind turbines, an important source of renewable energy (Wind Energy Scotland, 2017). The Scottish Government have set a target for renewable sources to generate 100 percent of Scotland's gross annual electricity consumption by 2020 and have identified wind energy as a major part of this goal (Scottish Government, 2016).

This study focuses on identifying suitable sites for medium-scale single wind turbines (100 - 500 kW; Hau, 2013), east of the Kindrogan Field Centre, Blairgowrie (Figure 1), to export energy to the national grid. As identified by the local council, the Blairgowrie area is known to have an exceptional wind resource (Perth & Kinross Council, 2005) and has existing 11kV electricity grid network, making it an ideal location to identify sites suitable for wind turbines. The prevailing wind direction in this area is from the south, south-west and west (Met Office, 2016).

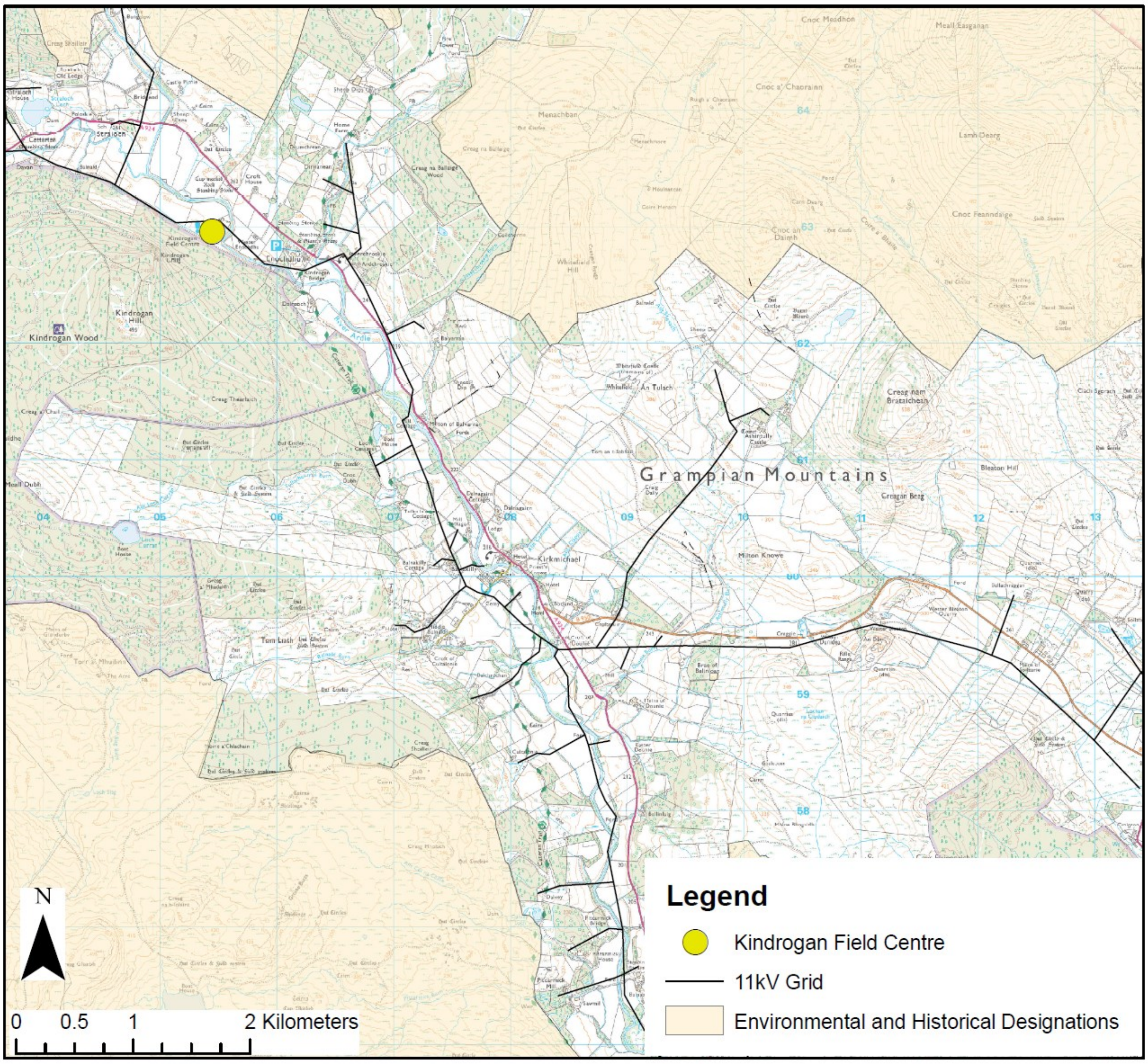

Figure 1: Extent of study. Data from: DIGIMAP, Scottish and Southern Energy. Background map: DIGIMAP

In this study GIS techniques and in-field verification is used to answer the following research questions:

- Which areas are suitable for medium-scale wind turbines?
- How suitable are the identified wind turbine sites in terms of planning permission potential and economic viability?
- How reliable are GIS techniques and datasets in identifying suitable sites?

2. Methodology

The methodology is described in Figure 2. Suitable sites were identified using the criteria in Table 1 using ArcGIS. Desktop study assumptions were tested in the field, followed by financial and visibility analyses post-field work.

2.1. Site Selection

Wind turbine sites were selected based on criteria illustrated in Table 1 using ArcGIS Buffer and Subtract tools. These criteria are divided into three main headings: wind resource, cost and planning permission potential.

Using the aforementioned criteria, four wind turbine sites (WT1, WT2, WT3, and WT4) were selected within the suitable areas where wind resource and proximity to the electricity grid and access tracks were prioritised (Figure 3).

Site selection criteria was tested in the field by comparing field observations with maps created in ArcGIS and recording the results in a pre-designed field template (see Appendix A).

Table 1: Criteria and data used to select suitable sites

	Criteria	Data Source	Justification
Wind Resource	Wind Speed	NCIC 25m and 45m (Scottish & Southern Electricity Networks, 2017)	Wind turbine sites with wind speeds > 6ms^{-1} at 25m were selected to optimise electricity generation.
	Forests	National Forest Inventory (Forest Research, 2017)	Sites were selected >200m away from forests to minimise wind shade effect.
Cost	Electricity Grid	Scottish and Southern Energy (SSE; Scottish & Southern Electricity Networks, 2017)	Wind turbine sites were selected in areas <1km from the electricity grid. Sites situated further away would be too costly to install.
	Access to the site	Ordnance Survey 1:25,000 OS Explorer (Ordnance Survey, 2017)	Sites were selected <1km from existing access tracks to minimise cost of constructing new access road.
Planning Permission	Buildings	Ordnance Survey MasterMap (Ordnance Survey, 2017)	Wind turbine sites were placed >350m from buildings to prevent noise disturbance to residents (Barclay, 2010).
	Environmental Designations	Scottish Natural Heritage (SNH): Special Protected Areas (SPA), Special Sites of Scientific Interest (SSSI) (Historic Environment Scotland, 2017)	SSSI's and SPA's were avoided to avoid opposition during planning process.
	Cultural Designations	Historic Scotland: Listed Buildings and Scheduled Monuments (Historic Environment Scotland, 2017)	Cultural designations such as scheduled monuments and archaeological sites were avoided to avoid opposition during planning process.

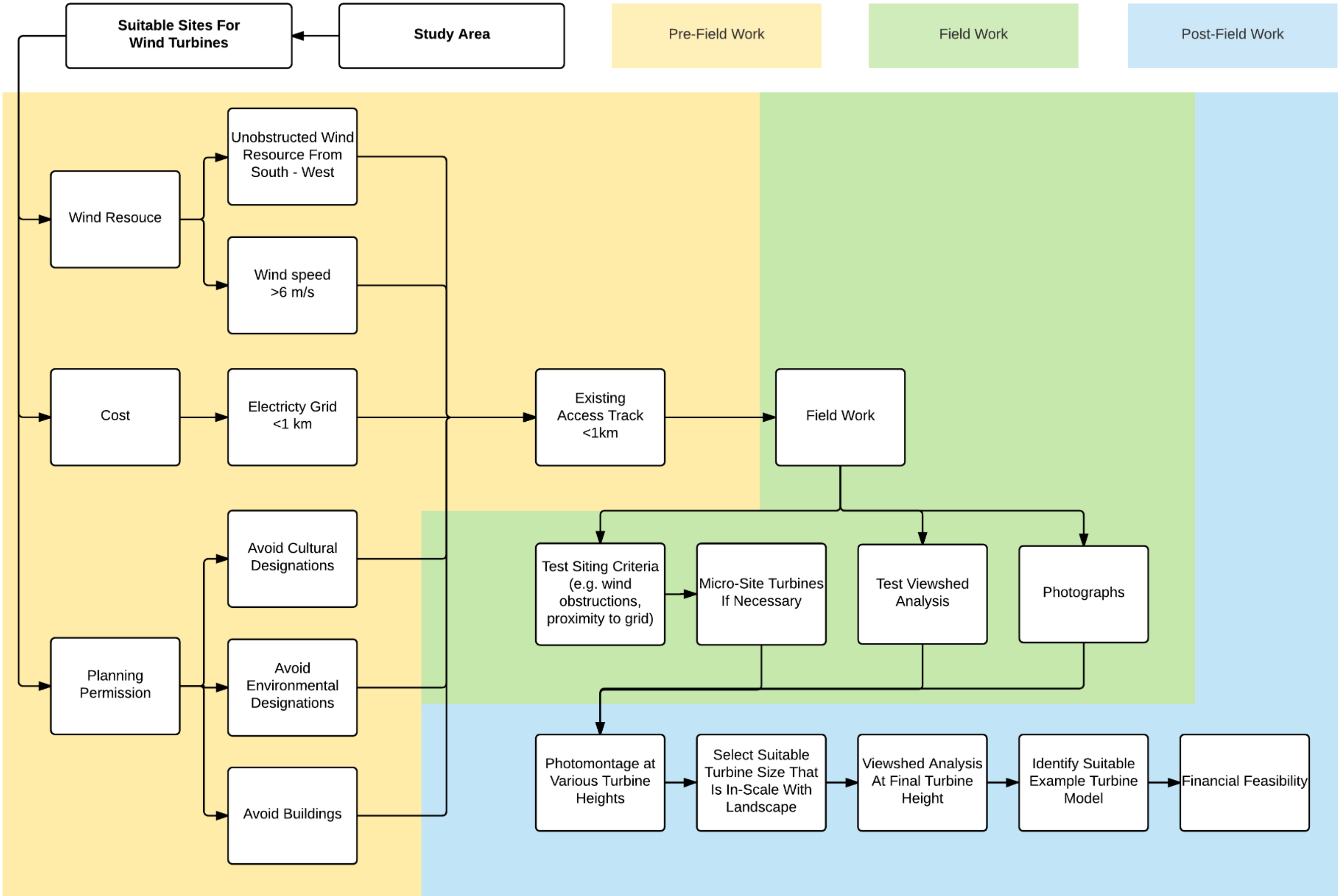

Figure 2: Overview of methodology

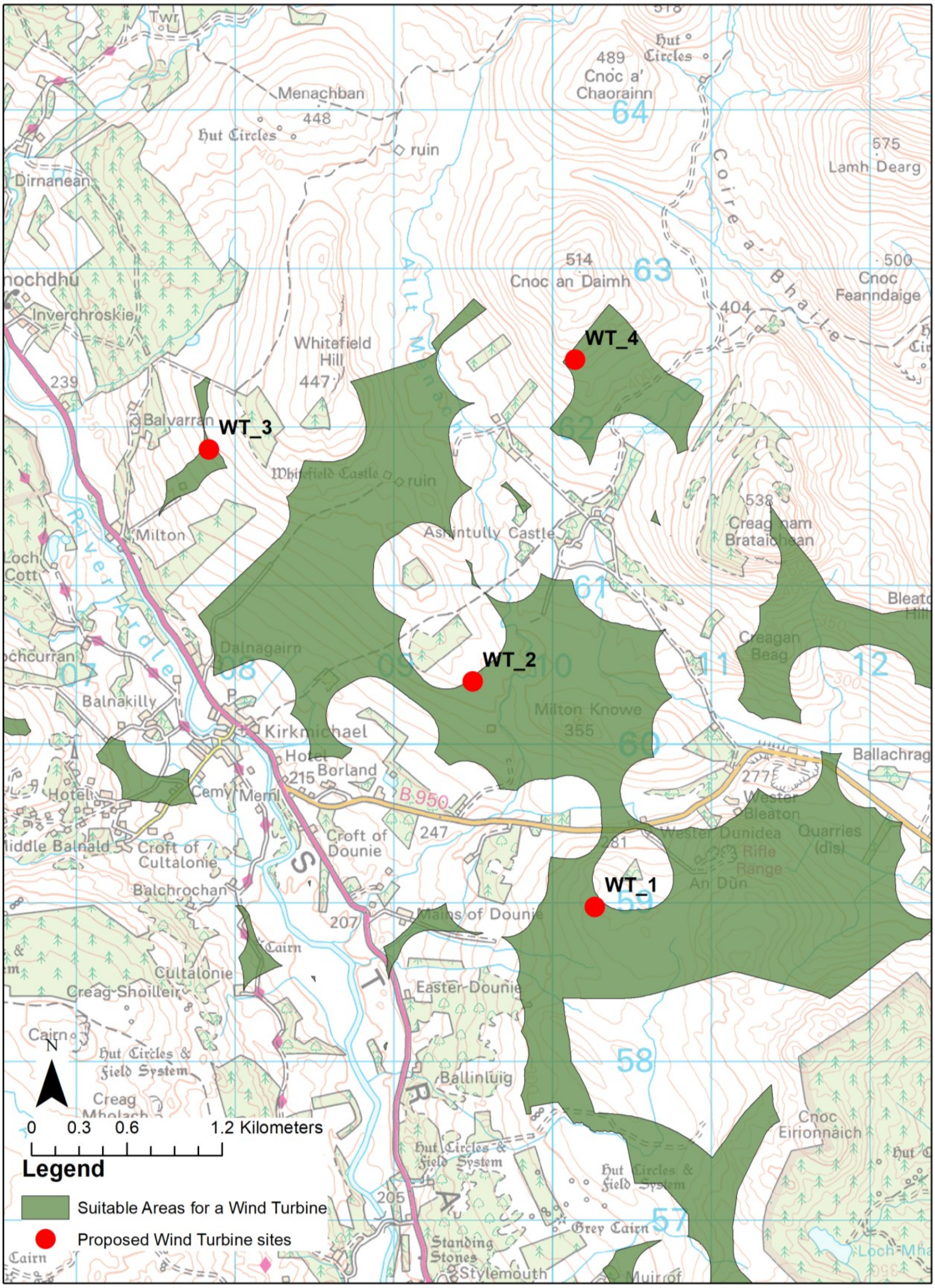

Figure 3: Suitable areas for a wind turbine identified using Table 1

2.2. Viewshed Analysis

Using sites selected in Section 2.1, viewshed analyses were carried out using the ArcGIS Viewshed tool. Viewshed analyses were run to establish the visibility of the wind turbine at proposed hub heights (i.e. blade axis) and tip heights (i.e. maximum height) using a 5m DTM at heights 30m and 50m allowing identification of visible and non-visible areas.

A viewshed analysis using an existing wind turbine at Drumderg Wind Farm was created. This viewshed was tested in the field by following a transect through visible and non-visible areas to establish the reliability the 5m DTM in creating viewshed analyses.

2.3. Photomontages

To assess the visual impact of wind turbines in the landscape, photomontages were created using photographs from the field (Scottish Natural Heritage, 2009). It is important to site turbines are in scale with the landscape because large wind turbines will appear out of scale and obtrusive in smaller-scale landscapes, which are often characterised in relation to buildings and features (Scottish Natural Heritage, 2014).

Two turbine models were designed on 3D SketchUp using the turbine dimensions described in section 2.5. The photomontage was carried out by superimposing the modelled turbines onto photographs of each turbine site using Adobe Photoshop. The visual impact of these was assessed using the Scottish Natural Heritage (2009) guidance.

2.4. Wind Speed

Wind speed was calculated using the National Climate Information Centre (NCIC) dataset at 25m and 45m (Table 1). In order to extrapolate the wind speed at the turbine hub height, the shear exponent (α) must first be calculated:

$$\alpha = \frac{ln\left({}^{V_{45}}/_{V_{25}}\right)}{ln\left({}^{Z_{45}}/_{Z_{25}}\right)}$$

where: V_{45} = wind speed (m/s) at 45m

V_{25} = wind speed (m/s) at 25m

Z_{45}= height in metres above ground level (45m for NCIC)

Z_{25} =height in metres above ground level (25m for NCIC)

Wind speed at hub height (V_{hub}) is calculated using the following formula:

$$V_{hub} = V_{45} * \left({}^{Z_{hub}}/_{Z_{45}}\right)^{\alpha}$$

where: Z_{hub} = Wind turbine hub height above ground level

Wind speed calculations are based on Danish Wind Association (2003).

2.5. Annual Energy Production (AEP)

Using the wind speed at the turbine hub height, the AEP in kWh can be calculated. This was completed using the Danish Wind Association (2003) 'Wind Turbine Power Calculator' and the power curve from two example wind turbines that suited the site selection criteria:

- Wind Technik Nord (WTN) 250kW, 30m hub height and 45m blade tip height
- Wind Technik Nord (WTN) 500kW, 50m hub height and 74m blade tip height

2.6. Financial Calculations

Using the AEP, financial estimates were calculated to allow the turbine sites to be compared quantitatively. A summary of the input assumptions is given in Table 2. Calculations were completed using the Internal Rate of Return (IRR) over a 25 year lifespan, which is the typical length of time a wind turbine is granted planning permission (Perth & Kinross Council, 2005).

Table 2: Description of financial calculation inputs

Input	Description
AEP	Calculated in section 2.5. AEP * (export rate + Feed in Tariff) = income per year.
£ / kWh of energy	Export rate (£0.0503) + Feed in Tariff (£0.0258) = £0.0761 (Ofgem, 2017)
Operation and Maintenance (O&M)	Estimated cost of operation and maintenance per year
Turbine cost	Estimated cost of turbine (The Hydro and Wind Company, 2017)
Installation	Estimated cost of installation
Development Fees	Estimated cost of acquiring necessary permissions (e.g. planning permission, legal land rights, securing grid connection etc.)
Grid connection	Estimate based on £150/metre for larger turbine and £100/metre or smaller turbine
Access track	Estimate based on £80/metre for larger turbine and £50/metre for smaller turbine

3. Results

Table 3: Wind turbine site results

Wind Turbine	WT1	WT2	WT3	WT4
Wind Speed ms^{-1}	8.43	7.29	6.51	9.89
Proximity to Grid (m)	450	200	1000	850
Length of Access Track (m)	800	300	1000	800

3.1. WT1

A larger turbine with a 50m hub and a 74m tip was chosen for WT1. This decision was made to keep the turbine in-scale with the large hill it is located on (Figure 4).

The site is clear from any trees allowing for an excellent wind resource (Table 3). Access to the site is poor as the ground is covered by thick heather on a steep gradient and would require the construction of an 800m track. The electricity grid is located 450m away at the bottom of the hill in the valley. The site is visible from a large proportion of visually sensitive areas such as buildings and roads (Figure 5).

Figure 4a: Photomontage of Wind Turbine 1 with a 30m hub height

Smaller turbine is difficult to see from a distance.

Figure 4b: Photomontage of Wind Turbine 1 with a 50m hub height

Larger turbine is in scale with the large open landscape.

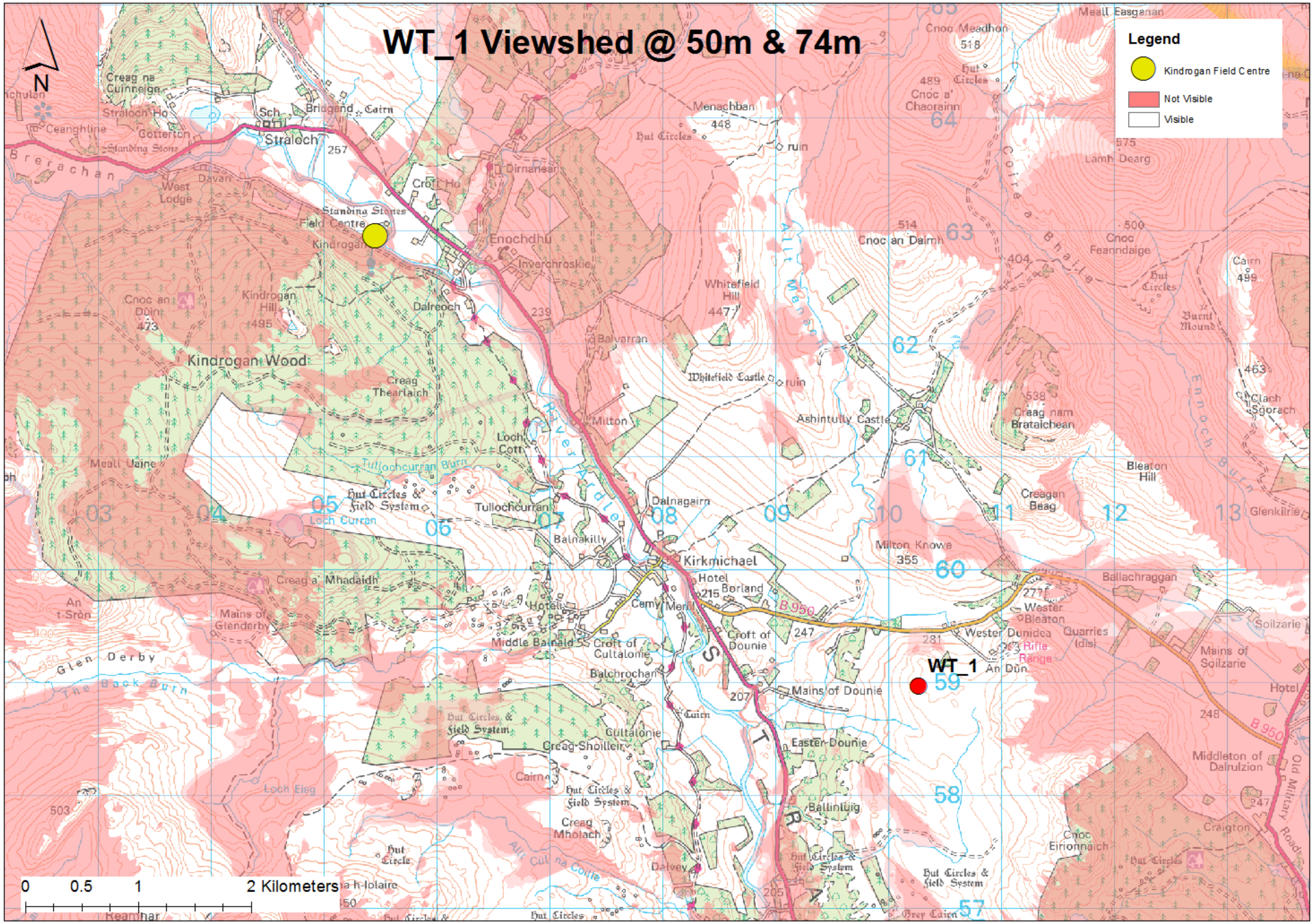

Figure 5: Viewshed Analysis for Wind Turbine 1. The site can clearly be seen from most habited locations within the valley.

3.2. WT2

A smaller turbine with a 30m hub and a 45m tip was chosen for this site. This decision was made to keep the turbine in-scale within the landscape due to its placement on flat open land, midway down the valley-side. The larger turbine would dwarf the existing features on the landscape (Figure 6).

WT2 has an excellent wind resource from all directions. The site is favourable in terms of the short access track and distance to the grid. Although, the site is in direct line of sight from some buildings and the B-road (Figure 7).

Figure 6a: Photomontage for Wind Turbine 2 at 30m hub height.

The turbine is in-scale with the surrounding landscape.

Figure 6b: Photomontage for Wind Turbine 2 at 50m hub height

The turbine appears large and obtrusive.

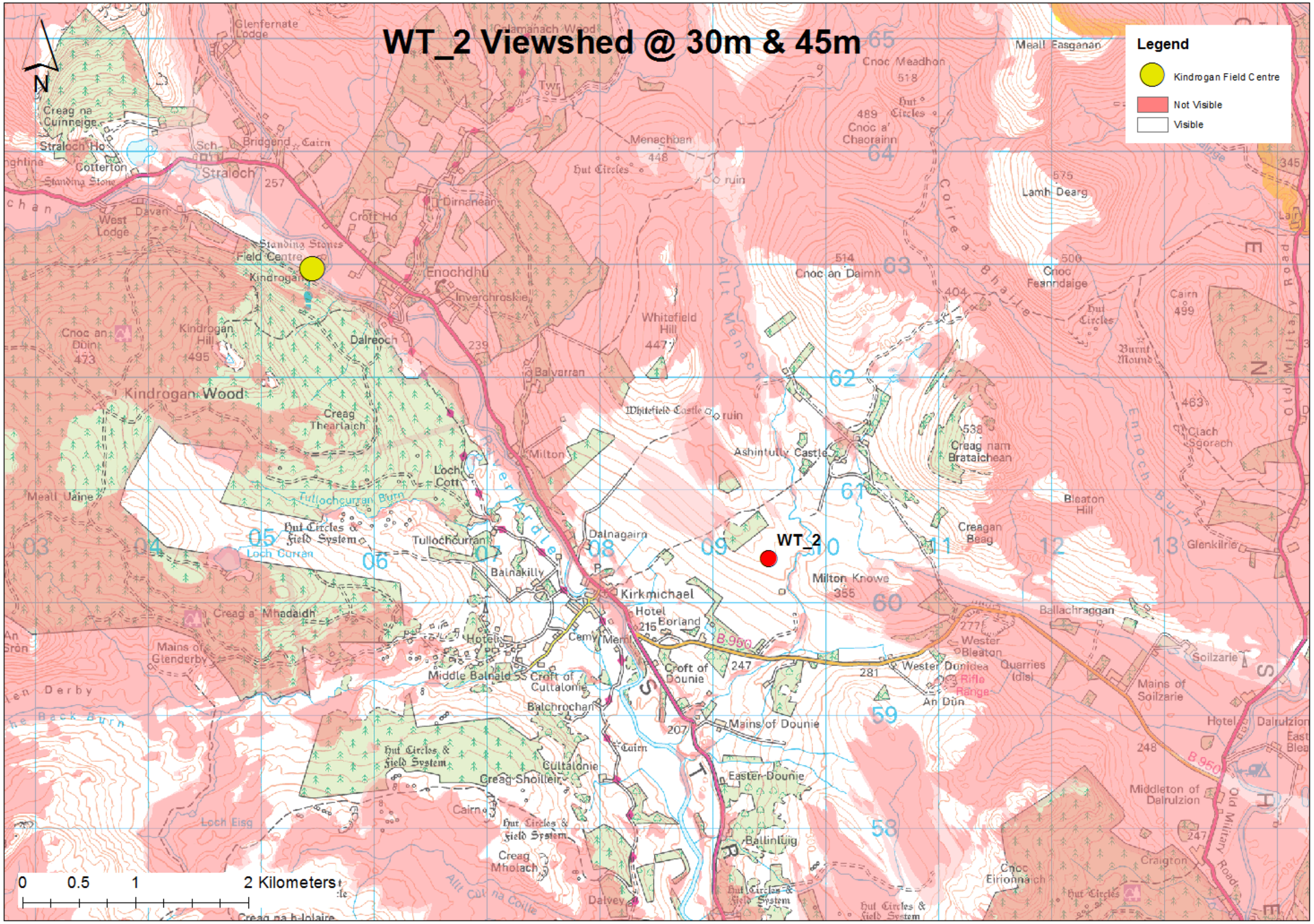

Figure 7: Viewshed Analysis of Wind Turbine 2. The turbine has reasonable visibility in the valley.

3.3. WT3

A smaller wind turbine with a 30m hub and a 45m tip was chosen for WT3. This decision was made to keep the turbine in-scale with the surrounding landscape, given its location midway down the valley-side (Figure 8).

The site is placed on a steeply inclined hill, and was relocated by ~20m in the field to avoid a fenced, rocky area. The access track identified on the 1:25,000 OS map is not suitable because it is too steep and narrow and therefore would require the construction of a new track 1000m long. The proximity to the electricity grid is at the top-end of our criteria, at 1000m. Eight buildings were visible on the other side of the valley, confirmed by the viewshed analysis (Figure 9)

Figure 8a: Photomontage for Wind Turbine 3 at 30m hub height

The turbine is in-scale with the surrounding landscape.

Figure 8b: Photomontage for Wind Turbine 3 at 50m hub height

The turbine appears large and obtrusive in the enclosed landscape.

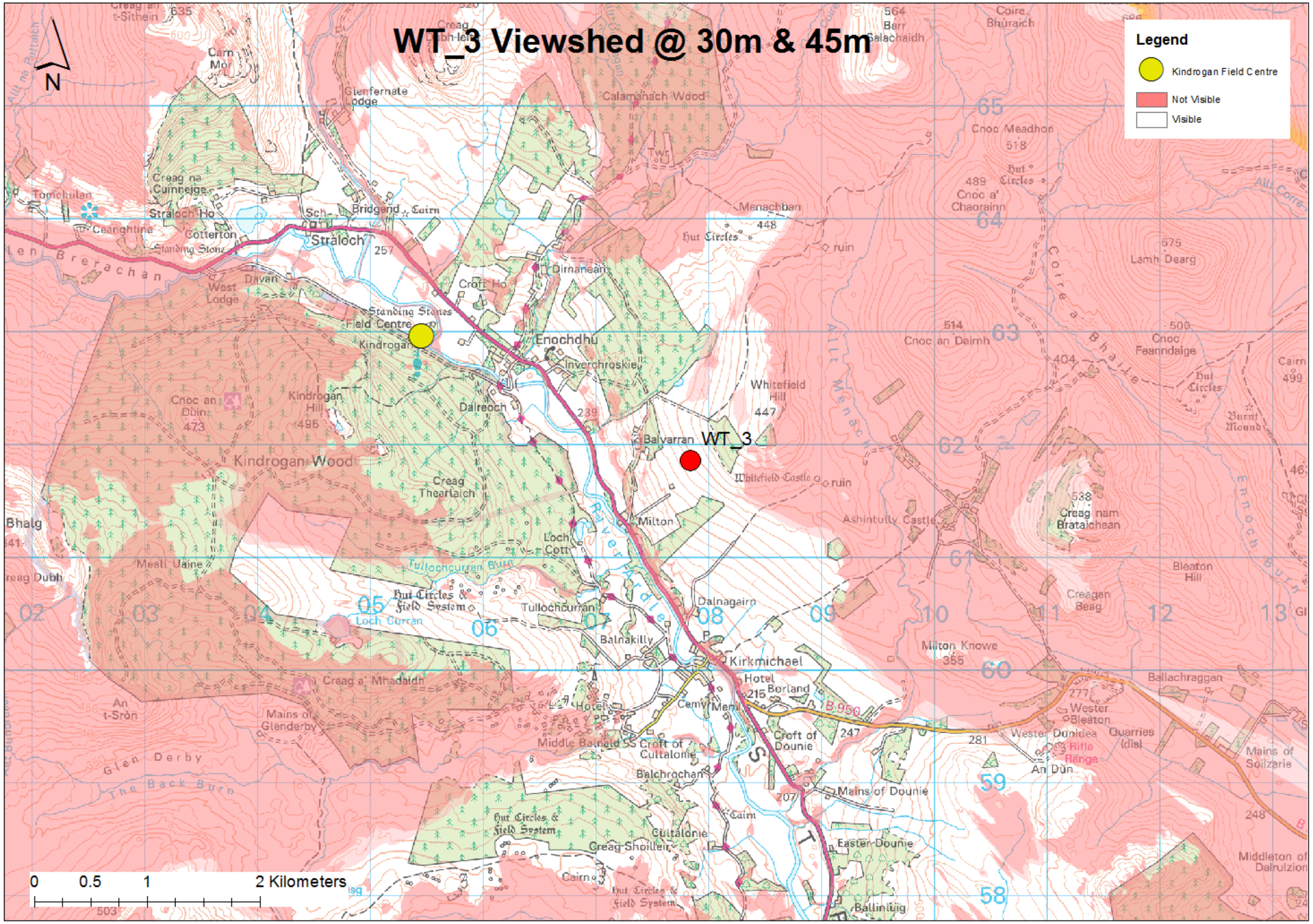

Figure 9: Viewshed Analyses of Wind Turbine 3. The wind turbine is highly visible from local roads and houses.

3.4. WT4

A larger turbine with a 50m hub and a 74m tip was chosen for this site due to its distance away from buildings and roads, and because of the large hill it is placed on (Figure 10).

Field observations revealed that the original site had a poor wind resource to the SW and the site was relocated to mitigate this, however the relocated turbine site is within an environmentally designated area (Figure 11). The accessibility to the turbine site was poor and would require the construction of an 800m track.

Figure 10a: Photomontage for Wind Turbine 4 at 30m hub height

The turbine is in-scale with the large open landscape.

Figure 10b: Photomontage for Wind Turbine 4 at 50m hub height

The turbine is in-scale with the large open landscape – allowing for a larger turbine to be chosen.

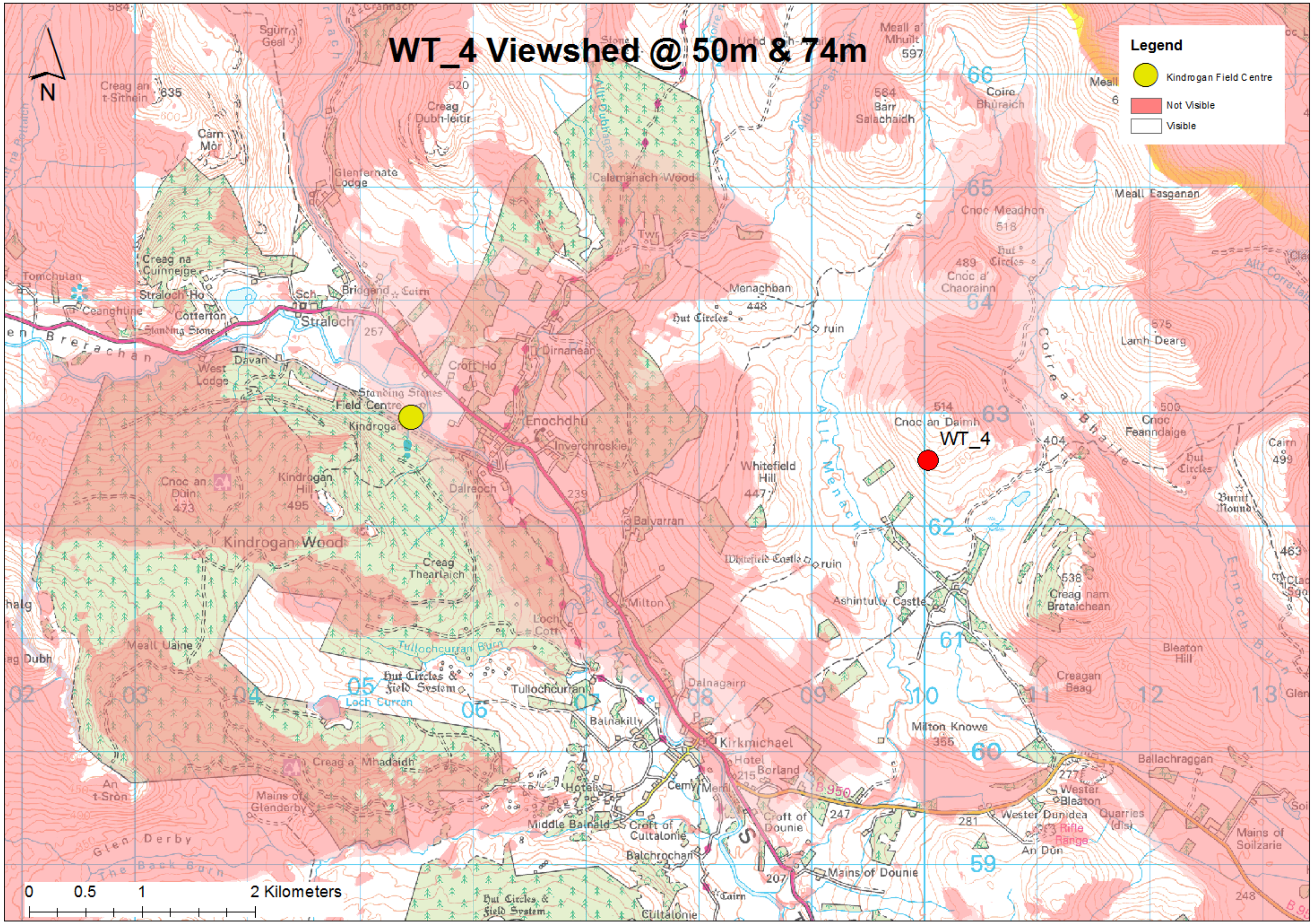

Figure 11: Viewshed Analysis of wind Turbine 4. The turbine has a reasonable visibility from local dwellings.

3.5. Field Testing of Viewshed Analysis

The viewshed analysis was tested on an existing wind turbine with a 67m hub and a 107m tip height to assess the accuracy of the 5m DTM (Figure 12). The observations made in the field agreed with the viewshed analysis except in areas where trees obstructed the line of sight. A Digital Surface Model (DSM) would be required to account for this discrepancy.

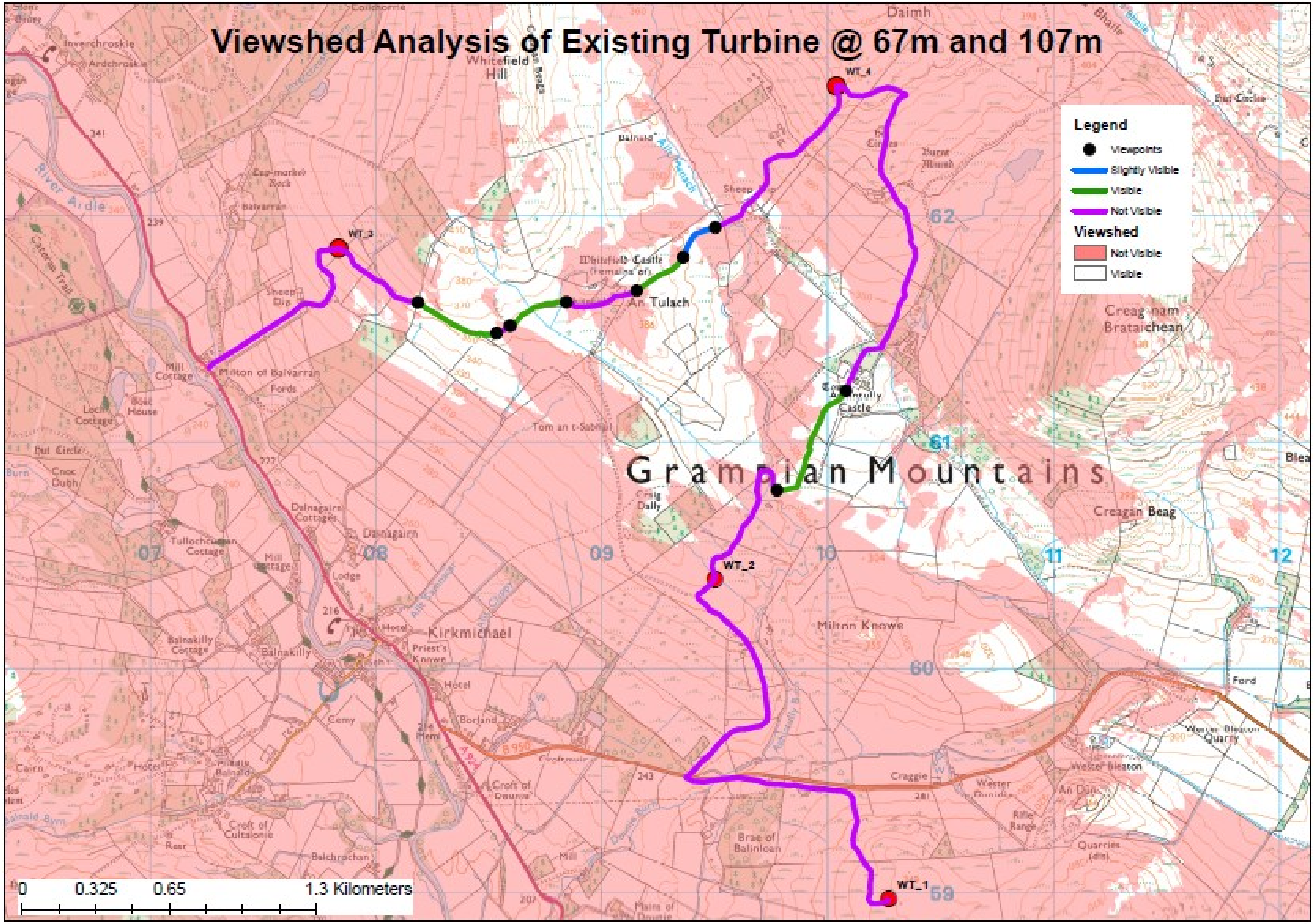

Figure 12 Viewshed Analysis of the existing Drumderg Wind Turbine. The transect followed in the field shows an agreement between field observations and the 5m DTM.

3.6. Financial Analysis

Table 4 describes the relative costs and internal rate of return (IRR) that could be expected from each wind turbine site. The larger turbines (WT1 and WT4) provide the highest returns, but at the expense of visual impact and potential for planning permission. The smaller turbines, WT2 and WT3, are calculated to return a small or negative IRR, respectively.

Table 4: Financial results

4a. TURBINE 1

	Rate	Quantity	Cost (£)	Description
AEP	2,077,998 kWh	0.076	£158,136	Yearly income
Operation & Maintenance	£20,000	1	-£20,000	Yearly cost
Turbine Cost	£1,000,000	1	-£1,000,000	
Turbine Installation	£80,000	1	-£80,000	
Development	£20,000	1	-£20,000	Year 0 CAPEX
Grid Connection	£150/m	450m	-£67,500	
Access Installation	£80/m	800m	-£64,000	
IRR (25 yr)	**10%**			

4b. TURBINE 2

	Rate	Quantity	Cost (£)	Description
AEP	693,988 kWh	0.076	£52,812	Yearly income
Operation & Maintenance	£15,000	1	-£15,000	Yearly cost
Turbine Cost	£500,000	1	-£500,000	
Turbine Installation	£60,000	1	-£60,000	
Development	£15,000	1	-£15,000	Year 0 CAPEX
Grid Connection	£100/m	200m	-£20,000	
Access Installation	£50/m	300m	-£15,000	
IRR (25 yr)	**3.5%**			

4c. TURBINE 3

	Rate	Quantity	Cost (£)	Description
AEP	557,669 kWh	0.076	£42,439	Yearly income
Operation & Maintenance	£15,000	1	-£15,000	Yearly cost
Turbine Cost	£500,000	1	-£500,000	
Turbine Installation	£60,000	1	-£60,000	
Development	£15,000	1	-£15,000	Year 0 CAPEX
Grid Connection	£100/m	1,000m	-£100,000	
Access Installation	£50/m	1,000m	-£50,000	
IRR (25 yr)	**-0.6%**			

4d. TURBINE 4

	Rate	Quantity	Cost (£)	Description
AEP	2,426,975 kWh	0.076	£184,693	Yearly income
Operation & Maintenance	£20,000	1	-£20,000	Yearly cost
Turbine Cost	£1,000,000	1	-£1,000,000	
Turbine Installation	£80,000	1	-£80,000	
Development	£20,000	1	-£20,000	Year 0 CAPEX
Grid Connection	£150/m	850m	-£127,500	
Access Installation	£80/m	800m	-£64,000	
IRR (25 yr)	**11.8%**			

4. Discussion

Based on the criteria identified in Table 1, pre-field work site identification provided a reasonable method for site selection, and the data sources used were useful and accurate. However, the access track for WT3, identified using OS 1:25,000 data, was not deemed to be suitable in the field; and WT4 was relocated due to poor wind resource. The viewshed analysis of the existing turbine (Figure 12) showed that the 5m DTM was a reliable dataset in the absence of trees. Thus, although GIS provides a good approximation, field work is important in verifying results.

The viewshed analyses reveal that all of the turbine sites would be visible from visually sensitive locations such as houses and roads (to varying degrees). To mitigate this, turbines sizes have been selected so that they have the least visual impact possible, whilst maximising economic potential. Thus, sites that are further from dwellings and in large open landscapes are sited with a larger turbine (WT1 and WT4), and sites that are positioned within the hillside and closer to dwellings and roads are sited with a smaller turbine (WT2 and WT3). The WTN 250 kW and WTN 500 kW turbines were selected due to their popularity in the UK market (Realise Energy Services, 2017).

Due to unexpected access costs and low wind speed, WT3 is an economically unviable site. WT4 is economically viable, but its proximity to a SSSI would make planning permission very difficult. WT1 is also economically viable but it is also the most visible of all the wind turbine sites. WT2 has a low IRR, but is favourable in all other respects, making it the most suitable site identified.

Given the concern of visual impact in this upland area, it can be deduced that a viable option would be a community development where profits from the turbine are fed directly back into the local economy. Involving the local community would thus lessen the negative associations of wind turbines in the landscape. This could be a viable option for the profitable sites: WT1, WT2 and WT4.

5. Limitations

Although the study provides a good indication of wind energy potential, there are a number of assumptions that are not considered:

- Investigation into electricity grid capacity;
- Land permissions (e.g. grid or access crossing multiple land ownership);
- Potential conflicts with Civil Aviation or Ministry of Defence low flying zones;
- Conflicts with telecommunication interference;
- Cumulative visual impact with existing local wind farm;
- Regarding financial calculations, no consideration of inflation, insurance, or tax.

In terms of equipment and tools, the camera used in the field to take photographs was not of adequate quality to produce clear photomontages, which limits the usability of these results.

Despite these limitations, it is considered that this study provides a good indication of wind energy potential. Where estimates or subjective decisions have been made, these have been consistent across the study, thus providing a reliable comparison between turbine sites.

6. Conclusion

In conclusion, wind turbine sites WT1, WT2, WT4 could be considered as viable projects. These would be most likely to go ahead in the form of a community development that would benefit local residents while helping to secure planning permission.

The 5m DTM used in the viewshed analysis is a reliable indication of visible / non-visible areas, although a high resolution DSM that includes forests would be more suitable. Photomontages provide a useful tool in assessing the visual impact of a wind turbine, but high resolution images are important for reliable results.

GIS is a useful tool in identifying suitable areas, however, individual sites must be verified with field recordings that investigate the ease of access, ground conditions and wind resource.

References

2017. *Wind Energy Scotland - An Overview Of The Scottish Wind Resource* [Online]. Available: http://www.scotsrenewables.com/windinfo.html [Accessed November 03 2017].

BARCLAY, C. 2010. *Wind farms-distance from housing* [Online]. Available: http://nottingham.ac.uk/renewableenergyproject/documents/[Accessed October 23 2017].

DANISH WIND ASSOCIATION. 2003. *Wind Turbine Power Calculator* [Online]. Available: http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/pow/index.htm [Accessed November 01 2017].

FOREST RESEARCH. 2017. Available: https://www.forestry.gov.uk/inventory [Accessed November 01 2017].

HAU, E. 2013. Wind turbines:fundamentals,technologies,application,economics. *Springer Science & Business Media.*

HISTORIC ENVIRONMENT SCOTLAND. 2017. *Designations* [Online]. Available: http://portal.historicenvironment.scot/designations [Accessed October 21 2017].

MET OFFICE. 2016. *Eastern Scotland:climate* [Online]. Available: http://www.metoffice.gov.uk/climate/uk/regional-climates/es#wind [Accessed October 21 2017].

OFGEM 2017. Feed-in Tariff (FIT): Generation & Export Payment Rate Table 1 April 2017 - 31 October 2019.

PERTH AND KINROSS COUNCIL. 2005. *Supplementary Guidance for Wind Energy Proposals in Perth and Kinross* [Online]. Available: http://www.pkc.gov.uk/article/15070/Supplementary-guidance-Wind-energy [Accessed November 03 2017].

REALISE ENERGY SERVICES. 2017. Available: http://www.realise-energy.co.uk/wind-solutions/wtn-225-wind-turbine/ [Accessed 5 Nov 2017]

SCOTTISH GOVERNMENT. 2016. *Renewable Energy* [Online]. Scottish Government, St. Andrew's House, Regent Road, Edinburgh EH1 3DG Tel:0131 556 8400 ceu@scotland.gsi.gov.uk. Available: http://www.gov.scot/Topics/Business-Industry/Energy/Energy-sources/19185 [Accessed November 03 2017].

SCOTTISH NATURAL HERITAGE. 2009. Siting and Designing windfarms in the landscape. Version 2.

SCOTTISH NATURAL HERITAGE. 2014. Visual Representation of Wind Farms. Version 2.1. Scottish Natural Heritage, Inverness, Scotland.

SCOTTISH & SOUTHERN ELECTRICITY NETWORKS. 2017. Available: http://north.sse-mapping.net/ngis/raswa001/html/frame_set_1i.html [Accessed November 01 2017].

ORDNANCE SURVEY. 2017. *OS MasterMap* Available: http://www.ordnancesurvey.co.uk/business-and-government/products/mastermap-products.html [Accessed November 01 2017].

Appendices

Appendix A

Pre-field template

- Turbine sites

Turbine sites	Access	Grid	Comments

- Photographs

Ref	Location	Azimuth	Comments	Turbine