

# TOBIN

**Lissinagroagh Wind Farm  
Karst Assessment  
Appendix 7-2**

**BUILT ON KNOWLEDGE**

Document Control Sheet	
Document Reference	10955_KRA_001
Client:	FuturEnergy Ireland
Project Reference	10955

Rev	Description	Author	Date	Reviewer	Date	Approval	Date
A	First Issue	PMCS	08/12/2025	JD	06/02/2026	SR	09/02/2026

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## SUMMARY

TOBIN has undertaken a karst assessment for the Proposed Lissinagroagh Wind Farm located to the northeast of Manorhamilton, Co. Leitrim. The assessment has been undertaken due to the identification of karst features within the study area of the proposed wind farm.

The purpose of this report is to evaluate the potential risks to karst associated with the construction and operation of the proposed wind farm and to outline mitigation measures and recommendations for consideration at the detailed design and construction stages. A desk study, site walkovers, ground investigation (GI) campaigns and assessment were conducted to assess the potential karst risks.

The walkover surveys and GI campaigns were conducted to assess karst across proposed wind farm site. Consultation with the published geological maps indicates that the proposed wind farm site is located in an area susceptible to the development of karst landforms.

The walkover surveys are supported by the findings of both the desk study review of aerial and topographic imagery as well as the site walkovers. A total of 73 potential karst features have been identified within 1km of the proposed wind farm site, with 6 potential features identified within the proposed wind farm boundary. The assessment findings showed that the majority of the proposed infrastructure locations are located in areas of low to medium karst hazard, with additional localised areas of high and very high hazard identified. No turbine was identified as being located in an area of high karst hazard, with a section of the proposed access track immediately south of T3 being classified as having a high karst hazard. Areas identified as being of very high karst hazard within the proposed wind farm site do not interact with any of the proposed infrastructure footprint.

## 1. INTRODUCTION

### 1.1 SITE LOCATION & ENVIRONMENTAL SETTING

The Proposed Project, known as Lissinagroagh Wind Farm is located in Leitrim approximately 3 km northeast of Manorhamilton. The Proposed Project comprises:

- A wind farm containing fourteen (14) wind turbines, an on-site 110 kV electrical substation and other ancillary infrastructure including access roads and drainage;
- A 110 kV underground grid connection to connect the wind farm to the National Grid at the existing ESNB Srananagh substation in Co. Sligo;
- Works required along the public road network between Killybegs, Co. Donegal and the proposed site to facilitate turbine and construction material delivery.

The proposed wind farm site is located in an upland area – see Figure 3-1 of this report and Figure 7-1 of EIA Volume II. Dough Mountain is located within and along the eastern site boundary and has a maximum elevation of 462 mAOD. Saddle Hill is located along the northwest site boundary and has a maximum elevation of 375 mAOD. The proposed wind farm site stretches through the valley between these two elevated areas and gently rises to the north. The southern portion of the site is where elevation is lowest at 100-140m AOD. As the site extends northwards through the valley between the two mountains, the elevation rises steadily to 285m AOD. The eastern section of the study area is mapped as elevated mountain dome, while the western section is mapped as mountain ridge, according to GSI physiographic mapping.

The Proposed Grid Connection Route (GCR) extends southward from the proposed substation in the west of the site southwest along the public road network for approximately 32 km to the existing ESNB 110/220kV Srananagh substation in Co. Sligo.

The land use/activities on the site itself is predominantly forestry plantation with agricultural lands to the northwest and east of the site. Forestry is comprised predominantly of coniferous with limited broadleaf areas. Approximately 800 ha are in Coillte's ownership whilst the remaining comprise third-party owned areas of agricultural grassland, and commercial forest. There is an extensive network of existing internal access roads and track across the proposed wind farm to facilitate the ongoing forestry operations as well as local access to farmlands. The wind farm site is characterised by locally steep topography.

### 1.2 DEFINITION OF KARST

Karst is a landscape with distinctive hydrology and landforms that arise when the underlying rock is soluble. Although karst can develop on evaporate rocks such as gypsum and siliceous rocks such as quartzite, the vast majority of karst landforms are found on carbonate rocks, such as limestones. Karst landscapes may have sinkholes, caves, enclosed depressions, disappearing streams, springs and sinkholes<sup>1</sup>.

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<sup>1</sup> (<https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/activities/understanding-irish-karst/Pages/What-is-karst.aspx>)



Karstification is an important process in Irish geology. It involves the enlargement of rock fissures when groundwater dissolves the fissure walls as it flows through them. The process can result in significantly enhanced permeability and groundwater flow rates. It occurs in ‘purer’ limestones. Pure, clean coarse limestone (90–100% calcium carbonate  $\text{CaCO}_3$ ) is prone to dissolution by rainfall. The enlargement (by dissolution) of geological discontinuities (joints, fractures, etc.) leads to the formation of a distinctive karst landscape which includes landforms such as closed depressions (dolines), sinkholes, springs, turloughs (seasonal lakes which occur in winter and early spring when the groundwater table rises above the land surface) and caves.

Much of the underlying limestone bedrock at the proposed wind farm site has the potential for varying degrees of karstification. The GSI Groundwater Karst Features database was consulted (GSI 2012). This database holds records of locations and types of reported karst features; however, the database focuses mainly on areas prone to karstification and is incomplete. No karst features were mapped on the proposed wind farm infrastructure. To aid in the identification of potential karst features across the proposed wind farm three phases of ground investigation and field reconnaissance surveys were undertaken.

## 2. METHODOLOGY

Outline summary of methodology – relevant guidance, consultation (e.g. GSI), desk studies, site walkovers, ground investigations, geophysical survey.

### 2.1 RELEVANT GUIDANCE

The karst assessment that is adopted for this project is based on assessments undertaken on previous road schemes in Ireland (Madden and O’Hara, 2016 and Ruddy and Jennings, 2012), discussion in published literature (Waltham et al., 2005); and previous project expertise of the project team on large linear infrastructure projects in karstic environments including the M17/M18.

### 2.2 DESKTOP STUDY & SCREENING

A desk study was undertaken to collate and review background information of the receiving environment. The following publicly available data sources and datasets were consulted (accessed December 2025):

- Geological Survey Ireland (GSI) datasets, including bedrock geology, quaternary geology, and extractive industry data<sup>2</sup>;
- Environmental Protection Agency (EPA) datasets on soils, subsoils, and land cover<sup>3</sup>;
- National Parks and Wildlife Service (NPWS) data on designated conservation sites<sup>4</sup>;
- GeoHive platform for mapping, topographic, and base imagery data<sup>5</sup>;
- Lidar data and other publicly available digital elevation models (DEMs) to support interpretation of topography and geomorphology;<sup>6</sup>
- Aerial photograph and LiDAR analysis (lineament, sinkhole mapping)
- Aerial imagery from the following sources has been used to identify potential karst features:
  - Bing Aerial Imagery (Jan and Dec 2025);
  - Google Earth Multitemporal Aerial Imagery (2009-2025);
  - Ordnance Survey Ireland Orthophoto (OSi, 1995-2013); and
  - OSi 6-inch and 25-inch historic base mapping.

A number of features which may be identified as possible enclosed depressions/dolines are visible in the OSI imagery from 2009 and 2025, but many are obscured by vegetation/forestry.

On the slopes of Dough Mountain, there are a number of ribbed moraines and stream gullies that flow from the mountain peak in a radial manner. Many of the streams are altered on the upgradient areas, likely due to natural geomorphological and hydrological processes which modify the channels and flow characteristics over time.

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2 Geological Survey Ireland (GSI). Available at: <https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx>

3 Environmental Protection Agency (EPA) Maps and Data. Available at: <https://gis.epa.ie/EPAMaps/>

4 National Parks and Wildlife Service (NPWS) Map Viewer. Available at: <https://www.npws.ie/maps-and-data>

5 GeoHive Public Mapping Platform. Ordnance Survey Ireland. Available at: <https://www.geohive.ie/>

6 Lidar and Digital Elevation Models from Bluesky, Geological Survey Ireland and Ordnance Survey Ireland via GeoHive. Available at: <https://www.geohive.ie/>



## 2.3 FIELD RECONNAISSANCE & KARST FEATURE INVENTORY

A field survey was undertaken in July 2021, July 2025 and January 2025. The survey work was completed by John Dillon (BSc, MSc, MCIWM, PGeo) who has over 20 years' professional experience including 10 years with karst assessment. The purpose of the survey was to:

- verify the presence of potential surface karst features identified as part of the aerial photography and DTM review; and
- identify additional karst features not visible on aerial photography or DTM.

A review of the aerial photography and DTM for the wind farm site was undertaken to identify landforms that may represent potential surface karst features.

In general, these features appear to follow broadly linear trends on the boundary of the Dartry Limestone formation, which are often parallel or perpendicular to the main fault line that passes near the north of the Site. The most notable of these occur at three locations, to the east and south of the proposed wind farm. These linear patterns indicate a correlation between the structural geology and the formation of karst features.

In general, the enclosed depressions (dolines) were circular in shape, had a bowl like morphology, and were typically between 0.5 m and 3 m in depth.

Based on the findings of the desk study, a geophysical survey was undertaken by Apex Geophysics at T7 that was being considered for the proposed layout. Geophysics was undertaken at T7 located 170 m west of the identified swallow holes.

The investigation that was undertaken comprised the following survey methods:

- 2 no. Electrical Resistivity Tomography (ERT) profiles
- Accompanying soft ground (peat) probing along each ERT profile to determine the thickness of soft peat deposits.

## 2.4 GROUND INVESTIGATIONS

A total of 13 walkovers were undertaken of the proposed wind farm site and auxiliary areas to review the ground conditions and assess the topography and geomorphology. These were carried out in October 2020, July 2021, October 2021, December 2021, January 2022, October 2022, July 2022, June 2024, December 2024, January 2025, April 2025, May 2025, July 2025 and November 2025. Karst specific surveys were undertaken in July 2021, October 2021, January 2025 and April 2025. Observations were used to guide the placement of exploratory locations and further investigative works.

Intrusive ground investigations (GI) were undertaken by specialist sub-consultants Ground Investigations Ireland (GII) and Causeway Geotech in a phased manner during 2021, 2024 and 2025. The objectives of the investigations were to determine the subsurface conditions at the proposed wind farm site including the distribution and depth of mineral soils and peat at key development locations. A geophysical survey was completed by Apex Geophysics on the 7<sup>th</sup> of October 2024. The geophysical investigation consisted of 2D Electrical Resistivity Tomography and 2D Seismic Refraction profiling. This data was used to inform the final layout design and the full GI reports can be located in Appendix 7-1 to Appendix 7-3, Volume II of the EIA.

All exploratory locations were surveyed, and their positions and elevations were accurately recorded using standard coordinate and elevation references. Laboratory testing was conducted on samples collected and included geotechnical analysis of soil samples – covering moisture content, Atterberg Limits, particle size distribution, compaction characteristics, and pH, as well as rock testing for Point Load Index and Slake Durability. All testing was carried out in accordance with BS 1377 and relevant rock mechanics standards. The ground investigation was completed in accordance with Eurocode 7 – Geotechnical Design, Part 2 (EN 1997-2) and BS 5930:2015 – Code of Practice for Ground Investigations. Mineral subsoils and peat were logged according to BS: 5930 and Von Post Scale respectively.

### Phase 1 – 2021

- Rotary core drilling was undertaken at two locations by GII in November 2021 supervised by TOBIN, which correspond to the proposed met mast location and proposed Borrow Pit 2. These boreholes were drilled to provide details on the depth of overburden and bedrock lithology/type.
- Trial pits were completed at thirty-six (36) locations, to a maximum depth of 4.1 m below site grades.
- Sixteen (16) Russian Samples were completed to a maximum depth of 15 m below existing site grades.
- Targeted walkovers were completed to support specific elements of the investigation.
- A peat depth assessment was undertaken in July 2021 using handheld peat probes, focusing on areas identified during the desk study and Phase 1 SI as potentially underlain by peat.

### Phase 2 - 2024

- Rotary core drilling was undertaken at one (1) location by Causeway Geotech in September and November 2024, supervised by TOBIN, which correspond to the location of proposed turbine T7. The borehole was drilled to provide details on the depth of overburden and bedrock lithology/type. Standard penetration tests were carried out at standard depth intervals using a split spoon sampler or solid cone attachment during the rotary core drilling.
- Trial pits were completed at three (3) locations, to a maximum depth of 3.5 m below site grades by Causeway Geotech during the Phase 2 site investigation works.

Thirty-nine (39) peat augers were conducted onsite by Causeway Geotech during the 2024 site investigation using an Edelman auger to a target depth of 2.00 metres or refusal. A follow-on peat probe was carried out if peat extended past 2.00 metres. The depth to this refusal was nominally taken as the thickness of peat at that location.

A geophysical survey was completed by Apex Geophysics on the 7<sup>th</sup> of October 2024. The geophysical investigation consisted of 2D Electrical Resistivity Tomography and 2D Seismic Refraction profiling.

### Phase 3 – 2025

- Rotary core drilling was undertaken at two (2) locations to a maximum depth of 12.8 mbgl, by GII in October 2025, supervised by TOBIN, which correspond to the locations of proposed borrow pit 2. The borehole was drilled to provide details on the depth of



overburden and bedrock lithology/type. Standard penetration tests were carried out at standard depth intervals. One (1) of the rotary core drilled boreholes was finished as a groundwater monitoring well to enable water sampling and the determination of the equilibrium groundwater level.

- Trial pits were completed at eight (8) locations, to a maximum depth of 3.2 m below site grades by GII during the Phase 3 site investigation works.

Ninety-seven (97) peat probes were conducted onsite in December by GII during the 2025 site investigation. The test consists of manually driving a cone on metre long extendible rods into the peat until a stiffer deposit or an obstruction is encountered. The depth to this refusal was nominally taken as the thickness of peat at that location.

Seventeen (17) peat augers were conducted onsite in December 2025, by GII. The corkscrew shaped tip of the sampler is inserted into the ground. The operator then manually turns the T handle while using their body weight to rotate the sampler into the ground. The corkscrew sampler fills with material as it is rotated into the ground. The hand auger recovers a 300mm disturbed sample which is recovered from the exploratory hole, logged, sampled and photographed.

All field work was conducted in compliance with best practice standards and relevant guidance, with oversight from qualified geologists and engineers. The site investigation works outlined above locations are shown on **Error! Reference source not found.**

This assessment also proposes a monitoring programme which will be implemented during the construction phase of the proposed project and a contingency plan should instability occur at the site. The assessment acts as a live document arising from information presented during the consenting process, possible planning conditions and the content of which will be updated as work is carried out on site.

### 3. SITE CHARACTERISATION

#### 3.1 GEOLOGICAL SETTING

Information on the bedrock geology in the study area was obtained from the Geology of Sligo-Leitrim, Sheet No. 7 (1:100,000), available in the Geological Survey of Ireland (GSI) Web Viewer. The bedrock geology underlying the Proposed Wind Farm site and GCR is shown in Figure 7-10 and 7-11, Volume II of the EIAR. The bedrock geology underlying the TDR is shown in Figure 7-12 Volume II of the EIAR.

The proposed wind farm site is underlain by a number of bedrock formations as detailed in Table 3-1. Bedrock outcrops are present across the proposed wind farm site, particularly concentrated to the north and center. Additionally, a number of geological faulting runs through the proposed wind farm site, contributing to the structural complexity of the area.

**Table 3-1 Bedrock Formations - Proposed Wind Farm & GCR**

Formation	Location	Lithology
Glenade Sandstone Formation	Southeast of the site and extends northwards through the centre of the site forming the western base of Dough Mountain.	Pale orthoquartzitic sandstone – Homogenous, thick bedded, medium-grained, orthoquartzitic, brown coloured sandstone with minor amounts of shale. Also contains impersistent coarse grained sandstone beds and pebble beds near the base.
Dartry Limestone Formation	Extends through the centre of the site and is the dominant lithology at the north of the site.	Dark fine-grained cherty limestone - The dominant facies is massive and thick-bedded, mostly very fine-grained and dark wackestone, locally rich in sponge spicules. Bedding is picked out by lines of chert nodules. There is pervasive dolomitisation and silicification also present.
Glencar Limestone formation	Southwest and west of the site.	Dark fine limestone and calcareous shale – The formation consists of an alternation of calcareous shales and limestones which range from argillaceous calcisiltites to very fine calcarenites. Cyclicity or rhythmicity occurs throughout. Individual composite limestone beds average 10-20cm in thickness.
Benbulbin Shale Formation	Southwest and west of the site.	Calcareous shale with minor calcarenite – Consists primarily of laminated dark-grey calcareous shale, with subordinate ribs of argillaceous fine calcarenite or calcisiltite. Bioclastic debris is abundant, crinoid, brachiopod, solitary coral with large caniniids in the upper part, and bryozoans.
Mullaghmore Sandstone Formation	Southwest and west of the site.	Sandstone, siltstone and shale – The formation consists of a series of cyclical units of siltstones and shales which coarsen up into medium to coarse grained sandstones. Trace fossils are abundant and varied, particularly in the shale; siltstones and rippled fine sandstones occur. The upper part consists of sandy oolite, calcareous siltstone and thin limestones.

Formation	Location	Lithology
Bundoran Shale Formation	Southwest and west of the site.	Dark shale, minor fine-grained limestone - The Bundoran Shale formation comprises dark grey, fissile, calcareous and micaceous laminated mudstones and siltstones interbedded with thinly bedded blue, grey to dark grey bioclastic limestones. Some units of the limestones may be classified as packstones or grainstones.
Ballyshannon Limestone Formation	Southwest corner of the site.	Pale grey calcarenite limestone – Most of the formation is composed of medium to light grey, massively bedded crinoidal calcarenite. Stylolites are common and are often the only indication of bedding. Very dark grey fine calcarenites with black chert nodules are interspersed.
Glenade Sandstone Formation	Southwest of the site	Comprised of thick-bedded, medium-grained, orthoquartzitic deltaic sandstone
Bellavally Shale Formation	Southeast of the site on the southern slopes of Dough Mountain.	Grey micrite, shale, laminate evaporite - Calcareous shale and micritic limestone, with a marine fauna of goniatites, corals and productids; laminated dolomitic or micrite with evaporite beds; grey green, often silty mudstone with calcareous concretions.
Carraun Shale Formation	Southeast of the site on the southern slopes of Dough Mountain.	Grey/black shale with minor limestone - The Formation is composed of grey to black fossiliferous shales and mudstones with thin subordinate limestones and dolomites.
Dergvone Shale Formation	Towards the centre and southeast of the site on the southern slopes of Dough Mountain.	Shale and minor turbiditic sandstone - The formation contains four main shale facies, arranged in rhythmical order.
Lacoon Flagstone Member of the Dergvone Shale Formation	Peak of Dough Mountain.	Interbedded sandstone and thin shale – Fine parallel-bedded sandstones with common groove casts are interbedded with grey micaceous silty shale.
Mudbank Limestone	In the centre of the site immediately to the adjacent west of the swallow holes and also occur as isolated regions in the northwest of the site.	Mudbanks limestone

### 3.2 SUBSURFACE CONDITIONS

The following subsoils and Quaternary sediments are present within the site boundary (Figure 7-7 and 7-9, Volume II of the EIAR):

- Blanket Peat (BktPt);
- Till Derived from Namurian Sandstones and Shales (TNSSs);
- Scree



- Karstified Bedrock Outcrop or subcrop (KaRck);
- Bedrock outcrop or subcrop (Rck)
- Alluvium (A).

The majority of the northern portion of the site is mapped as blanket peat, with the southern section of the site dominated by till derived from Namurian sandstone and shales. Site investigations undertaken within the proposed wind farm site indicate that peat depths vary from 0.1 m to 4.5 m in the north and 0.1 m to 1.8 m in the south. Depth of soils increases to the south with deep glacial deposits located at the substation and to south and southwest of the site.

Alluvium is mapped along the streams to the centre and south of the site and is typically well sorted, loose silt and sand sized particles. Scree is also located to the east of the proposed wind farm site along the slopes of Dough Mountain; however, the proposed wind farm layout has avoided the scree areas. A portion of the southern site entrance work areas are mapped as deep well drained mineral and deep poorly drained soils derived from mainly both calcareous parent material and non-calcareous parent material, which are underlain by till material deposited by or from glacial ice.

### 3.3 KARST FEATURE INVENTORY

No karst features are mapped on the GSI karst database<sup>7</sup> within the study area. A total of 73 unmapped karst features were identified using aerial photograph, lidar data and site walkovers in the wind farm study area, to the west of Dough Mountain, see Chapter 7 of the EIAR. These karst features mainly include dolines (enclosed depressions) with some swallow holes. The distribution of their locations is presented in Figure 7-14 Volume II of the EIAR and Figure 3-1 below. None of the features identified as part of this review were included in GSI's karst mapping.

These broadly circular features display varying diameters, as illustrated in Table 3-2. The morphology suggests that these features are most likely enclosed depressions (dolines), with three features described as swallow holes.

The proposed design has avoided the identified karst features and applied a 30 m buffer. The number of identified karst features within 250m of turbines and the substation has been determined using *ArcGIS Pro*. For infrastructure-specific analysis, the number of karst features within a 250m buffer of each infrastructure location has been considered. A 250m buffer has been used for this analysis as this is considered to provide a localised, yet sufficiently broad, spatial context to capture nearby karst features that may pose indirect or cumulative risks to infrastructure. A high density of karst features within 250m indicates that the development of karstic features at the location being assessed is more likely. There are less than 4 karst features within 250 m of the proposed turbines, construction compounds, borrow pits, substation and met mast. Details of the karst features are identified below in Table 3-2.

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<sup>7</sup> <https://gsi.geodata.gov.ie/portal/apps/webappviewer/>



Table 3-2 Karst Feature Summary

ID	x	y	Dimension	type	Description
1	591588	844177	<5x5m	Enclosed Depression	Shallow oval shaped depression
2	591592	844191	<5x5m	Enclosed Depression	Shallow oval shaped depression
3	591598	844203	<5x5m	Enclosed Depression	Shallow oval shaped depression
4	591607	844231	<5x5m	Enclosed Depression	Shallow oval shaped depression
5	592012	844537	<5x5m	Enclosed Depression	Shallow oval shaped depression
6	592177	844559	<5x5m	Enclosed Depression	Shallow oval shaped depression
7	592228	844602	<5x5m	Enclosed Depression	Shallow oval shaped depression
8	592324	844845	<5x5m	Enclosed Depression	Shallow oval shaped depression
9	592282	844755	<5x5m	Enclosed Depression	Shallow oval shaped depression
10	592242	844749	<5x5m	Enclosed Depression	Shallow oval shaped depression
11	592303	844874	<5x5m	Enclosed Depression	Shallow oval shaped depression
12	592217	845028	<5x5m	Enclosed Depression	Shallow oval shaped depression
13	592173	844967	<5x5m	Enclosed Depression	Shallow oval shaped depression
14	592845	844146	<5x5m	Enclosed Depression	Shallow oval shaped depression
15	592683	844039	<5x5m	Enclosed Depression	Shallow oval shaped depression
16	591569	844081	<5x5m	Enclosed Depression	Shallow oval shaped depression
17	591665	843901	<5x5m	Enclosed Depression	Shallow oval shaped depression
18	591626	844036	<5x5m	Enclosed Depression	Shallow oval shaped depression
19	591650	843956	<5x5m	Enclosed Depression	Shallow oval shaped depression
20	591559	844015	<5x5m	Enclosed Depression	Shallow oval shaped depression
21	592075	843873	<5x5m	Enclosed Depression	Shallow oval shaped depression
22	592273	842741	10x5m	Swallow hole	Shallow oval shaped depression
23	592358	842966	<5x5m	Swallow hole	Shallow oval shaped depression
24	592356	842941	<5x5m	Enclosed Depression	Shallow oval shaped depression
25	592083	842560	<25x55m	Swallow hole	Shallow oval shaped depression
26	591945	842746	<5x5m	Enclosed Depression	Shallow oval shaped depression
27	591869	842412	<5x5m	Enclosed Depression	Shallow oval shaped depression
28	591928	842320	30x25m	Enclosed Depression	Oval shaped depression
29	591797	842169	<5x5m	Enclosed Depression	Shallow oval shaped depression
30	591742	842278	<5x5m	Enclosed Depression	Shallow oval shaped depression
31	591980	842138	<5x5m	Enclosed Depression	Shallow oval shaped depression
32	591934	842148	<5x5m	Enclosed Depression	Shallow oval shaped depression
33	591870	842182	<5x5m	Enclosed Depression	Shallow oval shaped depression
34	591922	842027	<5x5m	Enclosed Depression	Shallow oval shaped depression
35	592143	840802	25x25m	Enclosed Depression	Shallow oval shaped depression
36	592289	840720	<30x25m	Enclosed Depression	Shallow oval shaped depression
37	592333	840678	<5x5m	Enclosed Depression	Shallow oval shaped depression
38	592402	840669	<10x10m	Enclosed Depression	Shallow oval shaped depression
39	591679	842476	<5x5m	Enclosed Depression	Shallow oval shaped depression
40	591722	842571	<10x10m	Enclosed Depression	Shallow oval shaped depression
41	591726	842596	<5x5m	Enclosed Depression	Shallow oval shaped depression
42	591694	842531	<10x10m	Enclosed Depression	Shallow oval shaped depression
43	591708	842555	<5x5m	Enclosed Depression	Shallow oval shaped depression
44	591706	842680	<5x5m	Enclosed Depression	Shallow oval shaped depression



ID	x	y	Dimension	type	Description
45	591704	842657	<5x5m	Enclosed Depression	Shallow oval shaped depression
46	591756	842661	<5x5m	Enclosed Depression	Shallow oval shaped depression
47	591761	842775	<5x5m	Enclosed Depression	Shallow oval shaped depression
48	591750	842798	<5x5m	Enclosed Depression	Shallow oval shaped depression
49	591773	842814	<5x5m	Enclosed Depression	Shallow oval shaped depression
50	591746	842866	<5x5m	Enclosed Depression	Shallow oval shaped depression
51	591989	843036	10x11m	Enclosed Depression	Shallow oval shaped depression
52	592002	843022	12x9m	Enclosed Depression	Shallow oval shaped depression
53	592255	843371	<5x5m	Enclosed Depression	Shallow oval shaped depression
54	592255	843371	<5x5m	Enclosed Depression	Shallow oval shaped depression
55	592413	843456	10x5m	Enclosed Depression	Shallow oval shaped depression
56	592480	843485	10x5m	Enclosed Depression	Shallow oval shaped depression
57	591427	844093	<5x5m	Enclosed Depression	Shallow oval shaped depression
58	591782	844336	<5x5m	Enclosed Depression	Shallow oval shaped depression
59	592144	840883	25x20m	Enclosed Depression	Shallow oval shaped depression
60	593017	840477	15x15m	Enclosed Depression	Shallow oval shaped depression
61	593110	840410	18x12m	Enclosed Depression	Shallow oval shaped depression
62	592628	840509	<5x5m	Enclosed Depression	Shallow oval shaped depression
63	592421	840641	<15x15m	Enclosed Depression	Shallow oval shaped depression
64	592205	840703	<5x5m	Enclosed Depression	Shallow oval shaped depression
65	591498	840929	<5x5m	Enclosed Depression	Shallow oval shaped depression
66	591427	840926	<5x5m	Enclosed Depression	Shallow oval shaped depression
67	591813	841187	<5x5m	Enclosed Depression	Shallow oval shaped depression
68	593151	840399	20x20x	Enclosed Depression	Shallow oval shaped depression
69	592414	838547	<5x5m	Enclosed Depression	Shallow oval shaped depression
70	592820	840211	<5x5m	Enclosed Depression	Shallow oval shaped depression
71	591712	844288	<5x5m	Enclosed Depression	Shallow oval shaped depression
72	591752	844313	<5x5m	Enclosed Depression	Shallow oval shaped depression
73	592320	844768	<5x5m	Enclosed Depression	Shallow oval shaped depression



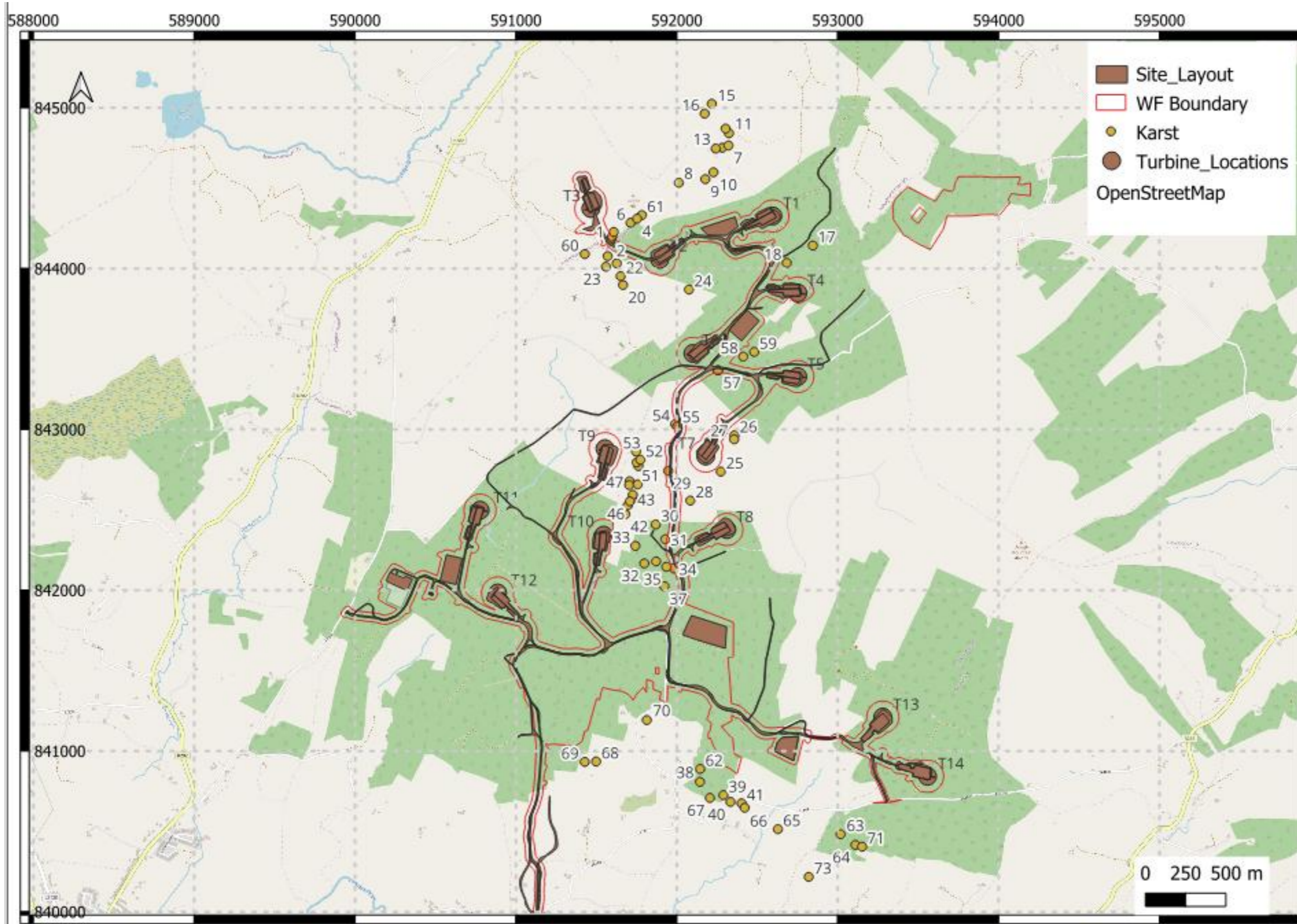


Figure 3-1 Karst Locations



## 4. MITIGATION MEASURES

The findings of the assessment indicate that the majority of the Proposed Wind Farm site can be classed as having a low to medium karst risk. In these locations, it is considered that significant karst development is unlikely, and unstable ground and significant cavities are not anticipated. All proposed infrastructure has been sited to avoid areas of very high karst hazard. Best practice measures as detailed in the Karst Protocol will be implemented if any karst feature is encountered – See Appendix A.

Embedded mitigation is listed in Chapter 7 Section 7.5.1 and includes a 30 m buffer from karst features and 100 m from swallow holes.

All earthworks will be designed by a suitably qualified Geotechnical Engineer during the detailed design stage and informed by a detailed confirmatory ground investigation. This investigation will include intrusive methods, such as trial pitting and borehole drilling, with a specified suite of in-situ and geotechnical laboratory testing to further assess the engineering characteristics of the infrastructure locations. Possible mitigation measures in relation to peat instability are considered below. Geophysical surveying is recommended to assist in the identification of any potential karstic voids not identified in this assessment, although none are anticipated based on current information and design.

Portions of the proposed wind farm site have been classed as having high karst hazard, based on professional judgement following site investigation and desktop analysis and proximity to features. In these areas, specific mitigation measures may be required, i.e piling and geogrid reinforcement. The following ground investigation works will be carried out at infrastructure locations identified as having medium or greater karst risk:

- Rotary core boreholes to confirm rockhead depth and quality.
- Geophysical Surveying to detect voids and solution features, including:
  - Electrical Resistivity Tomography (ERT)
  - Microgravity; and
  - Seismic Refraction
- Trial pits and dynamic probing to assess near-surface variability and soils.

Engineering large structures in karst landscapes has become a relatively common occurrence in Ireland. For example, large motorway bridges have been safely constructed in more active karst landscapes (Madden and O'Hara, 2016, Ruddy & Jennings, 2012). A number of wind farm projects have been successfully constructed and are operational in areas of dolomitised limestone including three wind farms at Lisheen, Co. Tipperary.

Mitigation is outlined in Appendix 2-4 Construction and Environmental Plan (CEMP) and below which will be implemented at detailed design stage to reduce the karst risk:

- For the turbine foundations, a geotechnical investigation will be carried out at each location prior to works commencing. Surveying will include the drilling of boreholes by rotary core to depth within competent bedrock to determine the strength of rock and assess the potential for karst or weathered rock at each location by a qualified geotechnical engineer to inform foundation design. Piling will be undertaken in areas



of weak rock to ensure long term stability, and that the turbine loads are taken to intact rock below any potentially dolomitised limestone. A larger number of small piles or micro piles designed with rock sockets to transfer loads via skin friction are preferred in karst landscapes (Rutty & Jennings, 2012, Traylor et al., 2002), rather than a smaller number of large piles relying on end bearing. It is recommended that piles are designed on the basis of transferring loads via skin friction to a rock socket.

- For access tracks and hardstandings, the karst feature inspection protocol documented by Madden & O'Hara (2016), included in Appendix A, is routinely followed for construction of linear infrastructure in karst landscapes. A similar karst feature inspection protocol will be developed and followed during detailed design.
- Where small-scale dissolution and voiding are encountered at turbine foundations during detailed ground investigation, mitigation strategy is the use of drilled or grouted piles. The use of piles transfers structural loads to competent rock beneath karst-affected zones. This approach bypasses voids and weak soils, reducing the risk of differential settlement or collapse.
- Ground stabilisation measures to be employed include compaction, grouting/stabilisation, geotextile or utilising raft foundations. Where weathered limestone or karst is encountered at formation level, the feature will be mapped in detail. Each feature and associated mitigation measure will be documented and included in the safety file. The stabilisation measures will be approved by a geotechnical engineer. Where infilling or grouting is undertaken works will be supervised by a suitably qualified hydrogeologist to ensure there is no effect on groundwater.
- Waltham et al. (2005) outline an approach for the remediation of shallow karst features. This methodology involves adding coarse granular fill to the base of karst feature, and progressive backfilling upwards with progressively finer granular fill. All backfill is to be placed in layers 150mm deep and compacted. Soil around the doline/sinkhole is to be excavated to a radius of 3-5m, before being replaced and compacted with or without incorporation of anchored geogrid. This methodology has been used effectively on Irish road projects in similar karst terrains in East Galway (Madden and O'Hara, 2016).

This methodology is applicable to the proposed wind farm site access tracks and shall be implemented if small scale sinkhole features (<5m in depth) are encountered beneath access tracks. No karst features were observed in line with any access track or other proposed infrastructure.

- Where construction takes place in areas of high karst hazard, and if karstic features are identified elsewhere during construction, the following measures shall be implemented:
  - Access tracks will incorporate geogrid-reinforced bridging layers over areas identified as having potential voids or collapse-prone soils.

- Crane hardstands will be designed with enhanced bridging layers to accommodate high point loads and dynamic stresses.
- Proper drainage control is therefore essential to maintain the stability of foundations and prevent erosion of fill materials. All works will be supervised by a suitably qualified geotechnical engineer or hydrogeologist.

## 5. MONITORING AND MAINTENANCE

A post-construction monitoring plan will be implemented, including visual inspections, settlement monitoring, and geophysical re-surveys. This proactive approach ensures that any emerging issues are detected and addressed promptly, maintaining the long-term integrity of the wind farm infrastructure.

Following the implementation of mitigation measures, the residual risk at each infrastructure location is low.

## 6. REFERENCES

- Madden, P. & Hara, M. (2014). Karst Risk Assessment Protocol for Development Projects
- Madden and Hara (2016) The treatment of karst features encountered during road construction in County Galway
- Ruddy, P. and Jennings, P. Investigation, design and construction in karst,. GSI Roads Conference, 2012
- Traylor, R., Cadden, A.W., Bruce, D. A. (2002) High Capacity Micropiles in Karst: Challenges and Opportunities
- Waltham, A.C, Fookes, P.G., Engineering classification of karst ground conditions, Quarterly Journal of Engineering Geology and Hydrogeology, 2003, vol 36,



APPENDIX A – KARST PROTOCOL

Madden and Hara (2016)

