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Feasibility study for a community wind turbine, Oileán Chléire, Ireland

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Glossary

AEP	Annual Energy Production
AGL / ASL	Above Ground Level / Above Sea Level
BOP	BOP (Balance of Plant) corresponds to civil and electrical infrastructures inside the wind farm (inter-array cables, junction boxes, foundations, etc.).
CORINE LAND COVER	The Corine Land Cover database is an inventory of land cover in 44 classes. It was initiated in 1985 by the European Union and has been taken over by the EEA. 3E associates roughness information to each class to create roughness maps that are used in the wind flow models.
DISPLACEMENT HEIGHT	Large areas of tall obstacles affect the wind shear, lifting the zero-velocity theoretical height by a value called displacement height.
DSM / DEM	As opposed to DTM (Digital Terrain Model), DSM / DEM (Digital Surface Model or Digital Elevation Model) includes objects on the ground surface like forests and buildings.
ERA-5	ERA-5 is an hourly reanalysis dataset produced by the European Centre for Medium-Range Weather Forecast (ECMWF) covering a period from 1979 to the present. It extends to the whole earth on a grid of 30km, resolving the atmosphere using 137 levels from the surface up to a height of 80km.
EU-DEM	The Digital Elevation Model over Europe from the GMES RDA project (EU-DEM) is a Digital Surface Model (DSM) representing the first surface as illuminated by the sensors. The EU-DEM dataset is a realisation of the Copernicus programme, managed by the European Commission, DG Enterprise and Industry.
HH	Hub height
MERRA-2	MERRA-2, the Modern-Era Retrospective Analysis for Research and Applications, is a NASA-reanalysis dataset. It covers the period from 1980 to present with a resolution of 1/2° x 0.625° (latitude x longitude).
NORMAL DISTRIBUTION	In probability theory, the normal (or Gaussian) distribution is a bell-shaped continuous probability distribution function with two parameters: the mean and the standard deviation. Normal distributions are extremely important in statistics and are often used in the natural sciences for real-valued random variables whose distributions are not known. One reason for their popularity is the central limit theorem (CLT), which states that, under mild conditions, the mean of a large number of random variables independently drawn from the same distribution is distributed approximately normally, irrespective of the form of the original distribution.
PROBABILITY OF EXCEEDANCE	In probability theory and statistics, the probability of exceedance is a number (in the range of 0 to 100%) that represents the probability that a random variable falls above (or exceeds) a certain value. It is calculated as one minus the cumulative distribution function (CDF),

	which describes the probability that a variable will be found at a value less than or equal to X.
RD	Rotor diameter
REANALYSIS	Reanalysis data are the results of a meteorological data assimilation process that aims to assimilate historical observational data spanning an extended period, using a single consistent assimilation (or “analysis”) scheme throughout this period.
RIX	The ruggedness index (RIX) at a specific location is the percentage of the ground surface that has a slope above a given threshold (e.g. 40%) within a certain distance.
RP	Rated power
TURBINE INTERACTION LOSSES	Combined production losses due to interaction effects (wake and blockage) between wind turbines within a wind farm.
WAKE LOSSES	The wake losses are production losses due to the mutual interaction of wind turbines caused by the wind energy deficit downstream of the wind turbine rotors.
WASP	WAsP (Wind Atlas Analysis and Application Program) is a software package that simulates wind flows to predict wind climates, wind resources, and power production from wind turbines and wind farms. WAsP was developed and distributed by DTU Wind Energy, Denmark. It has become the wind power industry-standard PC-software for wind resource assessment.
WEIBULL DISTRIBUTION	In probability theory and statistics, the Weibull distribution is a continuous probability distribution function with two parameters: k (shape) and A (scale). It is widely used in the wind power community as an approximation of the frequency distribution of wind speeds from a time series.
WIND FARM BLOCKAGE LOSS	The difference in production is due to the accumulated induction effect of the wind farm between a turbine when operating in isolation and when operating in an array.
WIND INDEX	The wind index of a period quantifies the windiness of this period compared to a long-term reference period. It is usually done in terms of wind turbine power output. The long-term period is given an index of 100. Hence, a period with an index of 105 is 5% windier than the long-term. In this case, the long-term correction factor is 0.95.
WIND REGIME	In the WAsP methodology, the wind rose is divided into twelve sectors and the wind speed distribution in each sector is approximated by a Weibull distribution defined by two parameters, A & k. A wind regime is determined by these parameters A & k, as well as the weight of each wind sector.
WIND SHEAR	The wind shear is a measure of how the wind speed decreases in the lower atmosphere close to the ground. This phenomenon is due to the drag forces exerted by the ground and its roughness on the air flow. It shapes the wind speed and turbulence profiles, the former of which is often described with a logarithmic or exponential law.

WINDPRO	WindPRO is a software package for designing and planning wind farm projects. It uses WAsP to simulate wind flows. It is developed and distributed by the Danish energy consultant EMD International A/S. It is trusted by many investment banks to create wind energy assessments used to determine financing for proposed wind farms.

SUMMARY

This report presents the results of a feasibility study for a community wind turbine in Oileán Chléire, Ireland. The project was initiated in 2022 by some members of the local community, who have already obtained a connection assessment from the local Distribution System Operator (DSO). This work goes one step further towards the implementation of the project and aims to (i) assess the wind energy resource on the island, (ii) assess the expected yield of a wind turbine installed at the project site under different possible hub heights, (iii) describe some of the key expected social and environmental impacts, namely noise, shadow flicker and visual impacts.

At this early project stage, and in the absence of wind measurements at the site and on the island, two wind turbine models have been considered, each with three different possible tower heights. All configurations are characterised by a total installed capacity of 500 kW and are listed as follows:

- Scenario 1: 1x EWT DW54x 500 kW wind turbine with 54 m rotor diameter and 40 m hub height,
- Scenario 2: 1x EWT DW54x 500 kW wind turbine with 54 m rotor diameter and 50 m hub height,
- Scenario 3: 1x EWT DW54x 500 kW wind turbine with 54 m rotor diameter and 59 m hub height,
- Scenario 4: 1x EWT DW52 500 kW wind turbine with 54 m rotor diameter and 35 m hub height,
- Scenario 5: 1x EWT DW52 500 kW wind turbine with 54 m rotor diameter and 40 m hub height,
- Scenario 6: 1x EWT DW52 500 kW wind turbine with 54 m rotor diameter and 50 m hub height,

This preliminary stage study is based on a Virtual Met Mast (VMM) developed by 3E and located near the expected location for the wind turbine. The terrain at the site was modelled (elevation, roughness and obstacles to the wind flow), and the wind flow model WAsP was used to extrapolate the wind regime to each wind turbine's location and hub height. Concerning the wind regime at the site, the expected Weibull mean wind speed at the location of the wind turbine at 50 m AGL is 8.85 m/s, with prevailing wind directions West-North-West (WNW), West (WNW) and West-South-West.

The wind regime at the chosen location and at the hub height of each wind turbine was then combined with the air density-adjusted power curves of each considered wind turbine type to assess its gross energy production. Energy production losses were assessed and deducted from the gross energy production of each wind turbine, resulting in its expected net annual energy production (‘AEP’). No curtailment has been applied in this report.

Energy production losses considered in this study are between 8.6 % and 10 %, depending on the configuration and breakdown as in Table 1.

Table 1: Breakdown of energy production losses in the different scenarios.

Configuration		DW54x, 0.5 MW @ 40 m	DW54x, 0.5 MW @ 50 m	DW54x, 0.5 MW @ 59 m	DW52, 0.5 MW @ 35 m	DW52, 0.5 MW @ 40 m	DW52, 0.5 MW @ 50 m
Scenario		1	2	3	4	5	6
Wake losses	[%]	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Unavailability losses	[%]	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**
Turbine		5.0	5.0	5.0	5.0	5.0	5.0
BOP		0.2	0.2	0.2	0.2	0.2	0.2
Grid		0.3	0.3	0.3	0.3	0.3	0.3
Performance losses	[%]	**2.2**	**2.2**	**2.2**	**0.5**	**0.5**	**0.5**
Generic performance losses		1.7	1.7	1.7	0.0	0.0	0.0
Site-specific losses		0.2	0.2	0.2	0.2	0.2	0.2
Suboptimal performance		0.3	0.3	0.3	0.3	0.3	0.3
Hysteresis losses		0.1	0.1	0.1	0.1	0.1	0.1
Electrical losses	[%]	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**
Environmental losses	[%]	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
Performance degradation not due to icing		1.0	1.0	1.0	1.0	1.0	1.0
Performance degradation due to icing		0.2	0.2	0.2	0.2	0.2	0.2
Shutdown due to icing, lightning, hail, etc.		0.1	0.1	0.1	0.1	0.1	0.1
Total losses (*)	[%]	**10.1**	**10.1**	**10.1**	**8.6**	**8.6**	**8.6**

(*) The production losses in % are combined as: $\boldsymbol{Total} = 100 - \frac{\prod_i (100 - Loss_i)}{100^{(N-1)}}$Net energy production

Uncertainties associated with energy production results were then evaluated. They range between 8.6 % and 12.2 % within 20 years, depending on the configuration and breakdown, as in Table 2.

Table 2: Breakdown of uncertainties associated with energy production results.

Configuration		DW54x, 0.5 MW @ 40 m	DW54x, 0.5 MW @ 50 m	DW54x, 0.5 MW @ 59 m	DW52, 0.5 MW @ 35 m	DW52, 0.5 MW @ 40 m	DW52, 0.5 MW @ 50 m
Scenario		1	2	3	4	5	6
Wind measurements	[%]	4.2	4.1	3.9	4.3	4.2	4.1
Vertical extrapolation	[%]	8.0	6.0	4.6	9.4	8.1	6.1
Future wind variability (20 years)	[%]	1.7	1.7	1.6	1.8	1.7	1.7
Spatial variation	[%]	4.5	4.4	4.2	4.7	4.6	4.4
Power curve	[%]	3.9	3.8	3.7	4.0	3.9	3.8
Production losses	[%]	1.8	1.8	1.8	1.6	1.6	1.6
Combined uncertainty (20 years)	[%]	**11.1**	**9.6**	**8.6**	**12.3**	**11.2**	**9.7**

Energy production exceeded with various probabilities (P75, P90 and P95 percentiles) over 1, 10, 15 and 20 years were then calculated. The 20-year annual energy production (AEPs) is presented in Table 3.

Table 3: Summary of energy production in different scenarios with different probabilities.

Configuration		**DW54x, 0.5 MW @ 40 m**	**DW54x, 0.5 MW @ 50 m**	**DW54x, 0.5 MW @ 59 m**	**DW52, 0.5 MW @ 35 m**	**DW52, 0.5 MW @ 40 m**	**DW52, 0.5 MW @ 50 m**
Scenario		1	2	3	4	5	6
AEP (P50)	[MWh/y]	2,321	2,397	2,456	2,318	2,369	2,448
	[h/y]	4,641	4,793	4,911	4,637	4,738	4,896
AEP (P75)	[MWh/y]	2,147	2,241	2,313	2,126	2,190	2,288
	[h/y]	4,293	4,482	4,626	4,252	4,381	4,577
AEP (P90)	[MWh/y]	1,990	2,101	2,185	1,953	2,029	2,145
	[h/y]	3,980	4,201	4,370	3,905	4,059	4,289
AEP (P95)	[MWh/y]	1,896	2,017	2,108	1,849	1,933	2,059
	[h/y]	3,792	4,034	4,217	3,698	3,866	4,117

Thereafter, the following potential impacts caused by the wind turbine were assessed:

- **Noise levels**: Noise contour lines were produced for each wind turbine. It was observed that potential receptors are out of the 40 dB contour line for all the scenarios analysed.
- **Shadow flicker**: It was demonstrated that, for all the scenarios analysed, potential receptors fall out of the 30 hours/year and 30 minutes/day areas in a real case scenario, i.e. taking into account sky conditions.
- **Visual influence**. The zone of theoretical visibility for each studied configuration was mapped within a radius of 15 km from the wind turbine.
- **Photomontage**. Some photomontage was developed for each studied configuration based on a set of landscape pictures captured at sensitive points on the island.

For further stages of the project development, it is recommended that:

- A one-year met-mast acquisition is performed to define the site's wind conditions, thus supporting the choice of the exact wind turbine model and providing a bankable assessment of the expected yield.
- The project's financial structure is assessed, and the best procurement solution is identified to ensure the highest possible positive impact on the community of Oileán Chléire.

The Clean energy for EU islands secretariat would like to remind the reader that the results presented in this report are only valid if the power curves considered in the study are consistent with those of the turbine supply agreement. Also, it should be noted that, for the purposes of this report and at the current project development stage, no curtailment strategy is applied (e.g., grid, wind sector management, shadow flicker and noise).

1. Introduction

1.1. Objectives

For the technical assistance of the CE4EUI secretariat for the Island of Oileán Chléire (the Beneficiary), it was agreed to develop a technical feasibility study for a community-owned wind turbine with an installed capacity of approximately 600 kW. The work consists of the analysis of the key aspects of Irish wind energy regulation, the analysis of the wind energy resource, the identification of possibly suitable wind turbine generators, the assessment of the long-term energy production of the Nasca Wind Farm project, and the analysis of noise, shadow flicker and visual impacts. The results of the study are suited for a financial analysis of the project.

1.2. Methodology

This study is carried out according to the best industry practices [1][8] and managed according to the ISO 9001:2008 standard, under which 3E has been certified since 2010.

1.3. Outline of the report

- Section 2 details the site and project, including the site location and regulation, the available wind measurements, the justified selection of suitable wind turbines and the wind farm configurations to be studied.
- Section 3 details the processing of wind data into a representative wind regime meant for energy production calculations.
- Section 4 details wind flow modelling.
- Section 5 details energy production calculations.
- Section 6 details the calculation of energy production exceeded with various probabilities.
- Section 7 describes the methodology and results of the assessment of noise levels caused by the wind turbine.
- Section 8 describes the methodology and results of the assessment of shadow flicker caused by the wind turbine.
- Section 9 provides an analysis of visual influence in terms of mapping the zones of theoretical visibility and photomontages.
- Section 10 draws some conclusions from the work performed.
- Section 11 provides recommendations for the next steps of the project.

2. Site and Project Description

2.1. Site Description

The site is located on Oileán Chléire, a few hundred meters north-east of the port, as indicated in Figure 1. The island's vegetation mainly consists of bushes, with only a few sparse trees, and presents several distributed houses and small settlements. The terrain is rather hilly, with a peak of 160 m on the eastern side of the island. Within the site envelope, 3E has identified a specific location which could be suitable for the installation of the wind turbine. This assumption will need to be verified on site based on the precise topography and terrain conditions.

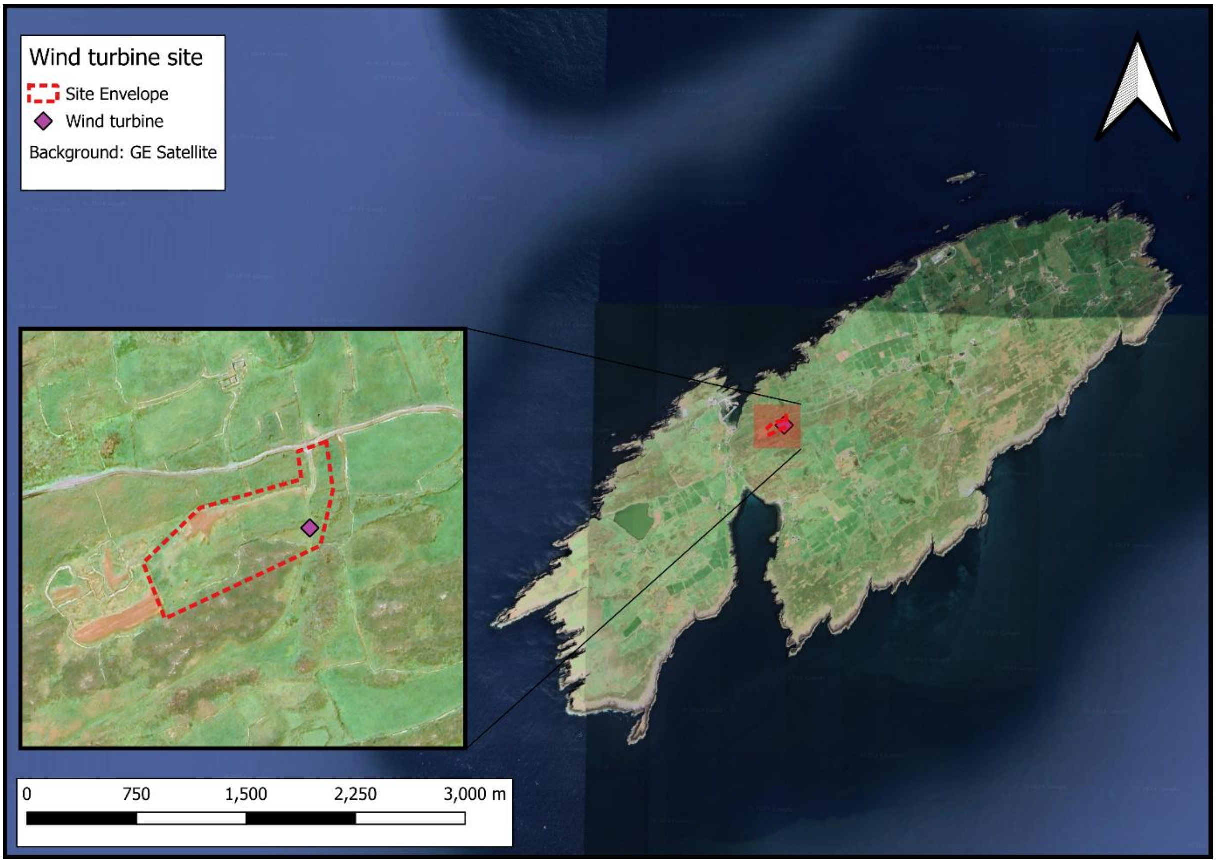

Figure 1: Wind turbine site envelope and position.

2.2. Regulation

Two levels of regulation are analysed as follows:

- **Wind Energy Development Guideline (2006):** it is the public Irish policy for developing wind farms, directed to both developers and authorities in charge of assessing the projects.
- **Cork County Development Plan (2022)**: The Cork County strategic spatial planning policy identifies the possible land uses in regard to main human activities, including wind energy.

2.2.1. Wind Energy Development Guidelines (2006)

The Wind Energy Development Guidelines [1] were published in 2006 by the Irish Department of Environment, Heritage and Local Government. They offer advice to planning authorities on wind energy planning through the development plan process and on determining applications for planning permission. They also assist developers and the broader public in considering wind energy development.

In recent years, the Irish government has repeatedly envisaged an update of the Wind Energy Development Guidelines. To date, no formal update has been published. However, in 2019, a draft version of the revised guidelines was circulated [2]. Although this does not have legal value to the current date, it is here discussed to highlight potential major differences with respect to the actual regulation.

The key requirements of the Guidelines in terms of noise levels, shadow flicker, assessment of visual impacts and distance from roads and railways are presented in Table 4. No regional roads and railways are present on Cape Clear. Therefore, the last raw is not applicable to the specific case study.

Table 4: Key requirements from Irish regulation in terms of noise levels, shadow flicker, and assessment of visual impacts for wind turbines.

Topic	Wind Energy Development Guidelines (2006)	Draft revised Wind Energy Development Guidelines (2019)
Noise	▪ Noise limits are to be applied outdoors, at noise-sensitive locations (receptors). ▪ All limits are to be intended as LA90, 10-min averaged. ▪ General limit: total noise limit of 45 dB(A) due to the wind turbines or maximum increase of 5 dB(A) above background noise. ▪ Low noise environments (background noise < 30 dB(A)): absolute daytime level of 35-40 dB(A). ▪ Higher limits can be fixed at night, namely 43 dB(A). ▪ Noise is unlikely to be a significant problem where the distance from the nearest turbine is more than 500 m.	Some changes are proposed to be consistent with WHO Guidelines. ▪ Relative Rated Noise Limit - The impact of noise levels from wind energy development shall not exceed: (i) background noise levels by more than 5 dB(A) within the range 35-43 dB(A); (ii) 43 dB(A).
Shadow flicker	▪ Shadow flicker at neighbouring receptors within 500 m should not exceed 30 hours per year or 30 minutes per day. ▪ Very low potential for shadow flicker at distances greater than 10 rotor diameters.	The proposed changes are more restrictive: ▪ No dwelling or other affected property should experience shadow flicker. ▪ An automated turbine shut down is requested to eliminate shadow flicker.

Topic	Wind Energy Development Guidelines (2006)	Draft revised Wind Energy Development Guidelines (2019)
Landscape and visual impacts	▪ The zone of theoretical visibility of the wind farm should be mapped within a radius of 15 km for tip heights up to 100 m in height. ▪ The degree of visibility is to be assessed based on the number of turbines visible to half the blade length, in addition to hub-height. ▪ A DTM of a maximum of 50 by 50 m should be used for the assessment. ▪ Photomontages: viewshed reference points for the development of photomontages should be established at varying distances from the project and agreed upon with the relevant stakeholders.	No changes are suggested in this regard.
Proximity to roads and railways	▪ It is advisable to achieve a safety setback from national and regional roads and railways within a distance equal to the height of the turbine and blade.	The proposed changes are slightly more restrictive: ▪ A safety setback is required from National and Regional roads and railways, corresponding to the turbine's tip height plus 10%.

2.2.2. County Cork Development Plan (2022)

The County Work Development Plan [3] was published in 2022 and sets policy objectives and overall strategy for the proper planning and sustainable development of the County over the plan period from 2022 to 2028.

Concerning wind energy, the Plan differentiates between:

- “Commercial wind energy developments” (ET 13-8), where the primary purpose is to generate electricity for connection to the grid irrespective of their scale. The area of Cape Clear is classified as “Normally discouraged” regarding commercial wind energy projects. Proposals of commercial wind energy developments can be considered “*[…] only in exceptional circumstances where adverse impacts do not arise […]*”.
- “Other wind energy developments” (Par 13.7.2) refers to small-scale renewable energy generation installations for domestic, agricultural and industrial activities. Small-scale projects may fall under an “exempted development” in relation to the planning permission (except when proposals are located within or on a site or feature of “heritage or environmental” value).

The Council also recognises the importance of community ownership of wind energy projects and how they enable local communities to directly benefit from local wind energy resources and ensure long-term income for rural communities. The Plan also explicitly mentions that these technologies “[…] *will give rural areas, and in particular islands off County Cork, the chance to be self-sufficient and have energy security*”.

The Island Transition Team intends to establish a locally shared ownership structure for the wind turbine project, which could bring positive economic impacts to the island community.

Given that the power consumption on the island amounts to ~304,700 kWh/year[1], a wind turbine of 600 kW is expected to produce more electricity than the one locally required. For this reason, based on the classification provided by the County Cork Development Plan, the project falls under the "Commercial wind energy development" category.

The Plan (Par 13.7.1) also provides a list of topics that wind project proposals should cover. A summary of those is presented in Section 10.4.

2.2.3. West Cork Islands Integrated Development Strategy (2022)

The West Cork Islands Integrated Development Strategy [3] is a strategic document dedicated to the rural development of the 7 West Cork Islands. In Section 4.1.9, the strategy sets a target for islands to become self-sufficient entities. Concerning wind energy, the strategy states:

"Careful consideration is required in terms of the erection and installation of wind turbines and other associated energy infrastructure given the sensitive landscapes associated with the islands and the fishing and aquaculture activities carried out in the surrounding waters. Local physical, economic and environmental circumstances will influence the type of technology or renewable power source best suited to the islands.

There may be potential for the islands to export energy to the grid in the longer-term if successful energy projects can be developed, thus providing the islands with an economic opportunity. The islands present a good opportunity for the implementation of pilot schemes, the outcomes of which could have national significance".

Therefore, the strategy, on the one hand, remarks on the need to pay particular attention to the local landscape and environmental components of West Cork Islands when proposing wind energy developments. On the other side, it also remarks on the economic opportunities arising from the possible export of electricity to the rest of the grid.

2.3. Project description

2.3.1. Current status

Cape Clear's Island transition team presented the project's current status to the Clean energy for EU islands secretariat. At the current stage, the following steps have been completed:

- **Ownership**: The site envelope highlighted in Figure 1 is owned by a member of the Island transition team who is willing to use it for a wind energy installation.
- **Grid connection**: a 300-kW grid connection with the local DSO has been secured to date. Nevertheless, the DSO also communicated that this could be upgraded to 600 kW via intervention on the mainland cabin. For this reason, the Island transition team asked the Secretariat to explore wind turbine models up to 600 kW rated power.
- **Bird survey**: a bird survey was carried out from October 2020 until October 2021 at the proposed wind turbine site. The survey concluded that a single wind turbine is unlikely to affect the Peregrine or Chough population or any other birdlife associated with the island.

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[1] Value communicated by the Island Transition Team in the application to the 30 for 2030 Programme.

- **Planning application:** a planning application was delivered to the County Cork Council in early 2024. After some informal interactions, the application was withdrawn months later.

2.3.2. Wind turbines selection

In the absence of on-site wind measurements to conduct detailed site compliance, the selection of suitable wind turbines is based on the classes defined in the relevant IEC norms [5], as well as on the Global Atlas of Siting Parameter (GASP) to provide for suitable wind statistics.

GASP indicates that the site has characteristics which make it suitable for:

- Wind turbines in Class IEC II, for hub heights up to 50 m.
- Wind turbines in Class IEC I, for hub heights up to 100 m.

Therefore, it is chosen to analyse the productivity of both IEC II and IEC I wind turbines at different hub heights. The compliance of the specific wind turbine models to the IEC requirements will have to be verified based on on-site wind data acquisitions at later project stages.

For the scope of this work, 3E identified the EWT DW54x – 0.5 MW (Class IA)[2] and the EWT DW52 – 0.5 MW (Class IIA)[3] as possibly suitable to the site characteristics. It should be noted that both wind turbine models are initially one MW machines, electrically adapted to a lower-rated power. On a specific request, the manufacturer can adapt the rated capacity to an intermediate value; however, datasheets are currently not available for the intermediate values.

2.3.3. Wind turbine configurations

In this report, **a configuration refers to the combination of a wind turbine model and a hub height**. Six configurations are considered, comprising one turbine each for a total installed capacity of 0.5 MW.

The selected configurations are detailed in Table 5. Wind turbine coordinates are listed in ANNEX B.

Table 5: List of wind turbine configurations analysed in this study.

Configuration		**DW54x, 0.5 MW @ 40 m**	**DW54x, 0.5 MW @ 50 m**	**DW54x 0.5 MW @ 59 m**	**DW52, 0.5 MW @ 35 m**	**DW52, 0.5 MW @ 40 m**	**DW52, 0.5 MW @ 50 m**
Scenario		1	2	3	4	5	6
Wind turbine manufacturer	[-]	EWT	EWT	EWT	EWT	EWT	EWT
Wind turbine type	[-]	DW54x	DW54x	DW54x	DW52	DW52	DW52
Number of wind turbines	[-]	1	1	1	1	1	1

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[2] https://ewtdirectwind.com/products/dw58/

[3] https://ewtdirectwind.com/products/dw61/

Configuration		DW54x, 0.5 MW @ 40 m	DW54x, 0.5 MW @ 50 m	DW54x 0.5 MW @ 59 m	DW52, 0.5 MW @ 35 m	DW52, 0.5 MW @ 40 m	DW52, 0.5 MW @ 50 m
Rated power per turbine	[MW]	0.5	0.5	0.5	0.5	0.5	0.5
Total rated power	[MW]	0.5	0.5	0.5	0.5	0.5	0.5
Rotor diameter	[m]	54	54	54	52	52	52
Hub height	[m]	40	50	59	35	40	50

3. Wind Data Processing

3.1. Preliminary remarks

3.1.1. Wind Resource assessment – industry best practices

For each project, 3E selects the most appropriate wind resource dataset, depending on the site location, the existence of wind statistics nearby, and the ability of these statistics to predict electrical production and measured data in the surroundings.

3.1.2. 3E's Virtual Met Mast

Since no such measurement campaign was carried out for this project, this study is based on 3E's Virtual Met Mast (see ANNEX D).

This database leverages more than 20 years of experience accumulated by 3E in the field of wind resource assessment. It combines three modelling stages: it starts from the reanalysis dataset ERA5, on which it applies a simplified version of the mesoscale model WRF using a deep-learning algorithm. Then, the resource is further refined geographically using WAsP as a microscale model. Finally, the time granularity is increased from 1 hour to 10 minutes using a statistical down-sampling methodology.

3.1.3. Validation, calibration and uncertainty

The model chain and results are permanently validated on measurement devices and operational farms across the world (more than 250 validation points). The analysis shows an improved standard deviation on the modelled wind speed and energy yield with respect to datasets such as ERA5 and the Global Wind Atlas, which are typically used when measurement data is lacking.

3.2. Selected wind data

For this project, wind statistics were generated from the Virtual Met Mast time series located at the site location, at a height of 55 m:

Table 6: VMM coordinates (Irish Grid (IG)-IRELAND65 (IE))

	Longitude (X)	Latitude (Y)	Altitude (m)
VMM	95,793	21,838	73.8

4. Wind Flow Modelling

4.1. Terrain model

Terrain features influence the wind flow and thus play a significant role in the spatial extrapolation of the wind regime. The software package WindPRO and the WAsP wind flow model are used in the present study. WAsP requires a terrain model describing elevation, roughness and other relevant obstacles to the wind flow that are not modelled as roughness (cf. ANNEX C).

The terrain model used in this study represents the current conditions, which are assumed to remain the same over the wind farm's lifetime.

4.1.1. Elevation

Elevation differences across the site can highly influence the wind regime. For this study, terrain elevation is modelled within a radius of 15 km (in line with WAsP recommendations [11]) based on EU-DEM data. Height contour lines are then generated with an elevation difference of 5 m between two successive lines.

WAsP is designed for ΔRIX values close to zero, where RIX quantifies the elevation model's complexity and ΔRIX the complexity difference between two locations. The validity of the WAsP model is checked according to WAsP recommendations [11] by computing ΔRIX between each wind turbine location and the location of the measurement device used for wind flow simulations.

The ΔRIX values are all close to 0 for this project, which allows WAsP to be used for wind flow simulations.

4.1.2. Roughness length

Roughness length is a key parameter of the equation that governs wind shear. Changes in roughness length cause variations of wind shear, which propagate vertically as the air flows over the site. Therefore, the impact at measurement or hub height varies with distance to roughness changes but is also related to atmospheric conditions.
Given that roughness length is closely related to land use, terrain roughness is modelled using a land-use database. The Sentinel-2 Land Cover (2023) database is used, and roughness length values specific to each land use are applied according to 3E’s methodology.
The land use areas' validity and roughness lengths are checked by comparing them to aerial imagery.

The aerial imagery from GeoData dated 2022 is used for this purpose and assumed to represent the site conditions at the time of this report's writing.
The roughness model is adapted so that the land use area shapes fit the aerial imagery.
Following WAsP recommendations, the terrain roughness is modelled within a radius of 20 kilometres.

4.1.3. Large obstacles to the wind flow

Terrain roughness might not properly consider the disturbance of the wind flow caused by tall, isolated obstacles. According to WAsP recommendations, isolated obstacles should be modelled separately if they are located within a radius of 50 times their height from any measurement device or wind turbine and if their height exceeds one-third of any measurement or hub height. In this study, no obstacles meet this criterion; hence, no obstacle is modelled separately.

4.1.4. Displacement height

When a measurement device or wind turbine is located within or close to a large obstacle (forest, industrial area, urban area, etc.), the wind is blocked and flows over the obstacles. In this case, a displacement height needs to be applied, according to WAsP recommendations.

Applying a displacement height consists of reducing the measurement or hub height by the value of the displacement height. 3E applies a displacement height if an area of obstacles having an average height over 10 m is located within 1 km from any measurement device or wind turbine and obstructs at least one of the twelve 30° sectors. Displacement heights are evaluated following best practices [14]. In this study, no obstacles meet this criterion to be identified as displacement heights. Hence, the displacement height values applied to each turbine are null.

4.2. Wind flow model

WAsP is used to extrapolate the wind regime to each wind turbine's location and hub height. It involves two steps: a vertical extrapolation of the wind regime to hub height and a horizontal extrapolation of the wind regime to each wind turbine location.

The results from the WAsP model are also presented in ANNEX E in the form of maps showing the variation of the wind resource across the island and at different hub heights.

4.3. Wind regime at the site

The long-term wind regime at 50 m hub height and the location of the wind turbine are given as an example in Table 7 and Figure 2.

Table 7: Long-term wind regime at the site

Location	[-]	Scenario 2
Height AGL	[m]	50
Weibull mean wind speed	[m/s]	8.85
Weibull A	[m/s]	9.99
Weibull k	[-]	2.174
Prevailing wind directions	[-]	WNW, W, WSW
Wind directions with the most energy content	[-]	WNW, W

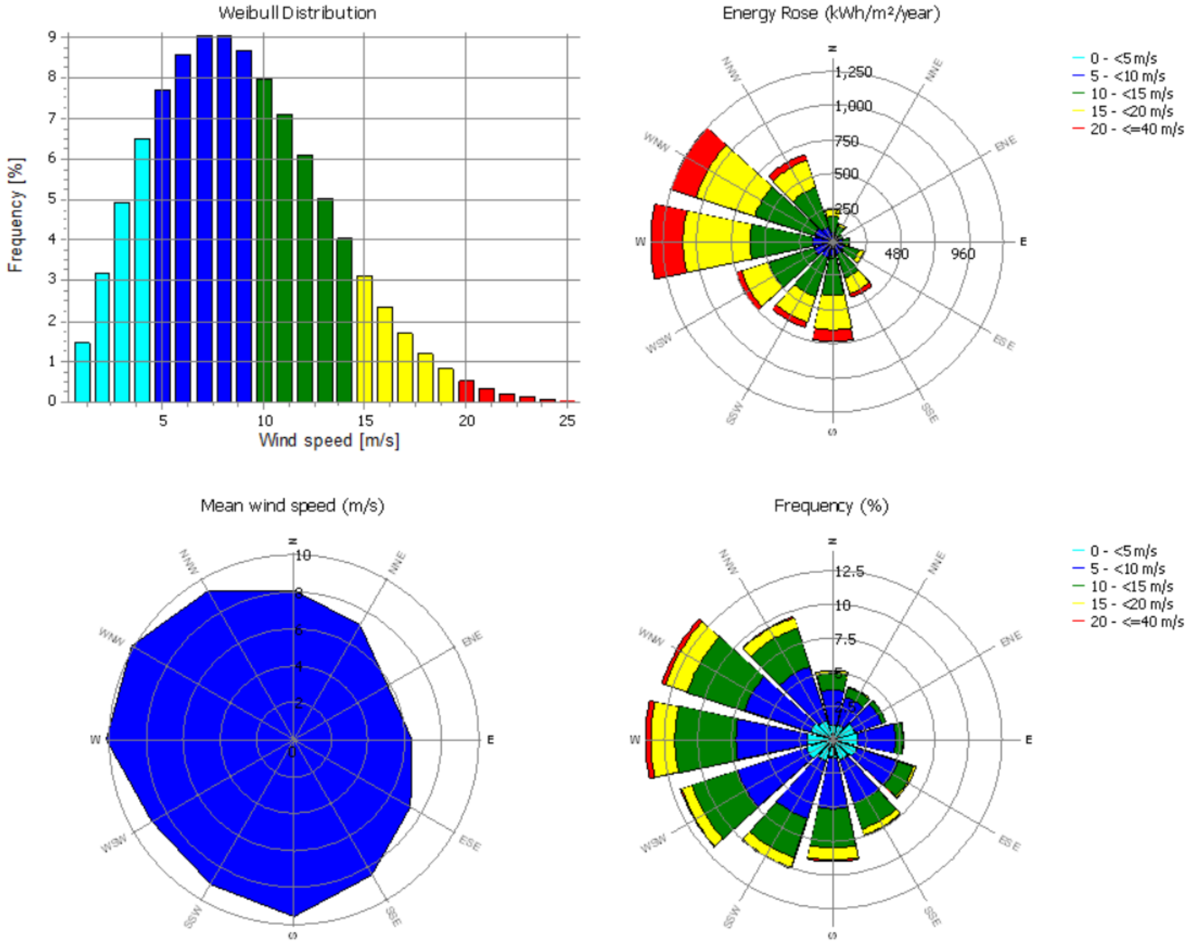

Figure 2: Long-term wind regime at the site.

5. Energy Production Losses

5.1. Gross energy production

Gross energy production refers to the theoretical energy production that would be achieved if there was no operational loss. It is calculated by combining the wind regime at a wind turbine location and hub height to the power curve specific to the considered wind turbine type and corrected for local hub height air density. This is done using the software WindPRO. For ease of reading, these results are provided in Table 9. Power curves are provided in ANNEX E.

Since the energy content of the wind varies proportionally to air density, power curves are adapted accordingly before being used in calculations. The adaptation is made using the new recommended WindPRO method (adjusted IEC 61400-12 method, improved to match turbine control) [15].

This project's air density at hub height ranges between 1.232 and 1.229 kg/m³, depending on the wind turbine location and hub height. WindPRO calculates air density based on temperature and pressure measurements from the Virtual Met Mast (VMM). According to the experience of 3E, this calculation is accurate enough for the scope of this study.

Important Note: AEP calculation results are specific to the wind turbine power curve considered. Therefore, when procuring the wind turbines for the project, it should be verified that the power curve guaranteed by the manufacturer in the procurement contract corresponds to the one used in this study. Any change to the power curve may require the recalculation of the AEP.

5.2. Energy production losses

5.2.1. General losses

In addition to energy conversion losses considered in the power curve, other losses affect the electrical power expected to be delivered to the grid. The following losses are taken into account in this study and are summarised in Table 8 further below. Other losses may apply but are considered negligible in this study.

5.2.1.1. Turbine interaction losses

The project consists of one single wind turbine; therefore, no losses are expected by the interaction with other wind turbines in the same park or by interactions with wind turbines of other wind farms: the abandoned micro-wind turbine on Cnoicin a Seabhaic has a minimal size, which will not impact the new installation.

5.2.1.2. Unavailability losses

Unavailability losses are due to downtime of the wind turbines or balance of the plant (maintenance or technical incidents) as well as downtime of the power grid as follows:

- Losses due to maintenance and technical incidents on the turbines are evaluated for this specific project as 5% of the energy production. This is a conservative estimate

based on the remoteness of the project site and on the eventual longer time required for reparations with respect to the mainland. It should be remarked that availability guarantees are often around 97% in operation and maintenance (O&M) contracts.
- Losses due to maintenance and technical incidents on the Balance of Plant (BoP) are typically evaluated by 3E as 0.2 % of the energy production.
- Grid unavailability loss is considered to be 0.3 % for this project. This value is based on the analysis of data from a large portfolio of operational wind farms. It should be noted that a more accurate estimate of grid unavailability losses might derive from the interaction with the Distribution System Operator (DSO) and the analysis of historical grid availability statistics.

It should be noted that the selected value is not the result of a detailed study, and an update might be needed in a later phase of the project.

5.2.1.3. Performance losses

Turbine performance losses are typically due to high wind hysteresis, yaw misalignment, wind flow inclination, turbulence, wind shear and other differences between turbine power curve test conditions and actual conditions at the project site:
- Generic performance losses are estimated at 1.65% for the DW54x and negligible for the DW52. Such a difference is strictly related to the differences in the power curves of the two wind turbine models.
- Site-specific losses are estimated at 0.2% for both wind turbine models.
- Turbine control limitations correspond to the following losses:
  - High wind hysteresis losses are estimated at 0.09% for this project. The wind distribution at the site is such that this type of event is not likely to occur very often.
  - Sub-optimal turbine performance due to the turbine system's limitations is considered 0.25% regardless of the complexity of the site. This loss is based on the analysis of operational data from a large number of wind farms. It is related to the unwinding of the cables, the configuration of the wind turbine and the physical limits of its control.

5.2.1.4. Electrical losses

Electrical losses occur in cables and transformers, ensuring electrical transmission to the wind farm substation. 3E typically evaluates them as 1.5 % of the energy production for a wind farm of this size and layout. This value is based on data analysis from a large portfolio of operational wind farms.

5.2.1.5. Environmental losses

Environmental losses account for the performance degradation of the wind turbines due to environmental conditions:
- Aerodynamic performance degradation of turbine blades due to dirt accretion (excluding icing) is estimated at 0.95% for this study,
- Aerodynamic performance degradation of turbine blades due to icing is estimated at 0.2% for this study,

- Potential turbine shutdowns due to icing conditions are estimated at 0.07%. This loss is estimated based on the icing frequency calculated from 3E's VMM. The actual loss will highly depend on the icing detection method and the operational strategy which will be applied to the follow-up of icing formation.
- At this stage, 3E does not consider any loss for potential turbine shutdowns due to lighting or hail. If specific shutdown rules are enforced, their impact on production should be evaluated separately.

5.2.2. Curtailment losses

These losses are due to modifications of wind turbine operation for technical or environmental reasons (e.g. related to noise or shadow flicker constraints, birds or bats preservation, etc.). No curtailment losses are applicable.

5.2.3. Losses summary table

The energy production losses defined in the preceding sub-sections are summarised in Table 8.
Important note: some losses considered in this study are industry standard values that 3E estimates are relevant for the project. They are not all based on contractual documents or specific studies, and they should be reviewed for the financial closing of the project.

Table 8: Expected energy production losses.

Configuration		**DW54x, 0.5 MW @ 40 m**	**DW54x, 0.5 MW @ 50 m**	**DW54x, 0.5 MW @ 59 m**	**DW52, 0.5 MW @ 35 m**	**DW52, 0.5 MW @ 40 m**	**DW52, 0.5 MW @ 50 m**
Scenario		1	2	3	4	5	6
Wake losses	**[%]**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Unavailability losses	**[%]**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**
Turbine		5.0	5.0	5.0	5.0	5.0	5.0
BOP		0.2	0.2	0.2	0.2	0.2	0.2
Grid		0.3	0.3	0.3	0.3	0.3	0.3
Performance losses	**[%]**	**2.2**	**2.2**	**2.2**	**0.5**	**0.5**	**0.5**
Generic performance losses		1.7	1.7	1.7	0.0	0.0	0.0
Site-specific losses		0.2	0.2	0.2	0.2	0.2	0.2
Suboptimal performance		0.3	0.3	0.3	0.3	0.3	0.3
Hysteresis losses		0.1	0.1	0.1	0.1	0.1	0.1
Electrical losses	**[%]**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**
Environmental losses	**[%]**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
Performance degradation not due to icing		1.0	1.0	1.0	1.0	1.0	1.0
Performance degradation due to icing		0.2	0.2	0.2	0.2	0.2	0.2
Shutdown due to icing, lightning, hail, etc.		0.1	0.1	0.1	0.1	0.1	0.1
Total losses (*)	**[%]**	**10.1**	**10.1**	**10.1**	**8.6**	**8.6**	**8.6**

(*) The production losses in % are combined as: $\boldsymbol{Total} = 100 - \frac{\prod_i (100 - Loss_i)}{100^{(N-1)}}$Net energy production

Energy production losses are applied to the expected annual gross energy production, resulting in the expected net Annual Energy Production (AEP). The expected AEP and other energy production figures are presented in Table 9. For each configuration, the following results are provided:

- Gross energy production corresponds to the theoretically recoverable annual energy production at the outlet side of the generator without production losses.
- Energy production losses: as computed in Section 5.
- Net energy production (AEP) corresponds to the annual energy production expected to be delivered to the grid (taking into account all energy production losses).
- Net full load equivalent hours: the amount of time it would take for the wind farm to yield its annual production if it could constantly produce at full load.
- Net capacity factor: is the net full load equivalent hours divided by the total number of hours a year. It represents the usage of the installed capacity.

Table 9: Expected wind farm energy production figures.

Configuration		**DW54x, 0.5 MW @ 40 m**	**DW54x, 0.5 MW @ 50 m**	**DW54x, 0.5 MW @ 59 m**	**DW52, 0.5 MW @ 35 m**	**DW52, 0.5 MW @ 40 m**	**DW52, 0.5 MW @ 50 m**
Scenario		1	2	3	4	5	6
Mean wind speed	[m/s]	8.64	8.85	9.01	8.50	8.64	8.85
Gross energy production	[MWh/y]	2,580	2,665	2,730	2,535	2,591	2,677
Other losses	[%]	10.1	10.1	10.1	8.6	8.6	8.6
Total energy production losses	[%]	10.1	10.1	10.1	8.6	8.6	8.6
Net energy production (AEP)	[MWh/y]	2,321	2,397	2,456	2,318	2,369	2,448
Net full load equivalent hours	[h/y]	4,641	4,793	4,911	4,637	4,738	4,896
Net capacity factor	[%]	52.9	54.7	56.0	52.9	54.1	55.9

6. Calculation of Energy Production Exceeded with Various Probability

6.1. Uncertainty assessment

Some uncertainty components are directly quantified in terms of energy production. In contrast, some other uncertainty components are first quantified in terms of wind speed and then translated into uncertainties in terms of energy production by applying a sensitivity factor calculated for each configuration. The sensitivity factor relates energy production change to wind speed change.

The global uncertainty is then calculated from the individual uncertainty components by assuming that they are independent and that the resulting uncertainty follows a normal distribution (central-limit theorem). They can be combined by calculating the square root of the sum of the squares of each uncertainty.

This study considers the following sources of uncertainty (other sources of uncertainty exist but are considered negligible). Individual and combined uncertainties are provided in Table 10.

6.1.1.1. Wind measurements (wind speed)

The uncertainty on wind data is mainly due to model inaccuracies and data processing. It is assessed based on the 3E’s VMM.

6.1.1.2. Vertical extrapolation (wind speed)

The uncertainty on vertical extrapolation results from inaccuracies and approximations in the terrain and wind flow models (WAsP). It is a function of the wind shear, terrain complexity and turbine hub height.

6.1.1.3. Future wind variability (wind speed)

The uncertainty on climate variability is due to the inter-annual variability of the wind regime and the assumption that the past wind regime is representative of the coming years. It is calculated for periods of 1, 10, 15 and 20 years based on data from a large portfolio of meteorological masts and operational wind farms.

6.1.1.4. Spatial variation (wind speed)

The uncertainty of spatial variation results from inaccuracies and approximations in the terrain and wind flow models (WAsP) and is a function of the site's extent and terrain complexity.

6.1.1.5. Power curve (production)

The uncertainty on the power curve used in the simulations includes the deviations of actual atmospheric conditions from reference conditions (including air density correction). It refers to the random part of the deviation of the wind turbine performance from the guaranteed power curve, as opposed to its bias related to non-standard wind flow conditions, which is potentially taken into account as a loss in Section 5.2. This uncertainty is calculated based on standard wind turbine procurement contracts and on the local wind regime.

6.1.1.6. Energy production losses (production)

The uncertainty on the other energy production losses covers the possibility that the expected energy production losses (including turbine interaction losses) deviate from the values in Section 5.2 because of model approximations and the variable atmospheric conditions. This uncertainty is calculated based on 3E's experience and is proportional to the value of each individual loss.

Table 10: Uncertainties associated with AEP results

Configuration	**DW54x, 0.5 MW @ 40 m**		**DW54x, 0.5 MW @ 50 m**		**DW54x, 0.5 MW @ 59 m**		**DW52, 0.5 MW @ 35 m**		**DW52, 0.5 MW @ 40 m**		**DW52,0.5 MW @ 50 m**	
Scenario	**1**		**2**		**3**		**4**		**5**		**6**	
Turbine sensitivity [%AEP/%WS]	1.02		0.99		0.96		1.06		1.03		1.00	
	[% WS]	[% AEP]	[% WS]	[% AEP]	[% WS]	[% AEP]	[% WS]	[% AEP]	[% WS]	[% AEP]	[% WS]	[% AEP]
Wind measurements	4.1	4.2	4.1	4.1	4.1	3.9	4.1	4.3	4.1	4.2	4.1	4.1
Vertical extrapolation	7.8	8.0	6.1	6.0	4.8	4.6	8.9	9.4	7.8	8.1	6.1	6.1
Future wind variability (20 years)												
1 year	6.1	6.2	6.1	6.1	6.1	5.9	6.1	6.5	6.1	6.3	6.1	6.1
10 years	2.3	2.4	2.3	2.3	2.3	2.2	2.3	2.5	2.3	2.4	2.3	2.3
15 years	1.9	2.0	1.9	1.9	1.9	1.8	1.9	2.0	1.9	2.0	1.9	1.9
20 years	1.7	1.7	1.7	1.7	1.7	1.6	1.7	1.8	1.7	1.7	1.7	1.7
Spatial variation	4.4	4.5	4.4	4.4	4.4	4.2	4.4	4.7	4.4	4.6	4.4	4.4
Power curve	///	3.9	///	3.8	///	3.7	///	4.0	///	3.9	///	3.8
Production losses	///	1.8	///	1.8	///	1.8	///	1.6	///	1.6	///	1.6
Combined uncertainty												
1 year	///	12.6	///	11.3	///	10.3	///	13.8	///	12.7	///	11.3
10 years	///	11.2	///	9.8	///	8.7	///	12.4	///	11.3	///	9.8
15 years	///	11.2	///	9.7	///	8.6	///	12.3	///	11.2	///	9.7
20 years	**///**	**11.1**	**///**	**9.6**	**///**	**8.6**	**///**	**12.3**	**///**	**11.2**	**///**	**9.7**

6.2. Energy production exceeded various probabilities

The calculation of the energy production exceeding the given probabilities is meant for the project's financial risk assessment. It is done assuming that the net AEP is the most probable energy production (50th percentile or P50) and that production follows a normal distribution characterised by a mean value equal to the P50 and a standard deviation equal to the combined uncertainty. Confidence intervals for the AEP are calculated using the statistical properties of the normal distribution.

AEPs over 1-, 10-, 15- and 20-year periods exceeded with probabilities of 50% (P50) to 95% (P95) are provided in Table 11.

Table 11: AEPs exceeded with various probabilities (percentiles)

Configuration			DW54x,0.5 MW @ 40 m	DW54x, 0.5 MW @ 50 m	DW54x, 0.5 MW @ 59 m	DW52, 0.5 MW @ 35 m	DW52, 0.5 MW @ 40 m	DW52, 0.5 MW @ 50 m
1 year	**AEP (P50)**	**[MWh/y]**	2,321	2,397	2,456	2,318	2,369	2,448
	AEP (P75)	**[MWh/y]**	2,123	2,215	2,285	2,103	2,166	2,261
	AEP (P90)	**[MWh/y]**	1,945	2,051	2,132	1,908	1,983	2,093
	AEP (P95)	**[MWh/y]**	1,838	1,953	2,040	1,792	1,873	1,992
10 years	**AEP (P50)**	**[MWh/y]**	2,321	2,397	2,456	2,318	2,369	2,448
	AEP (P75)	**[MWh/y]**	2,145	2,239	2,311	2,124	2,188	2,286
	AEP (P90)	**[MWh/y]**	1,986	2,097	2,181	1,949	2,026	2,141
	AEP (P95)	**[MWh/y]**	1,891	2,012	2,103	1,844	1,928	2,053
15 years	**AEP (P50)**	**[MWh/y]**	2,321	2,397	2,456	2,318	2,369	2,448
	AEP (P75)	**[MWh/y]**	2,146	2,240	2,313	2,125	2,190	2,288
	AEP (P90)	**[MWh/y]**	1,989	2,099	2,184	1,951	2,028	2,143
	AEP (P95)	**[MWh/y]**	1,894	2,015	2,107	1,847	1,932	2,057
20 years	**AEP (P50)**	**[MWh/y]**	2,321	2,397	2,456	2,318	2,369	2,448
	AEP (P75)	**[MWh/y]**	2,147	2,241	2,313	2,126	2,190	2,288
	AEP (P90)	**[MWh/y]**	1,990	2,101	2,185	1,953	2,029	2,145
	AEP (P95)	**[MWh/y]**	1,896	2,017	2,108	1,849	1,933	2,059

7. Noise

One of the key potential social impacts of wind energy is represented by the noise emitted by wind turbines. Noise during the operation phase of wind plants derives from mechanical components (gearbox, generator, yaw motors) and from aerodynamic interactions (interaction between airflow and turbines). Noise attenuates with increasing distance from wind turbines and is typically comparable to the existing background noise after some hundred meters.

7.1. Methodology

Wind turbine manufacturers typically have sound power levels (emission levels) associated with different wind speeds for a specific wind turbine model. Such noise levels are typically released at hub height to allow consideration for the impact of various towers. Higher hub heights usually generate lower noise levels on the ground. Emission noise levels from manufacturers can be used in noise dispersion models to simulate sound propagation and predict noise levels at different locations. Results from such models can be typically presented in two ways:

- Noise contours (isolines) represent fixed noise levels around the wind turbines. For a single wind turbine, noise isolines are like concentric circles around the emission point (i.e., the wind turbine), with larger circles representing lower noise levels. Different wind turbines contribute to noise levels in the case of multiple wind turbines, originating irregular shapes typical of the specific configuration.
- Maximum noise levels at specific receptors. In this case, maximum noise levels are assessed at relevant receptors.

Regulation of noise varies on a country basis and can be based on total noise levels (maximum noise level originated from the wind energy project and observed at a specific location) or on differential noise levels (maximum increase of background noise caused by the wind turbine).

Irish regulation in this regard, presented in Section 2.2.1, is a mix of the two approaches. The key requirements specified in the Wind Energy Development Guidelines (2006) [1] are presented as follows:

- General limit: total noise limit of 45 dB(A) due to the wind turbines or differential level of 5 dB(A).
- The limit for low noise environments, characterised by background noise < 30 dB(A): total daytime noise levels of 35-40 dB(A).
- Night limits: 43 dB(A).

Oileán Chléire is a small island with limited noise emissions associated with human activities. However, the strong wind typically blowing on the island is also expected to cause significant background noise. In the absence of specific indications or measurements on whether Oileán Chléire can be considered a low-noise environment, we will assess all the relevant total noise levels in this report. If the project is shown to comply with regulation in the most restrictive case (low-noise environment), no further analysis will be required.

The sound power levels at hub height associated with the two wind turbine models are presented in Table 12.

Table 12: Sound power levels concerning wind speed at hub height.

Wind speed	L_{WA} emission levels (dB(A))	
(m/s)	DW54x, 0.5MW	DW52, 0.5 MW
5	9.1	90.6
6	94.1	94.6
7	96.7	96.2
8	97.3	97.3
9	97.5	98.6
10	97.5	99.5
11	97.6	99.9
12	97.7	99.9

Noise dispersion models make use of several input parameters to assess - with the highest accuracy possible - the attenuation of noise by air and ground and then its propagation. The key parameters used in the analysis are presented in Table 13.

Table 13: Key parameters used in the noise dispersion model.

Parameter	Value
Noise calculation model	ISO 9613-2 General
Wind speed used for the assessment	Wind speed corresponding to the 95% rated power
Ground factor	0.7
Height of immission point AGL	2 m
Atmospheric attenuation coefficient	1.9 dB/km
Noise reflections	No
Pure tones	No

It should be noted that wind direction affects noise propagation and that – to verify compliance with the norms - the analysed condition is the worst possible. Real immission levels are expected to exceed the maximum thresholds this report analysed.

Noise contour isolines for the wind energy project analysed in this report have been produced for each studied configuration using the “DECIBEL” module of the WindPro software [15].

7.2. Results

All the resulting charts showing noise contours are made available in ANNEX G.
Key results and observations are presented as follows:

- DW54x 0.5 MW:
    - The 45 dB contour is at approx. 160 m from the wind turbine. No residential buildings or other receptors can be observed from satellite imagery in this area.
    - The 40 dB contour is at approx. 270 m from the wind turbine. No residential buildings or other receptors can be observed from satellite imagery in this area.

    Only very light differences can be observed for the three DW54x 0.5 MW configurations, with differences in tower heights not significantly affecting the resulting noise levels.

- DW42 0.5 MW:
    - The 45 dB contour is at approx. 190 m from the wind turbine. No residential buildings or other receptors can be observed from satellite imagery in this area.
    - The 40 dB contour is at approximately 335 m from the wind turbine. A single residential building located 300 m south of the wind turbine falls within this area.

    Only very light differences can be observed for the three DW52 0.5 MW configurations, with differences in tower heights not significantly affecting the resulting noise levels.

Please refer to ANNEX G for the pictures presenting the three isolines for each configuration.

It was demonstrated that all the DW54x configurations are expected to be compliant with the maximum total noise thresholds indicated by Irish regulations.

In the case of the DW52 0.5 MW, the maximum values could be instead exceeded at a single receptor. However, given the directionality of wind at the site from the W, WSW and WNW sectors, it is unlikely that the receptor will experience higher values than those set by regulation.

As a result of the above analysis, **noise is not considered a significant risk for the project**. No noise-related curtailment is recommended in this phase. Should the noise levels at any receptor exceed those set by regulation during the operation phase, noise curtailment strategies could be implemented at potentially limited yield expenses.

8. Shadow flicker

Shadow flicker is the rotational shadow that occurs when the sun passes behind wind turbines and has the potential to affect communities at sunrise and sunset times. Its effect is more important at higher latitudes, where the sun can be low in the sky for a longer time. However, shadow flicker can only occur in clear sky conditions, with direct sunlight. No negative effects can be observed with a cloudy sky.

8.1. Methodology

The potential for shadow flicker related to a specific turbine depends on two key characteristics of the technology, i.e. the tower height and the rotor diameter, and on the characteristics of the site, such as the duration of sunrise and sunset and cloudiness.

International standards [12] recommend that the predicted duration of shadow flicker effects experienced at a sensitive receptor not exceed 30 hours/year and 30 minutes/day on the worst affected day. The Irish regulation in this regard, analysed in Section 2.2.1, imposes the same limits but does not specify the conditions for the calculation of shadow flicker duration.

Following the industrial practice, and in consideration of the cloudiness at the site, 3E here analyses in this report the following quantities:

- Hours per year: A 30 hours/year contour is produced based on a real-case scenario (i.e., considering the average cloudiness at the site). Cloudiness values are obtained from the Valentia Observation station, located 75 km from the site.
- Minutes per day:
  - A 30 min/day contour is produced based on a real-case scenario (i.e., considering the average cloudiness at the site).
  - Another 30 minutes/day contour is produced based on a worst-case scenario (i.e., assuming the sky is completely clear during sunrise and sunset).

The model, implemented on the “SHADOW” module of the WindPro software [15]., uses an eye height of 1.5 m and does not consider the relevant buildings' obstacles and facades/windows. Detailed modelling of obstacles, facades and windows can lead to a – sometimes very significant – reduction of the indoor shadow flicker. The results provided in this report are, therefore, to be intended as conservative.

8.2. Results

All the resulting charts showing noise contours are made available in ANNEX H.

Key results and observations are presented as follows:

- DW54x 0.5 MW:
  - Real case: no receptors fall within the real case 30 hours/year and 30 min/day isolines.
  - Worst case:
    - Hub height 40 m: no residential buildings fall within the worst case 30 min/day isoline. The only building falling at the border of the isoline is

    a restaurant located at the port. However, as the port is located west of the site, shadow flicker will potentially impact at sunrise, with limited potential impact on such economic activity.
    - Hub heights 50 m and 59 m: a few more buildings, or parts of them, located near the port fall within the border of the worst case 30 min/day isoline.
- DW42 0.5 MW:
  - Real case: no receptors fall within the real case 30 hours/year and 30 min/day isolines.
  - Worst case:
    - Hub height 35 m: no buildings fall within the worst case 30 min/day isoline.
    - Hub height 40 m: only the restaurant at the port partially falls within the worst case 30 min/day isoline.
    - Hub height 50 m: a few more, or parts of them, located near the port, fall within the border of the worst case 30 min/day isoline.

Please refer to ANNEX H for the pictures presenting the three isolines for each configuration.

It was demonstrated that in the most restrictive scenario possible (without modelling obstacles and facades), the configurations with lower tower heights comply with the requirements indicated by Irish regulations concerning shadow flicker. The real potential of shadow flicker for affecting the local communities is very limited also with the higher tower heights.

As a result of the above analysis, **shadow flicker is not considered a significant risk for the project**, and automated shut-down is not recommended as unnecessary. Should the authorities request the implementation of automated shut-down, the wind turbine models proposed in this report can be equipped with the technology for its implementation.

9. Visual influence

Because of their tower heights and rotors, the installation of wind turbines causes a modification of the landscape. Although many human activities cause smaller or larger modifications of the landscape, it is important to describe and discuss them in advance with the relevant authorities and the affected communities.

The Irish guidelines on wind turbines require the development of two analyses to study the visual influence of wind turbines: the mapping of the so-called *zone of theoretical visibility* and the production of photomontages from relevant points of observation.

9.1. Zone of theoretical visibility

9.1.1. Methodology

The analysis of the zone of theoretical visibility is developed according to the requirements of the Wind Energy Development Guidelines [1], presented in Section 2.2.1. The zone of theoretical visibility of the wind farm should be mapped within a radius of 15 km. The degree of visibility is to be assessed based on the number of turbines visible to half of the blade length in addition to the hub height. The analysis should make use of a digital terrain model of a maximum of 50 x 50 m.

The viewshed height of each turbine configuration, calculated as in the previous paragraph, is indicated in Table 14. As for the digital terrain model, we use the EU-DEM one, characterised by a resolution of approximately 30 x 30 m, which complies with the above requirements. Because the project consists of a single wind turbine, the maps produced in this report only highlight from which parts of the land – within a 15 km radius from the site - the wind turbine will be theoretically visible.

Table 14: Parameters for the calculation of the zone of theoretical visibility

Scenario	Wind turbine model	Hub height [m]	Rotor diameter [m]	Tip height [m]	Viewshed height AGL [m]
1	DW54x	40	54	67	54
2	DW54x	50	54	77	64
3	DW54x	59	54	86	73
4	DW52	35	52	61	48
5	DW52	40	52	66	53
6	DW52	50	52	76	63

9.1.2. Results

The analysis results are provided in ANNEX I. The amplitude of the theoretical visibility zone increases with the tower height. The turbine is located on top of a small topographic feature and will be visible from most of the southern and eastern parts of the island.

9.2. Photomontage

9.2.1. Methodology

The Wind Energy Development Guidelines [1], presented in Section 2.2.1, require that developers provide some photomontages from relevant viewpoints showing the insertion of the wind farm in the local landscape.

For the purposes of this work, photomontages were produced starting from pictures captured from two viewpoints on the island (see Figure 3):

- The “Old turbine” site is located at the coordinates 51°26'33''N, 9°28'47''W and ~1’530 m from the turbine site.
- The “Windsock” site is located at the coordinates 51°27'01''N,9°29'07''W and ~1’530 m from the turbine site.

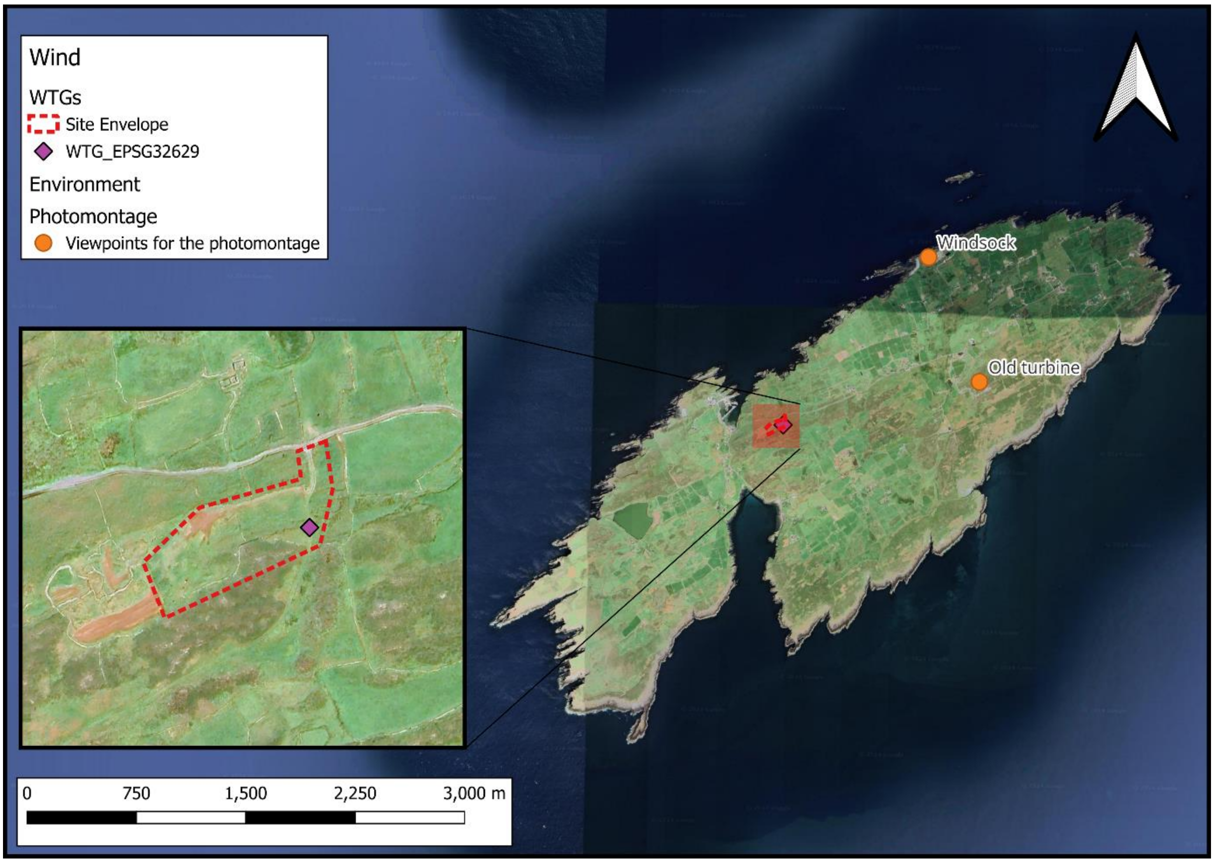

Figure 3: Viewpoints for the photomontage.

For each viewpoint, single images taken on-site were merged, making use of a cylindrical projection to generate panorama pictures. The “PHOTOMONTAGE” module of WindPRO software was used to perform this activity. The same digital terrain model used for the wind flow modelling, i.e. EU-DEM, has been given as an input to the module.

9.2.2. Results

The results of the analysis are provided in ANNEX J.

10. Other considerations

10.1. Island energy balance

As for the application compiled by the Island Transition Team for the 30 for 2030 Programme, the power consumption on Cape Clear amounts to ~304,700 kWh_{el}/year. The island’s heating and transportation needs amount instead to ~415,900 kWh_{th}/year, for a total energy consumption of 720,607 kWh/year.

Based on these figures and on the results of the long-term yield assessment discussed in Section 6, the island – with any of the configurations studied - would be able to self-produce 100% of its electrical demand, with an expected positive electricity export of over 2,000 MWh_{el}/year. Such a self-production of electricity could also promote the electrification of the rest of the demand on the island (mostly heating and land transport).

10.2. Site access

Transporting the oversized (wind blades, wind tower sections) and overweighted equipment (nacelle, hub) of the wind turbine will require careful planning and analysis of the alternatives with the identified supplier/manufacturer. As a common practice in small island environments, the possibility of transporting the equipment through the island port – normally preferred but not always feasible - should be compared to the possibility of transporting it via the so-called “beach landing”, consisting of the use of barges from which trucks transporting the equipment are directly unloaded on the island coast. The feasibility of this option needs to be carefully evaluated on the characteristics of the coast.

A preliminary list of possible access points, identified remotely making use of satellite imagery, is presented in Figure 4. The identified possible access points are the following:

- **AP1: Oilean Chleire Harbour**. Possible constraints are the turning radius at the end of the quay and the narrow curve at the end of the port area.
- **AP2: Beach near Cape Clear Distillery**. Possible constraints: rocks in front of the beach.
- **AP3: Quay/ramp on the eastern part of the island**. Possible constraints: The status of the quay is to be assessed.
- **AP4: Beach/ramp in Glen Middle**. Possible constraints: narrow curve at the end of the ramp.

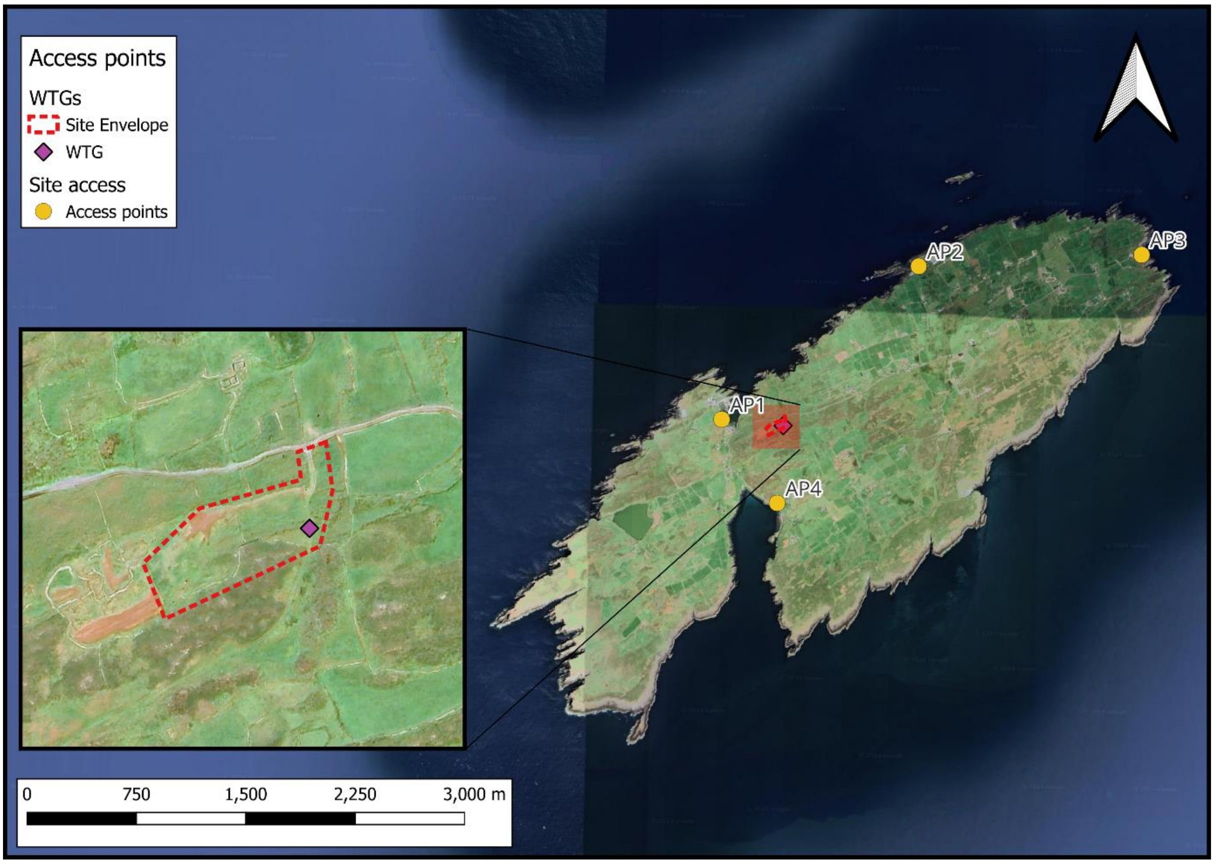

Figure 4: Possible access points to the island, to be further evaluated with in-person surveys and with the supplier/manufacturer

10.3. Electromagnetic interference

Wind turbines have the potential to cause disruptions to telecommunication systems by means of electromagnetic interference. This normally happens when a wind turbine is located on the line between a receiver and a transmitter. *Ex-ante* mitigation measures mostly consist of a discussion with the telecommunication system provider (TV/Radio broadcasters and cellular network service provider) and the wind turbine's eventual slight relocation. *Ex-post* measures normally applied to limit the impact on a small number of affected users may consist instead of installing higher quality or directional antennae, redirecting antennae towards alternative broadcast transmitters, and installing amplifiers.

It is recommended that the topic of potential magnetic interference is analysed with the relevant authorities for the specific territorial case, eventually asking for a clearance letter of the specifically identified configuration.

10.4. Planning application

The County Cork Development Plan [3], at Par. 13.7.1 provides a list of topics that applications should cover for wind farm developments. A summary is provided in Table 15.

Table 15: Summary of key requirements for wind farms planning requests from County Cork Development Plan, Par. 13.7.1

Topic	Comment
Requirement for Environmental assessments	The size of the envisaged wind turbine could be eligible for categorisation under "sub-threshold development" as for Planning and Development Regulations, 2001
Community engagement and participation aspects of the proposal	The topic is to be further developed by the Island Transition Team.
Grid connection	A grid capacity of 300 kW was secured for the project. An informal availability of 600 kW connection capacity upon upgrade of the substation was also communicated.
Geology and ground conditions	Local experts and on-site surveys will be dealt with, together with the identified manufacturer/supplier.
Site drainage, water storage and hydrological effects	Local experts and on-site surveys will be dealt with, together with the identified manufacturer/supplier.
Landscape and visual impact assessment	The topic is analysed in this report (Section 9).
Visual impact of ancillary development	Topic not analysed in this report. This will be further assessed upon identification of the POD and cable route and the existing distribution grid and cables.
Potential impact of the project on natural heritage	The topic was analysed by the Island Transition Team using a bird survey. The potential impact on other species will be further discussed.
Potential impact of the project on the built heritage, including archaeological and architectural heritage	The topic is to be analysed by a relevant local expert.
Consideration of carbon emissions balance is peat extraction is required	Evaluations on the ground composition are to be developed by local experts.
Local environmental impacts including noise, shadow flicker, electromagnetic interference	Topics of noise and shadow flicker are analysed in this report (Section 7 and Section 8). Electromagnetic interference to be discussed with relevant authorities and service providers (see Section 10.3)
Adequacy of local access road network to facilitate construction of the project and transportation of large machinery and turbine parts	Turbines of medium-size (up to 600 kW) with limited logistical requirements. Site access is to be further discussed with the supplier.
Information on any cumulative effects due to other projects, including effects on natural heritage and visual effects	One dismissed windmill of small size (30 kW installed capacity and 12.5 m rotor diameter) was installed in the eastern part of the island, with a limited foreseen cumulative visual effect due to the significant difference in size.
Information on the location of quarries to be used or borrow pits proposed during the construction phase	The topic is to be analysed by a relevant local expert and with the supplier/manufacturer (due to the small size of the plant, the material could be fully imported from the mainland).
Disposal or elimination of waste/surplus material from construction/site clearance, particularly for peatland sites	The topic will be further discussed after considerations of the soil composition are conducted.
Decommissioning considerations	The recommendation is to foresee a specific guarantee fund for the decommissioning, fed by part of the annual revenues. To be discussed within a detailed financial analysis.

11. Conclusion

3E has calculated the expected energy production and the associated uncertainties for the six proposed configurations of the community-owned wind turbine in Oileán Chléire. The main production results expected for a 20-year period are summarised in Table 16.

Table 16: 20-year expected AEP.

Configuration		DW54x, 0.5 MW @ 40 m	DW54x, 0.5 MW @ 50 m	DW54x, 0.5 MW @ 59 m	DW52, 0.5 MW @ 35 m	DW52, 0.5 MW @ 40 m	DW52, 0.5 MW @ 50 m
AEP (P50)	[MWh/y]	2,321	2,397	2,456	2,318	2,369	2,448
AEP (P75)	[MWh/y]	2,147	2,241	2,313	2,126	2,190	2,288
AEP (P90)	[MWh/y]	1,990	2,101	2,185	1,953	2,029	2,145
AEP (P95)	[MWh/y]	1,896	2,017	2,108	1,849	1,933	2,059

The two considered wind turbines have very similar yields, with the DW52 – an IEC Class IIA wind turbine – performing slightly better than the DW54x (an IEC Class IA wind turbine) for the same hub height. As expected, the yield increases with increasing hub height because of the increase in wind speed with height.

For the DW54x, the difference between the 40 m and the 59 m hub height is relatively limited, in the order of 240 MWh/year. For the DW52, the difference between the 35 m and the 50 m hub height is even lower, around 230 MWh/year. The profitability of higher hub heights, also leading to increased tip heights, needs to be assessed with respect to the required increase in investment costs and the considerations in terms of visual impact.

The modelling of noise emission and dispersion demonstrated that results for the studied configurations align with the requirements set by Irish legislation. Noise does not represent a significant risk for the implementation of the project.

Also, the modelling of shadow flicker has shown that, for the specific hub heights and rotor diameters used in this report, the expected impact is in line with the requirements set by Irish legislation. Shadow flicker does not represent a significant risk for project implementation.

Finally, the visual influence of the wind turbine was studied in terms of the zone of theoretical visibility within a 15 km radius from the site and through the development of some photomontages.

Important notes:

- It should be noted that 3E assumes that any information communicated by the Beneficiary is correct.
- The results of AEP calculations are specific to the curtailment strategies taken into account in this study. Any change to these curtailment strategies will require the recalculation of AEP.
- Several energy production losses taken into account in this study are industry standard values that 3E estimates are relevant for the project. They are not all based on

contractual documents or specific studies, and they should be reviewed for the financial closing of the project.

- The generic performance losses of the DW52 estimated in this report are null, whereas those for the DW54x have been assessed at 1.7%. The authors believe that this difference is related to the power curve values available in the manufacturer's datasheet of the DW52, which are on 1 m/s bins instead of 0.5 m/s and show a sharp behaviour around the rated speed. An eventual more accurate estimate of such losses could be done at later stages with updated values.

12. Next steps and recommendations

This report can be used by the Island transition team to compare the different options available and to submit a planning request to the relevant authority. It can especially be used to agree with the relevant stakeholders on the most suitable configuration in terms of rotor size and turbine height.

For further stages of the project development, it is advised that the following activities are performed:

- **1-year met-mast acquisition for defining the wind conditions of the site**. This step is important to assess the compliance of different wind turbine models with the local site conditions and provide a bankable assessment of the expected yield. A tubular met mast of approx. 40 m height could provide relevant information in terms of wind speed, direction and turbulence for wind turbines with hub heights up to 60 m. Such a campaign could have a cost in the order of ~75 kEUR, to be further evaluated with potential service providers.
- **Presentation of a planning request with a conservative configuration**. It is recommended that a planning request be presented to the relevant authority to make use of a wind turbine with tower height and rotor diameters that are higher or equal to the envisaged ones. This will facilitate an eventual change in the rotor diameter and tower height before construction.
- **Definition of the financial structure of the project**. Once the preferred configuration is identified, the Beneficiary can request a detailed quotation for the supply, transport and installation of the preferred wind turbine model. Once the investment's profitability is verified, the procurement solution will have to be discussed with the relevant stakeholders. A preliminary CAPEX estimation for the project amounts to approximately 1,500 kEUR, including the cost of civil works, transport and installation. Details on the variation of the cost based on the tower height should be further discussed with manufacturers.

Relevant references for the further development and financial assessment of the project are cited as follows:

- Small-Scale Renewable Electricity Support Scheme [31].
- SEAI’s Community Enabling Framework [32].
- SEAI’s Community Energy Resource Toolkit – The Planning Process [33].
- SEAI’s Community Energy Resource Toolkit – Onshore Wind [34].

References

[1] Department of the Environment, Heritage and Local Government – Government of Ireland, Wind Energy Development Guidelines, 2006. Available at: link.

[2] Department of Housing, Planning and Local Government – Government of Ireland, Draft revised Wind Energy Development Guidelines, 2019. Available at: link.

[3] County Cork Council, County Work Development Plan 2022-2028, 2022. Available at: link.

[4] West Cork Islands Interagency Group, West Cork Islands Integrated Development Strategy, 2022. Available at: link.

[5] IEC 61400-1, Wind energy generation systems – Part 1: Design requirements, February 2019

[6] EMD International, GASP – The first Global Atlas of Siting Parameters and wind turbine Design Classes. Available at: link.

[7] MEASNET. Evaluation of site-specific wind conditions. Version 2, April 2016.

[8] IEA (International Energy Agency). Recommended practices for wind turbine testing and evaluation. Wind speed measurement and use of cup anemometry. Second print 2003.

[9] IEC 61400-12-1, Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines, March 2017

[10] The CDS Climate Copernicus, https://cds.climate.copernicus.eu

[11] The WAsP team, "WAsP best practices and checklist", DTU, June 2013.

[12] World Bank Group, Environmental, Health and Safety Guidelines for Wind Energy, 2015

[13] Y. Cabooter, K. De Ridder, J.P. Van Ypersele, C. Tricot. Improved prediction of wind power in Belgium, Part 1. SPSD II, Belgian Science Policy, October 2006.

[14] GL Garrad Hassan: "Optimizing the parameterization of forests for WAsP wind speed calculations: A retrospective empirical study", EWEA 2012.

[15] WindPro user manual.

[16] Nils G. Mortensen, Ib Troen and Erik Lundtang Petersen. European Wind Atlas published for the Commission of the European Communities Directorate-General for Science, Research and Development, Brussels, Belgium by Risoe National Laboratory, Roskilde, Denmark, 1989, ISBN 87-550-1482-8.

[17] T. Burton, D. Sharpe, N. Jenkins, E. Boussanyi. Wind Energy Handbook.

[18] H. Alexandersson, A homogeneity test applied to precipitation data. J. Climatol, 1986

[19] H.B. Mann, Non-parametric tests against trend, Econometrica, 1945

[20] M.G. Kendall, Rank Correlation Methods, Charles Griffin, 1975

[21] Lloyd W. Wind Resource assessment using Measure-Correlate-Predict Techniques, Crest MSc thesis, 1995.

[22] A. Rogers, J. Rogers and J Manwell. Comparison of the performance of four measure-correlate-predict algorithms, Journal of Wind Engineering and Industrial Aerodynamics 93, 2005, pp. 243-264.

[23] A Comparison of Measure-Correlate-Predict Techniques for Wind Resource Assessment, Crest MSc thesis, 1996.

[24] J.C. Woods and S.J. Watson. A new matrix method of predicting long-term wind roses with MCP, J Wind Engineering and Industrial Aerodynamics 66, pp 85-94, 1997.

[25] C. Heipke, A. Koch, P. Lohmann. Analysis of SRTM DTM – Methodology and practical results. Institute for Photogrammetry and Geoinformation (IPI), University of Hannover.

[26] G. Mortensen, L. Landberg, I. Troen, E.L. Petersen. Wind Atlas Analysis and Application Program (WAsP). Risoe National Laboratory, Roskilde, Denmark, 1993 and updates.

[27] Bowen, A.J. and N.G. Mortensen (1996/2005). WAsP prediction errors due to site orography. Risø-R-995(EN). Risø National Laboratory, Roskilde. 65 pp.

[28] Bowen, A.J. and N.G. Mortensen (1996). Exploring the limits of WAsP: the Wind Atlas Analysis and Application Program. Proc. 1996 European Union Wind Energy

[29] A. Albers (2013), "Assessment of Production Losses Due Due to Rotor Blade Icing"

[30] Irish Statute Book, Planning and Development Regulations, 2001. Available at: link.

[31] Department of the Environment, Climate and Communications, Small-Scale Renewable Electricity Support Scheme, 2023. Available at: link.

[32] Sustainable Energy Authority of Ireland, Community Enabling Framework. Available at: link.

[33] Sustainable Energy Authority of Ireland, Community Energy Resource Toolkit – The Planning Process, 2024. Available at: link.

[34] Sustainable Energy Authority of Ireland, Community Energy Resource Toolkit – Onshore wind, 2024. Available at: link.

ANNEX A SITE DESCRIPTION ILLUSTRATIONS

Figure 5: Drone image of the site (1/2). Courtesy of Ciaran O Driscoll.

Figure 6: Drone image of the site (2/2). Courtesy of Ciaran O Driscoll.

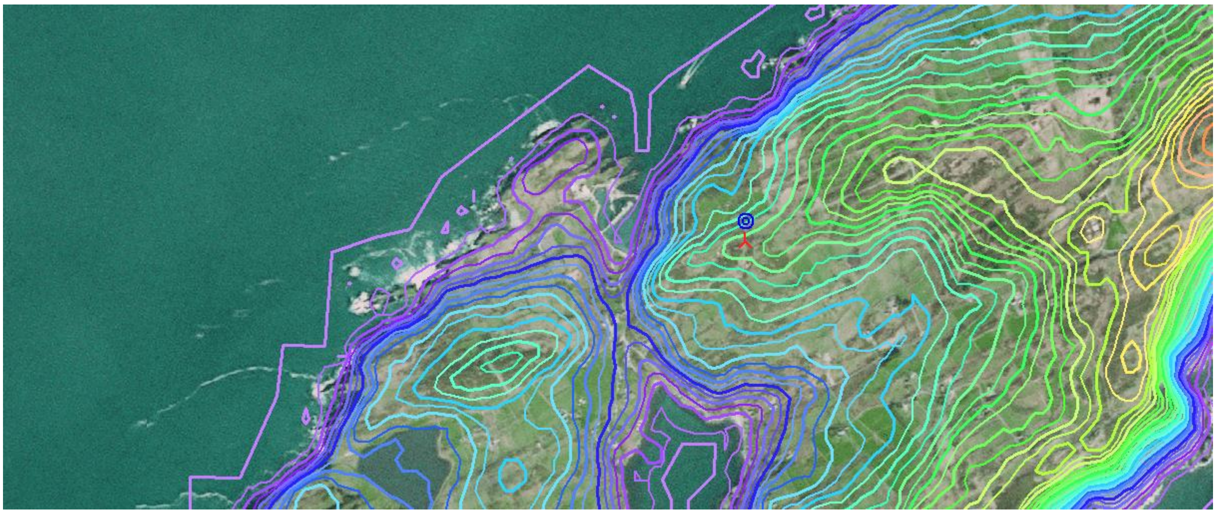

Figure 7: Site elevation (contour lines every 5 metres, and wormer colours denote higher elevations).

ANNEX B WIND TURBINE COORDINATES

Table 17: Wind turbine coordinates (Irish Grid (IG)-IRELAND65 (IE))

Turbine	**Longitude (X)**	**Latitude (Y)**	**Altitude (m)**
WT1	95,791	21,778	80.1

ANNEX C The WAsP Model

The central point in the wind transformation model of WAsP – the so-called Wind Atlas Methodology – is the concept of a Regional or Generalized Wind Climate or Wind Atlas. This Generalized Wind Climate is the hypothetical wind climate for an ideal, featureless, flat terrain with uniform surface roughness, assuming the same overall atmospheric conditions as the measuring position. The basic "machine" of WAsP is a flow model, representing the effect of different terrain features:

- Terrain height variations,
- Terrain roughness,
- Sheltering obstacles.

To deduce the Generalized Wind Climate from measured wind in actual terrain, the WAsP flow model is used to remove the local terrain effects.

To deduce the wind climate at a location of interest from the Generalised Wind Climate, the WAsP flow model is used to introduce the effect of terrain features.

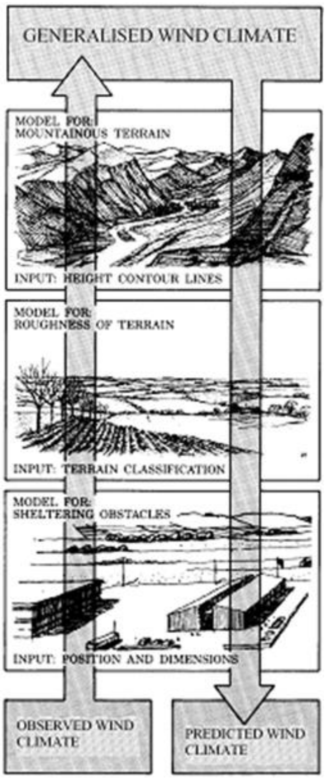

Figure 8: Wind Atlas methodology (Source: wasp.dk)

ANNEX D 3E’S VIRTUAL MET MAST (VMM)

Introduction

In 2022, 3E introduced its micro-scale wind resource model - the Virtual Met Mast (VMM). The model uses detailed orography and land cover data combined with meso- and micro-scale wind flow models at sub-hourly resolutions.
The resulting VMM has the following features:

- The temporal resolution of up to 10 minutes is comparable with most measuring masts;
- Spatial resolution of 30 meters;
- Availability anywhere on land, for onshore and offshore sites;
- At any height between 10 m and 300 m above ground level;
- It includes most parameters relevant to wind resource analysis, such as wind speed, direction, temperature, atmospheric pressure, relative humidity, air density, and Monin-Obukov length (MOL).

The model undergoes continuous validation at numerous sites around the world. To date (August 2023), the model has a mean absolute error on hourly wind speed of 9.5%.

This appendix presents the characteristics of the model and its validation, focusing on validation in the Belgian domain, and is based in part on academic publications produced by 3E [8][9][10].

Model chain

Like many wind data services, Virtual Met Mast is based on the WRF model (Weather Research & Forecasting model) [1].
Firstly, ERA5 reanalysis data are used to generate a mesoscale wind climate on a 3x3 km grid with hourly resolution by combining an adapted version of the Weather Research & Forecasting (or WRF) model and a Deep Learning model to optimize the computation process over long periods.
To achieve a spatial and temporal resolution capable of capturing the local effects of topography at a specific location and height, three models are successively applied to these mesoscale results over the entire computational domain:

- Spatial resolution is increased to 30 m by correcting for topographical effects using the WAsP flow model. Very high-resolution topographic data (10 m for land cover, 30 m for elevation) are used in this process best to capture the heterogeneity in the site's surroundings.

- The WRF model's spectral domain is corrected using the Spectral Correction Method (SCM) principles, which corrects the smoothing effect of WRF mesoscale simulations at hourly time resolution.
- The spectral domain of the WRF model is extended by including sub-hourly turbulence effects with a micro-scale spectral Atmospheric Boundary Layer (ABL) model to achieve an output resolution of 10 minutes [5].

Figure 9 shows a graphical overview of the final modelling approach, illustrating the various steps in the 3E micro-scale model. The following sections present each model and its corrections.

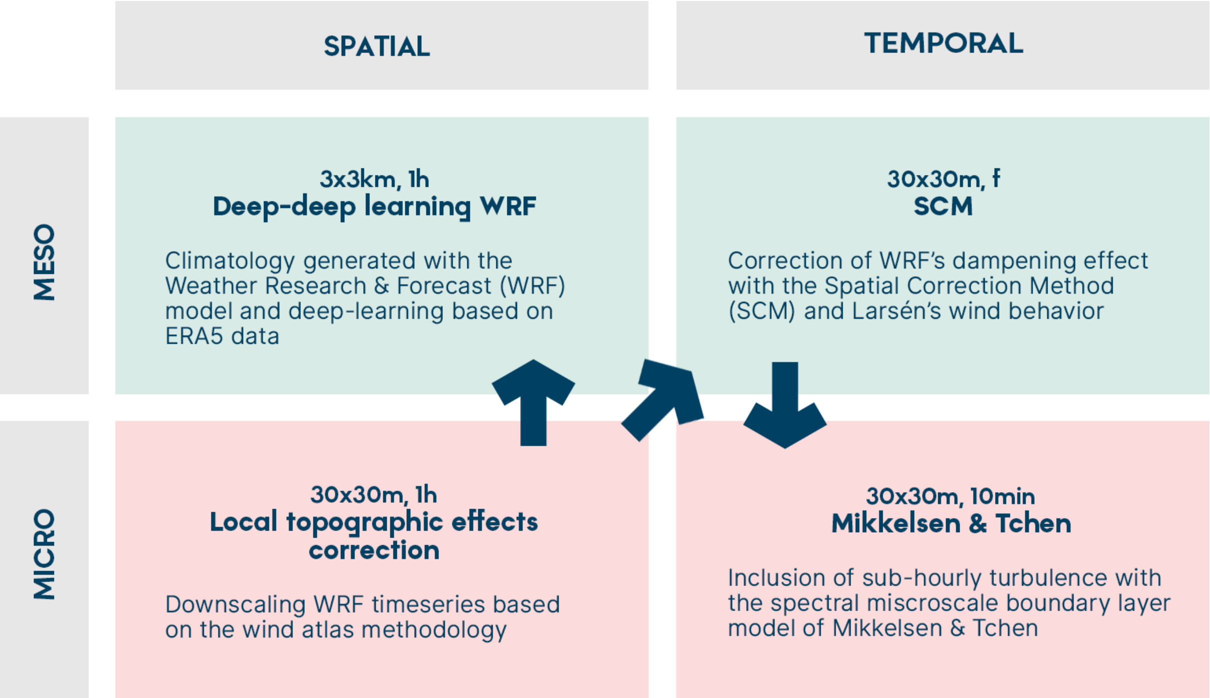

Figure 9. Overview of the different modelling steps in the 3E micro-scale model

The DL-WRF model of 3E

3E's large-scale wind model is based on the Weather Research & Forecasting (WRF) climate model, a state-of-the-art mesoscale numerical weather prediction system for atmospheric research and operational forecasting applications widely used in the wind energy community.

3E runs its own version of the WRF model, based on research carried out as part of the development of the New European Wind Atlas (NEWA), and incorporates a Deep Learning (DL) component to reduce computation times [3][4].

The output of the DL-WRF model is a mesoscale atlas comprising a series of surface and atmospheric boundary layer meteorological variables with a spatial resolution of three kilometres and an hourly resolution for any desired historical period from 1989 onwards.

Given this spatial resolution in kilometres, the results of the DL-WRF mesoscale model do not represent local characteristics resulting from micro-scale variations in orography and surface roughness. However, considering these effects is crucial for accurately determining the local wind climate at a site.

The resolution of the results is therefore increased using the micro-scale model developed by 3E on the basis of Jackson & Hunt's (1975) wind flux model for flux corrections and an adapted version of Troen & Petersen's (1989) wind atlas methodology for the final time series, using very high-resolution elevation and roughness maps derived from Sentinel satellites [2][3].

WRF spectral corrections

The WRF model has two main shortcomings with respect to spectral or temporal properties relevant to wind turbine performance modelling, namely:

- The smoothing effect that occurs in the mesoscale range of the spectrum, i.e. at frequencies between day^{-1} and h^{-1}, results in an underestimation of available energy.
- Higher-frequency fluctuations in the micro-scale range of the spectrum, i.e. frequencies above h^{-1}, are not integrated into the hourly result. However, modelling 10-minute fluctuations is essential for modelling wind turbine performance.

3E’s full-scale wind model resolves both limitations by correcting and extending the spectral domain of the WRF model, as shown in Figure 10.

3E corrects the dampening effect of WRF’s mesoscale simulations directly in the frequency domain, following the principles of the Spectral Correction Method (or SCM) [4] and based on Larsén’s observed wind behaviour in the mesoscale spectrum of 10^{-6} to 10^{-3} Hz [5].

The spectral correction consists of two steps. First, a regression of WRF’s observed spectrum is performed in the frequency range from 8.10^{-6} to 3.10^{-5} Hz, for which it is assumed that WRF simulations are correctly capturing the spectral energy, together with a log-linear regression of Larsén’s observed wind behaviour in the range of 10^{-6} to 10^{-3} Hz. Second, the simulated WRF spectral energy is scaled pro-rata for both regressions for frequencies above 2.10^{-5} Hz or approximately 1.7 d^{-1}.

3E corrects the absence of higher-frequency fluctuations by extending the spectral domain of the WRF model before converting it to the time domain with a fast Fourier transformation.

3E includes sub-hourly turbulence effects by using the spectral microscale boundary-layer model of Mikkelsen & Tchen [6] and superimposing the model to the corrected mesoscale model to create a single full-scale boundary-layer spectral model. Starting from the hourly WRF simulations, the spectral microscale model ranges from $(2\ h)^{-1}$ to $(2\ s)^{-1}$ to arrive at a time series with an output frequency of 1 Hz. After a fast Fourier transform, the high-resolution time series is grouped into 10-minute periods, for which realistic mean and standard deviation wind speed values can be obtained that resemble the typical output of a meteorological mast from a wind resource measurement campaign.

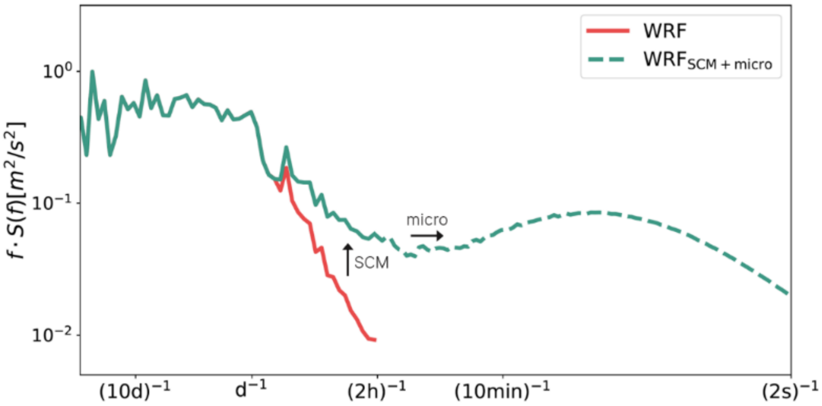

Figure 10. The spectrum of the WRF model and the resulting spectra of the two-step spectral corrections.

Validation of the Virtual Met Mast

As for most validations of physical or numerical models, our permanent internal validation model consists of three distinct steps:

- Measurement data, i.e., wind measurements of high-quality anemometers, can be obtained as a reference for the validation of the modelled wind data.
- Performing a data validation, i.e. setting validation rules & constraints to ensure the quality of the reference measurement data.
- Defining and calculating the validation metrics, i.e. the key indicators used to validate the data accuracy and fit-for-purpose.

Each step is discussed separately below.

Reference measurement data

Consistent measurement data from 253 sites has been obtained and included in our internal permanent validation framework.

The sensor heights are between 59 and 115m above ground, with the bulk at around 80m. The validation period considered for each mast was a contiguous period of at least a full year between 1996-2022.

In most cases, the period was approximately two years (Min: 200 days, max: 21 years). The modelled time series were masked to the measurements (filtering out the missing data) to get a matching time series.

To allow the comparison with ERA5, the validation was carried out with hourly resolution. An hourly average of the measurement time series was performed to allow the comparison. The modelled wind speed and direction data was linearly interpolated to the measurement's height. This interpolation was done in velocity-component form (U and V) and then transformed back to magnitude and angle form (WS and WD).

The breakdown of the 253 sites per continent is detailed in the following table.

Table 18: Number of sites per continent

	Europe	**Africa**	**Asia**	**America**	**Offshore**
Sites	84	41	13	4	4

Data validation

Different quality checks and site selection rules are applied to the obtained data sets of wind measurements. The following validations are applied to the data time series with hourly resolution:

- From all datasets, only the sites were used with at least 1 year of measurement data, with 90% availability and a height of 60 metres or more.
- A min/max quality check: the minimum & maximum wind speed values are calculated and should be plausible, i.e. between 0 and 60 m/s.

Apart from these quality checks and parsing, no additional process is applied to the measurement data.

Validation metrics

For the location of each validation site, 3E's Virtual Met Mast (VMM) data is requested through our operational API at hourly resolution for the validation period of the reference data source. Also, ERA5 data are requested to be compared with the validation metrics.

Successively, the following two metrics are calculated for both 3E's VMM as well as the ERA5 data for each site based on the measurement:

- The Mean Percentage Error on the mean wind speed (MPE)

- The Mean Absolute Percentage Error on the mean wind speed (MAPE)

In the following section, we will discuss the validation metrics that were obtained in detail.

Global accuracy

The mean absolute percentage error (MAPE) of 3E's Virtual Met Mast is 7.2% for hourly data considering all 253 reference sites.

This MAPE represents the average of the absolute percentage errors of each entry in a dataset to calculate how accurate the forecasted quantities were in comparison with the actual quantities. Since a MAPE below 10% is generally considered 'highly accurate forecasting', while a MAPE between 10-20% is considered 'good forecasting', 3E's VMM can be considered 'highly accurate.'

For the same 253 sites, the ERA5 data has an average MAPE of only 12.8% for hourly data. Given the significantly lower average MAPE, 3E's VMM is more accurate and more certain than ERA5 wind data.

Local accuracy

The mean absolute percentage error (MAPE) of 3E's Virtual Met Mast is 12.5 % for hourly data considering all 15 reference sites in Southeast Asia. In general, it has been observed that the Virtual Met Mast underestimates the wind speeds in the continent, as the mean percentage error (MPE) is -6.4%. These values were used to calibrate the wind speed values obtained from the VMM generated for the current project.

References

[1] Skamarock, W.C. et al. (2008), "Description of the Advanced Research WRF Version 3", Tech. Rep. NCAR/TN-475+STR, National Center for Atmospheric Research.

[2] Jackson, P.S. & J.C.R. Hunt (1975), "Turbulent wind flow over a low hill", Quarterly Journal of the Royal Meteorological Society 101, 929–955.

[3] Troen, I. & E.L. Petersen (1989), "European wind atlas". Published for the Commission of the European Communities, Directorate-General for Science, Research, and Development, Belgium by Risoe National Laboratory, Denmark.

[4] Bastine D. et al. (2018), "Extreme Winds in the New European Wind Atlas", J. of Physics: Conf. Series, 1102 and Skamarock W.C. (2004), "Evaluating Mesoscale NWP Models Using Kinetic Energy Spectra", Monthly weather review 132 3019–32.

[5] Larsén X.G., C.Vincent & S.E.Larsen (2013), "Spectral structure of mesoscale winds over the water", Quarterly J. of the Royal Meteorological Society 139, 685–700.

[6] Larsén X.G. et al., A Model for the Spectrum of the Lateral Velocity Component from Mesoscale to Microscale and Its Application to Wind-Direction Variation, Boundary-Layer Meteorology 178(3):1-20, 2021

[7] Lewis, C.D. (1982) International and Business Forecasting Methods.

[8] Schillebeeck D. & G. Leroy (2022), “Generating long-term sub-hourly wind speed time series by coupling mesoscale models with full-scale spectra”, Journal of Physics: Conference Series 2151 012003.

[9] Witha B. et al. (2019), “WRF model sensitivity studies and specifications for the NEWA mesoscale wind atlas production runs”, Deliverable 4.3 of FP7-ENERGY.2013.10.1.2.

[10] Witha B. et al. (2019), “The NEWA Mesoscale Wind Atlas: production and ensemble runs”, Wind Europe Conference, Bilbao.

ANNEX E MAPS OF WIND RESOURCES AND SPECIFIC PRODUCTION

This Annex presents the results of the WaSP model (vertical and horizontal extrapolation of wind speed and direction) in the form of maps showing the wind energy resource and the specific production of the DW54x across the island at different heights.

Specific energy

The specific energy represents the energy contained in the wind per unit of vertical unit area and per year. The following charts, depicting the spatial variation of specific energy at hub heights relevant to the project, are presented:

- Figure 11 shows specific energy at 35 m (AGL).
- Figure 12 shows specific energy at 40 m (AGL).
- Figure 13 shows specific energy at 50 m (AGL).
- Figure 14 shows specific energy at 59 m (AGL).

It can be observed that, although the highest wind energy resource is available on the cliffs on the south-eastern coast of the island, the chosen location is also subject to considerable wind energy resources. Furthermore, it should be noted that differences in specific energy between the different areas of the island decrease as the hub height increases; this is related to the decreasing influence of terrain and topography as the height above ground level increases.

Specific production

The specific production represents the gross energy that a specific wind energy turbine can produce yearly. The following charts, depicting the spatial variation of DW54x-specific production at the different hub heights analysed in this report, are presented:

- Figure 15 shows DW54x specific production at 40 m hub height.
- Figure 16 shows DW54x specific production at 50 m hub height.
- Figure 17 shows DW54x specific production at 59 m hub height.

It can be observed that the chosen location is among those with the highest expected specific production for the DW54x on the island. Also, it is noted that, although an increase in specific production is expected with increasing height, this does not seem very significant for the specific site analysed.

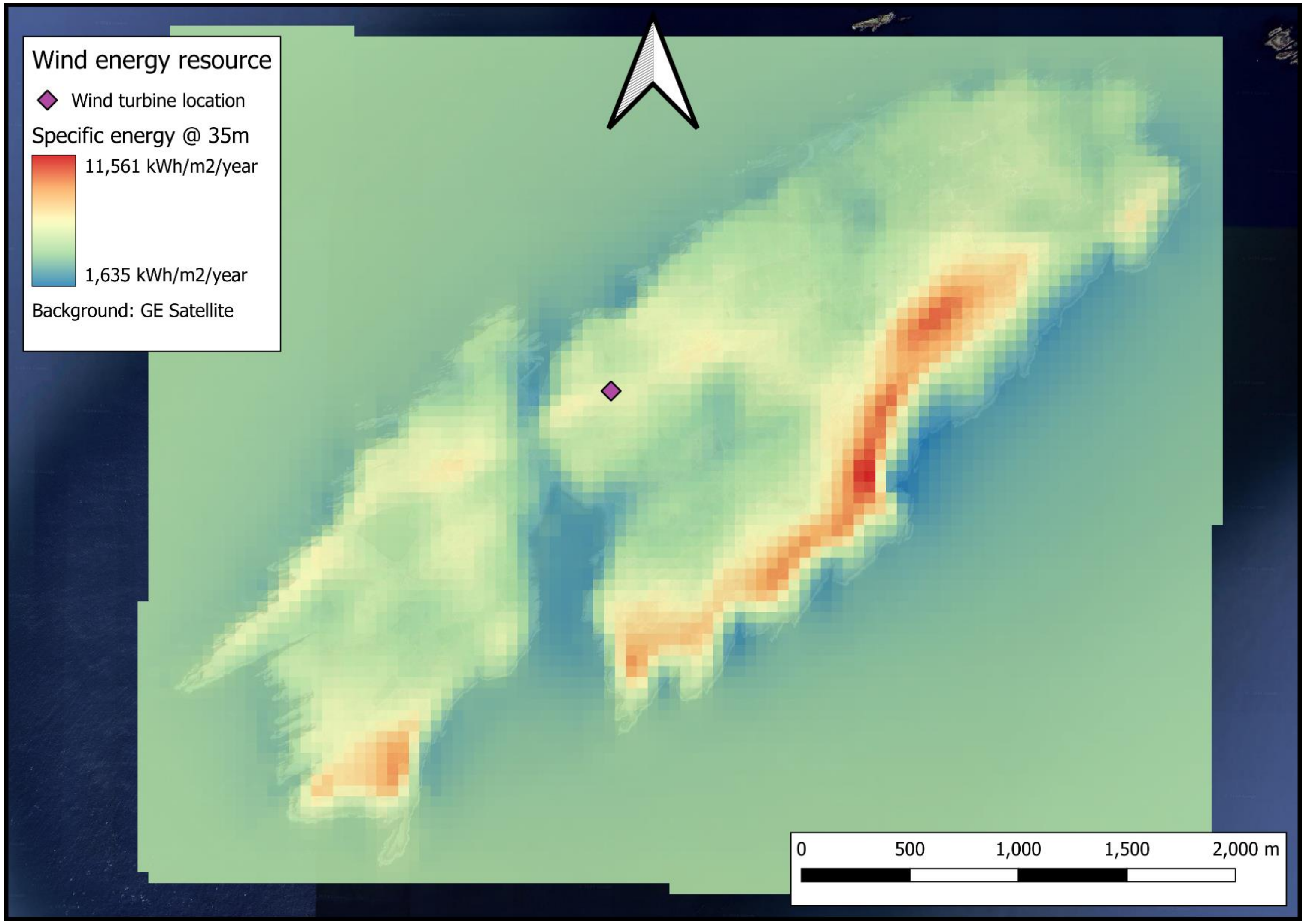

Figure 11: Specific wind energy per vertical unit area and per year (kWh/m²/year)) at 35 m (AGL).

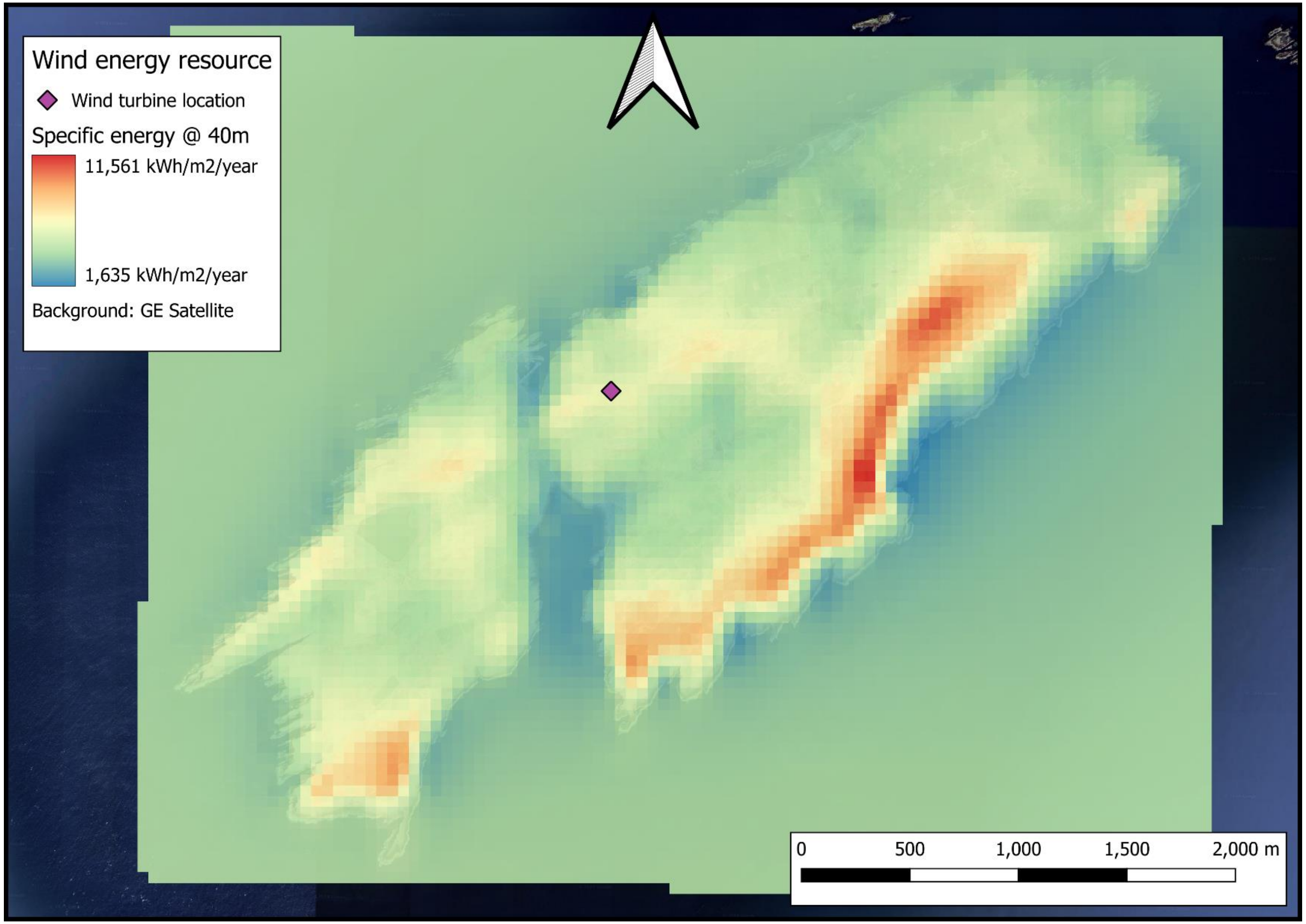

Figure 12: Specific wind energy per vertical unit area and per year (kWh/m²/year)) at 40 m (AGL).

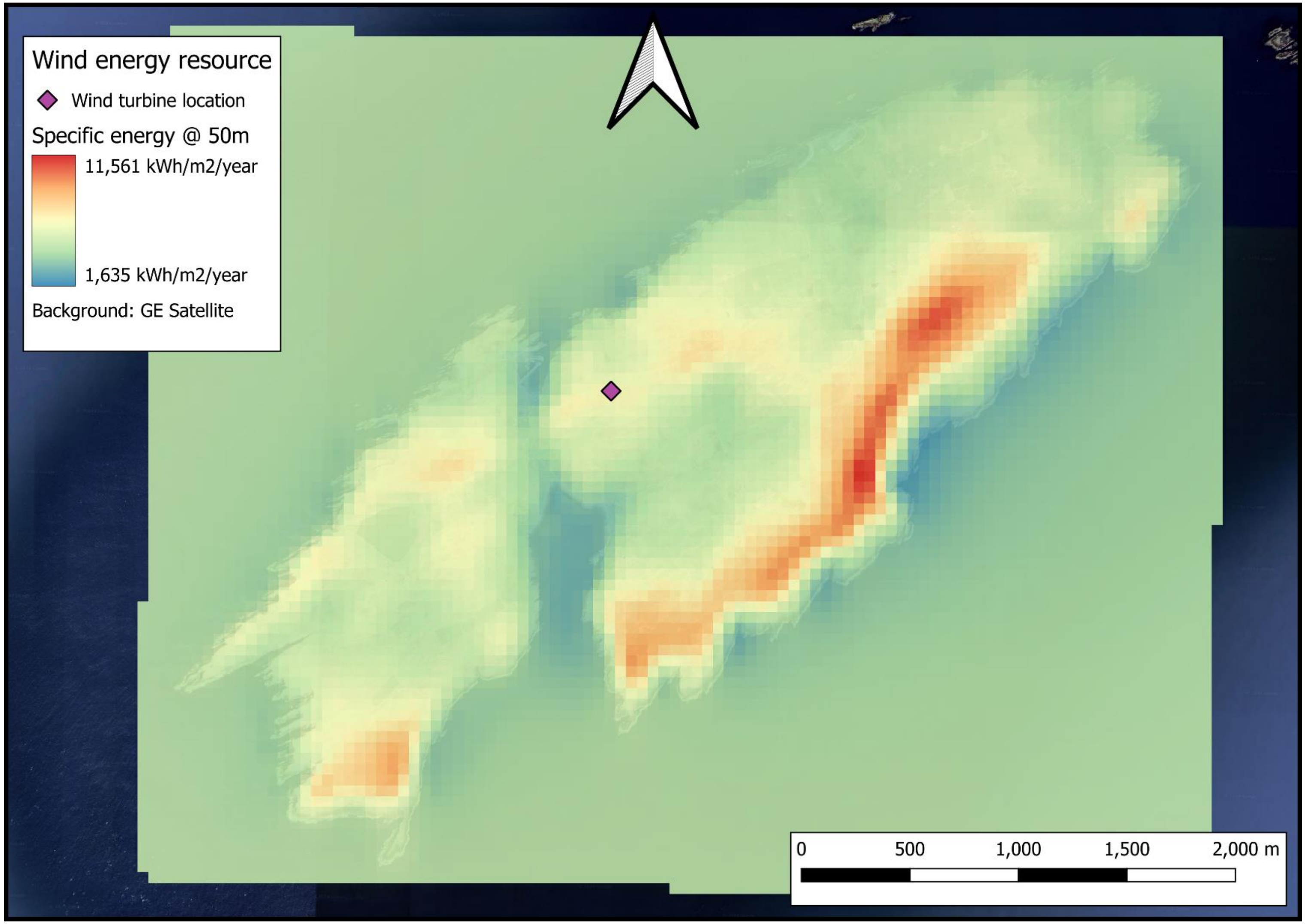

Figure 13: Specific wind energy per vertical unit area and per year (kWh/m^2/year)) at 50 m (AGL).

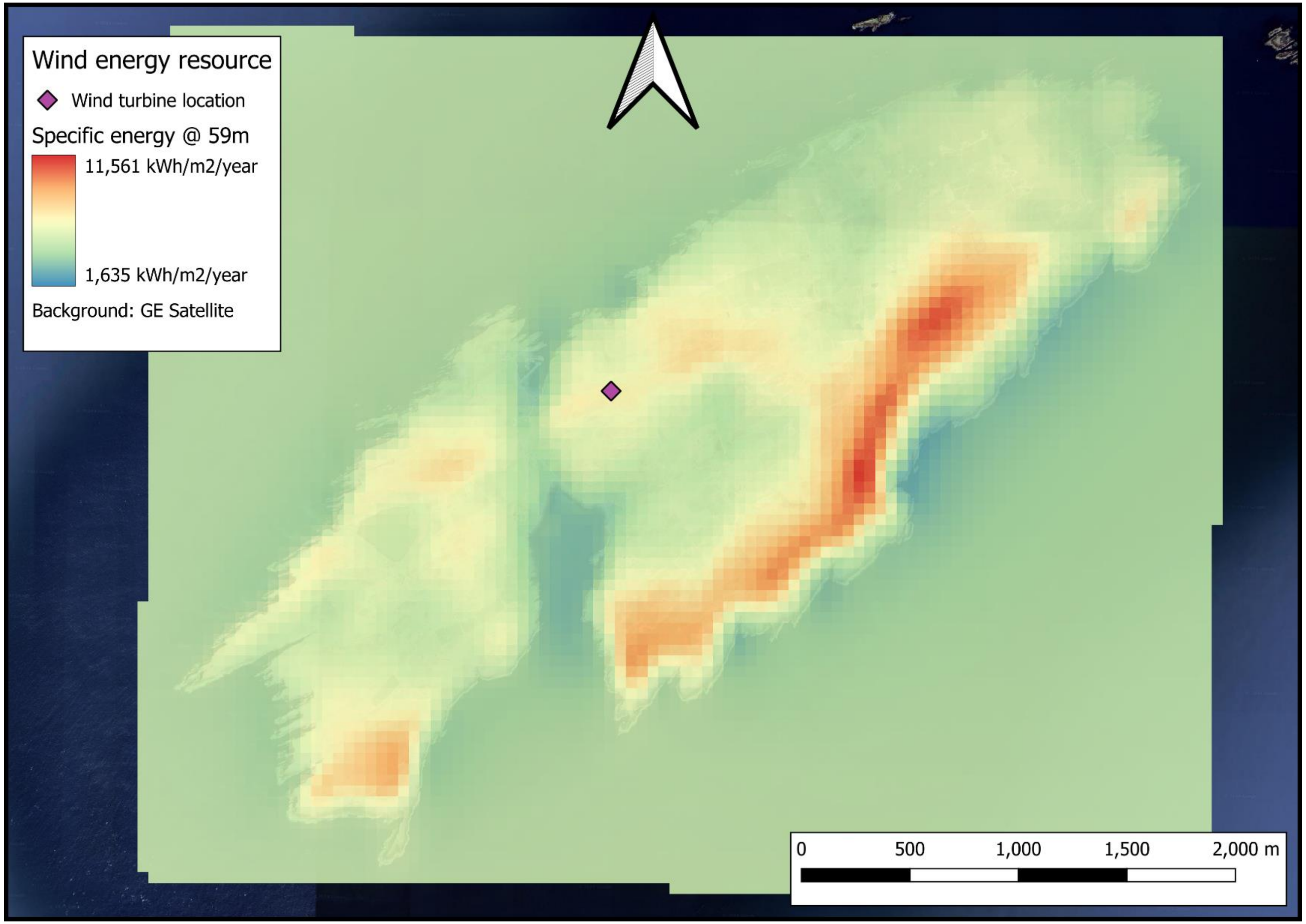

Figure 14: Specific wind energy per vertical unit area and per year (kWh/m²/year)) at 59 m (AGL).

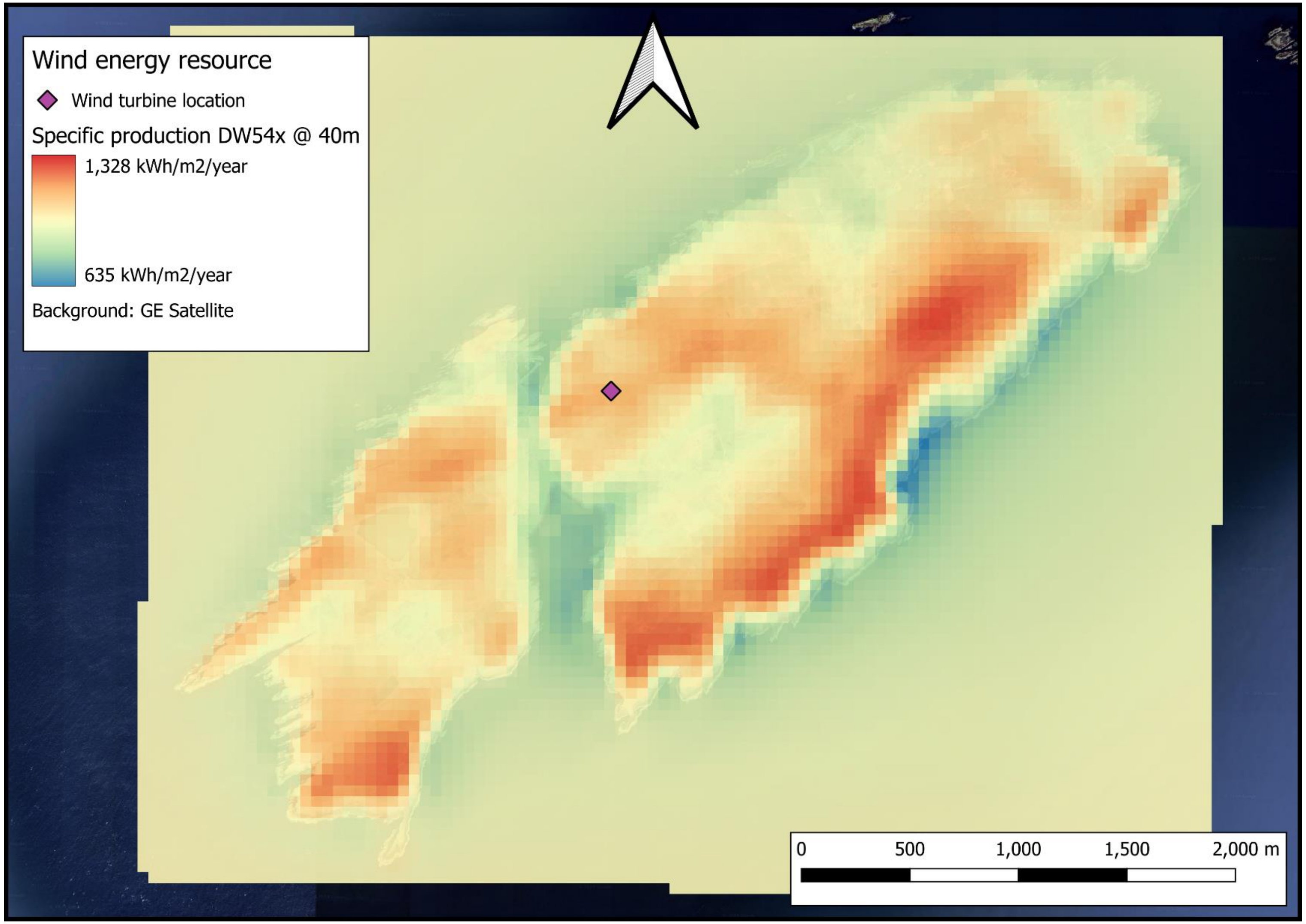

Figure 15: Gross specific production of the DW54x @ 40 m per rotor diameter area and per year (kWh/m²/year)).

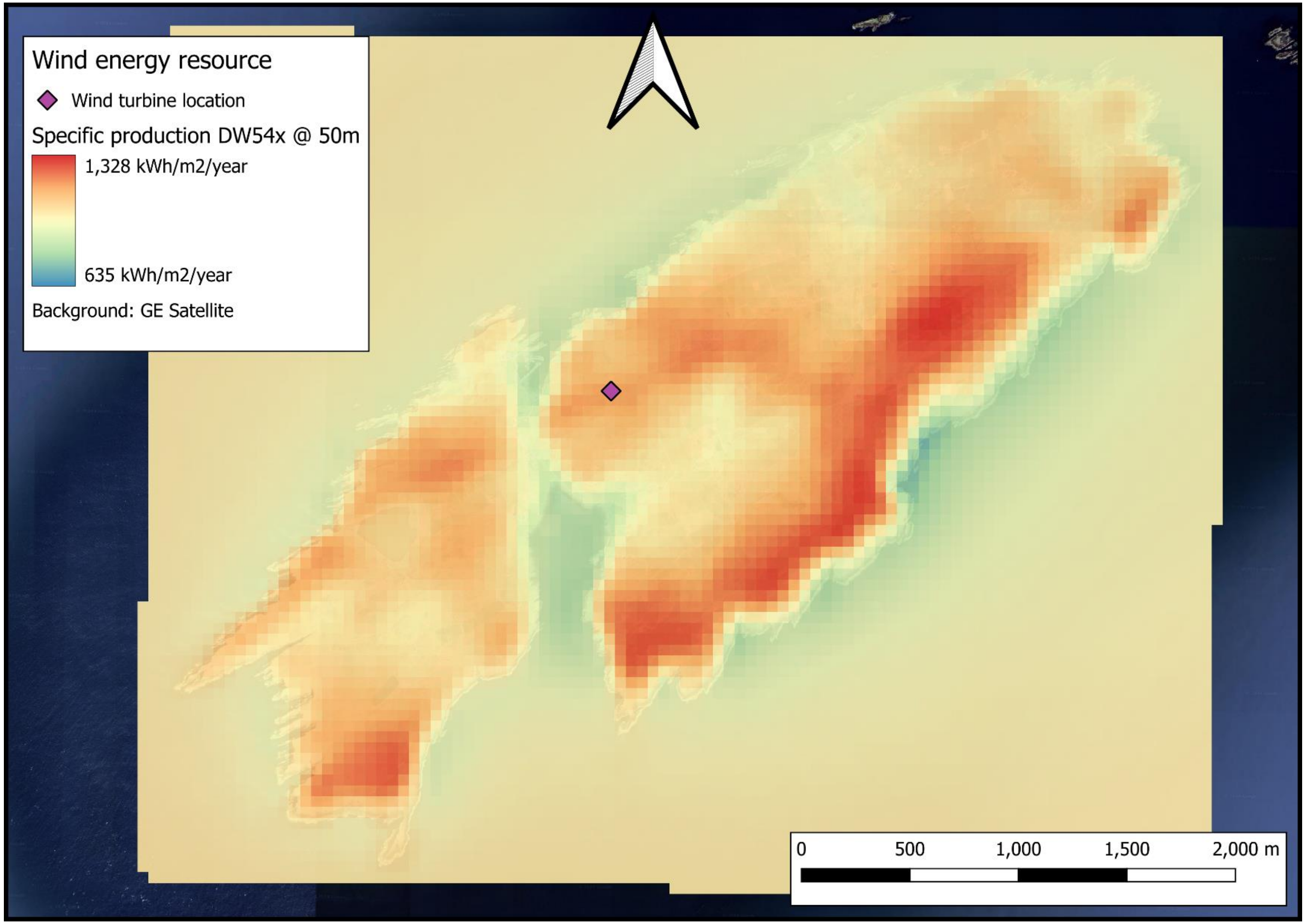

Figure 16: Gross specific production of the DW54x @ 50 m per rotor diameter area and per year (kWh/m²/year)).

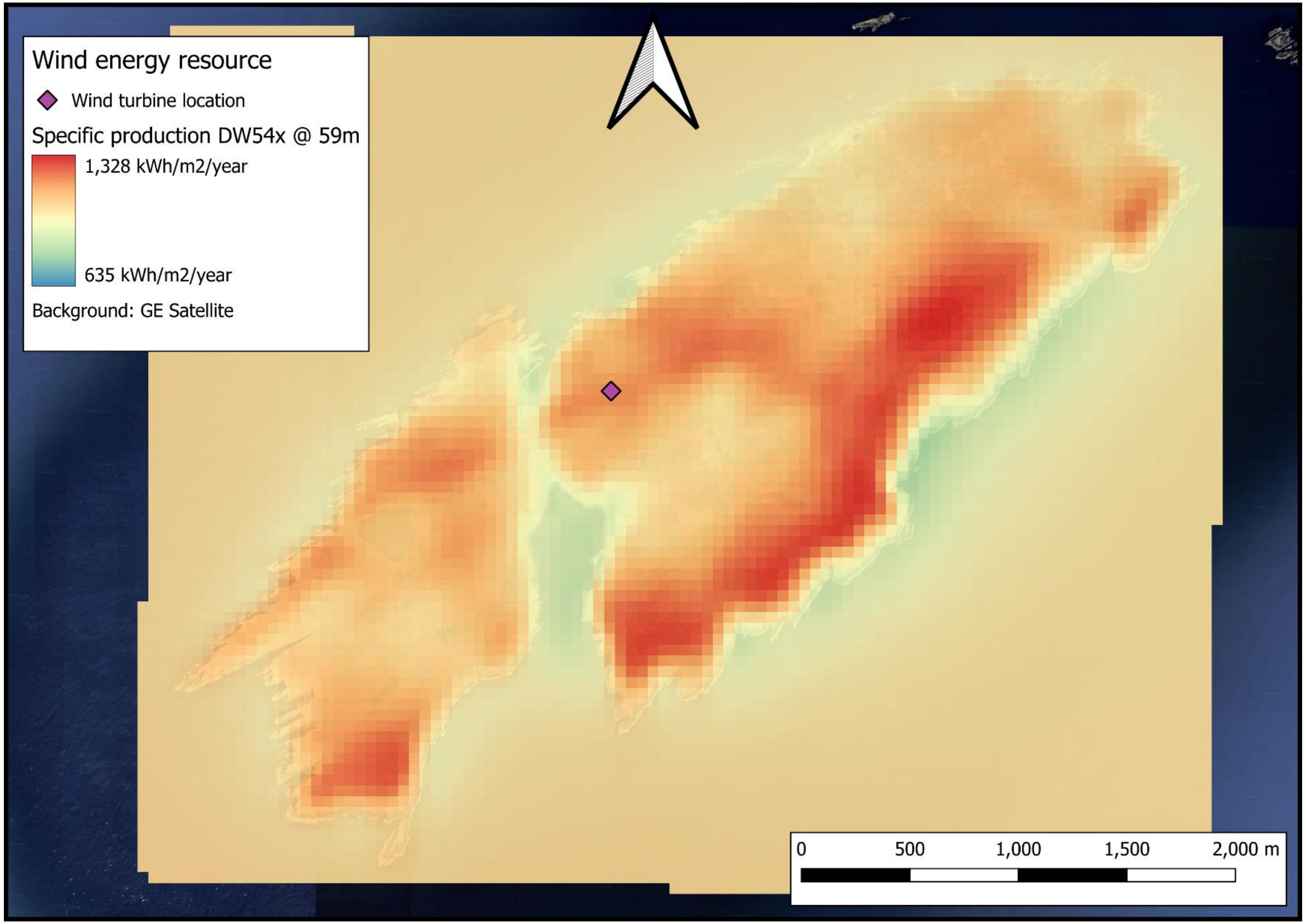

Figure 17: Gross specific production of the DW54x @ 59 m per rotor diameter area and per year (kWh/m²/year)).

ANNEX F POWER & THRUST CURVES

Table 19: Power curves (PC), air density = 1.225 kg/m³

Wind speed	**DW54x, 0.5 MW**	**DW52, 0.5 MW**
	PC	PC
[m/s]	[kW]	[kW]
2	0	0
3	12	7
3.5	23	N/A
4	39	30
4.5	56	N/A
5	78	69
5.5	105	N/A
6	138	124
6.5	175	N/A
7	217	201
7.5	264	N/A
8	315	308
8.5	359	N/A
9	401	439
9.5	437	N/A
10	465	500
10.5	486	500
11	495	500
11.5	500	500
12	500	500
13	500	500
14	500	500
15	500	500
16	500	500
17	500	500
18	500	500
19	500	500
20	500	500
21	500	500
22	500	500
23	500	500
24	500	500
25	500	500

Table 20: Thrust curves (TC), air density = 1.225 kg/m³

Wind speed	**DW54x, 0.5 MW**	**DW52, 0.5 MW**
	Ct	**Ct**
[m/s]	[kW]	[kW]
2	0.000	0.000
3	0.935	0.942

Wind speed	**DW54x, 0.5 MW**	**DW52, 0.5 MW**
	Ct	**Ct**
4	0.856	0.869
5	0.796	0.804
6	0.797	0.804
7	0.797	0.805
8	0.768	0.784
9	0.731	0.75
10	0.569	0.654
11	0.396	0.442
12	0.297	0.329
13	0.230	0.255
14	0.184	0.203
15	0.147	0.162
16	0.123	0.135
17	0.104	0.114
18	0.089	0.098
19	0.079	0.086
20	0.069	0.075
21	0.061	0.066
22	0.054	0.059
23	0.048	0.052
24	0.043	0.047
25	0.039	0.043

ANNEX G Noise contours

The full results of the noise dispersion model in terms of noise contours, discussed in Section 7.2, are presented in the following charts:

- Figure 18 for the DW54x 0.5 MW @ 40 m.
- Figure 19 for the DW52 0.5 MW @ 50 m.
- Figure 20 for the DW52 0.5 MW @ 59 m.
- Figure 21 for the DW52 0.5 MW @ 35 m.
- Figure 22 for the DW52 0.5 MW @ 40 m.
- Figure 23 for the DW52 0.5 MW @ 50 m.

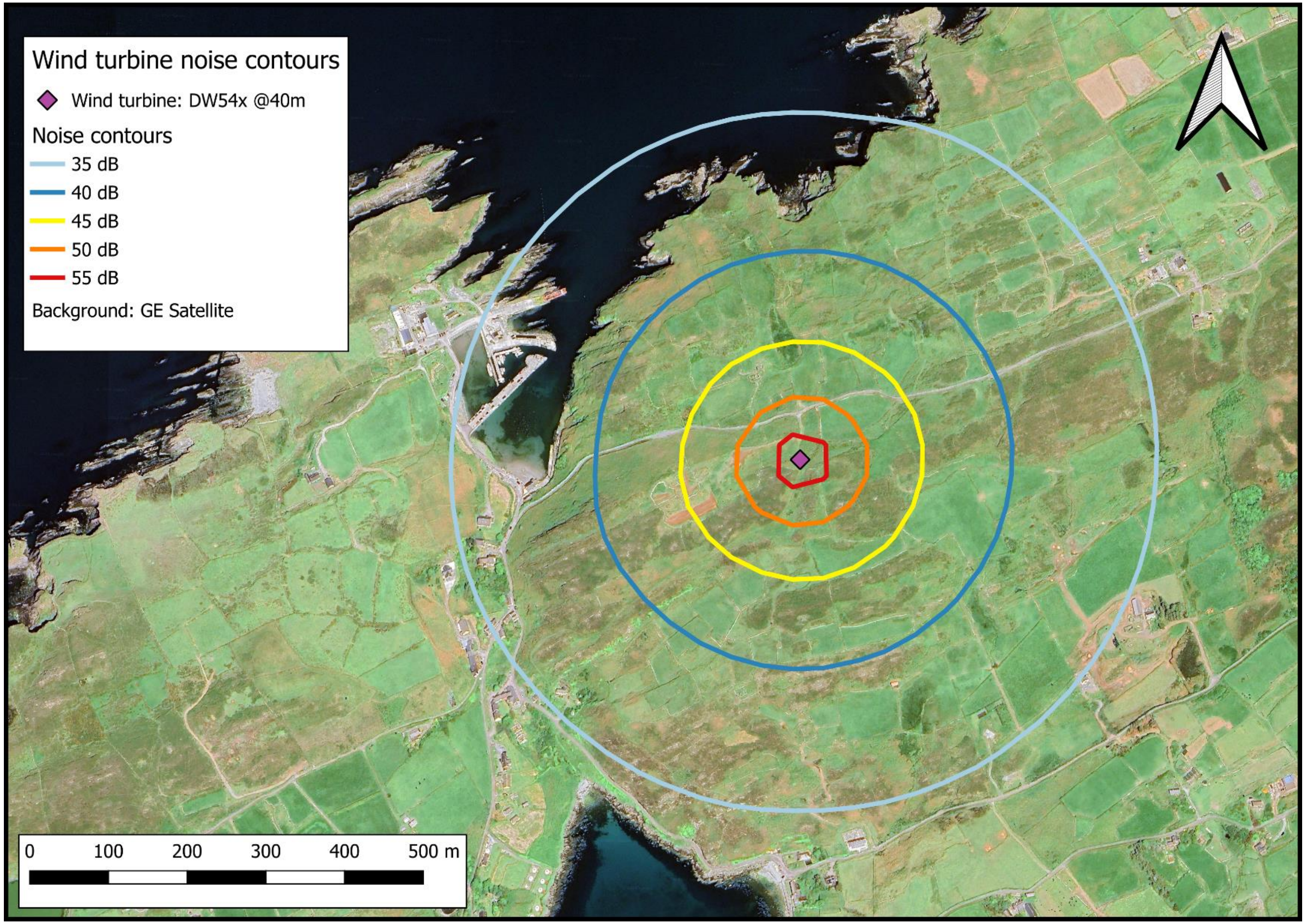

Figure 18: Noise contours for the DW54x 0.5 MW @40 m.

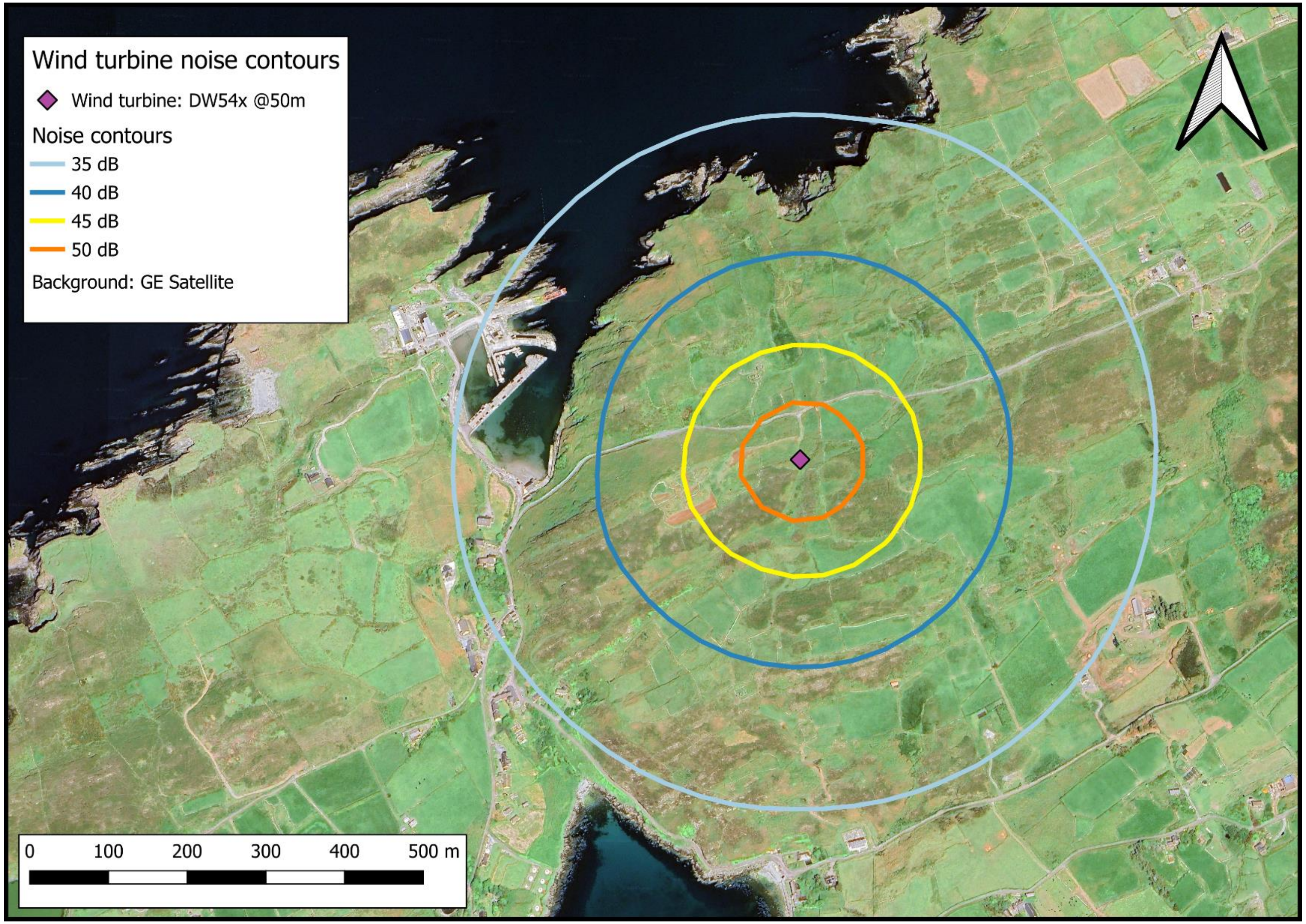

Figure 19: Noise contours for the DW54x 0.5 MW @50 m.

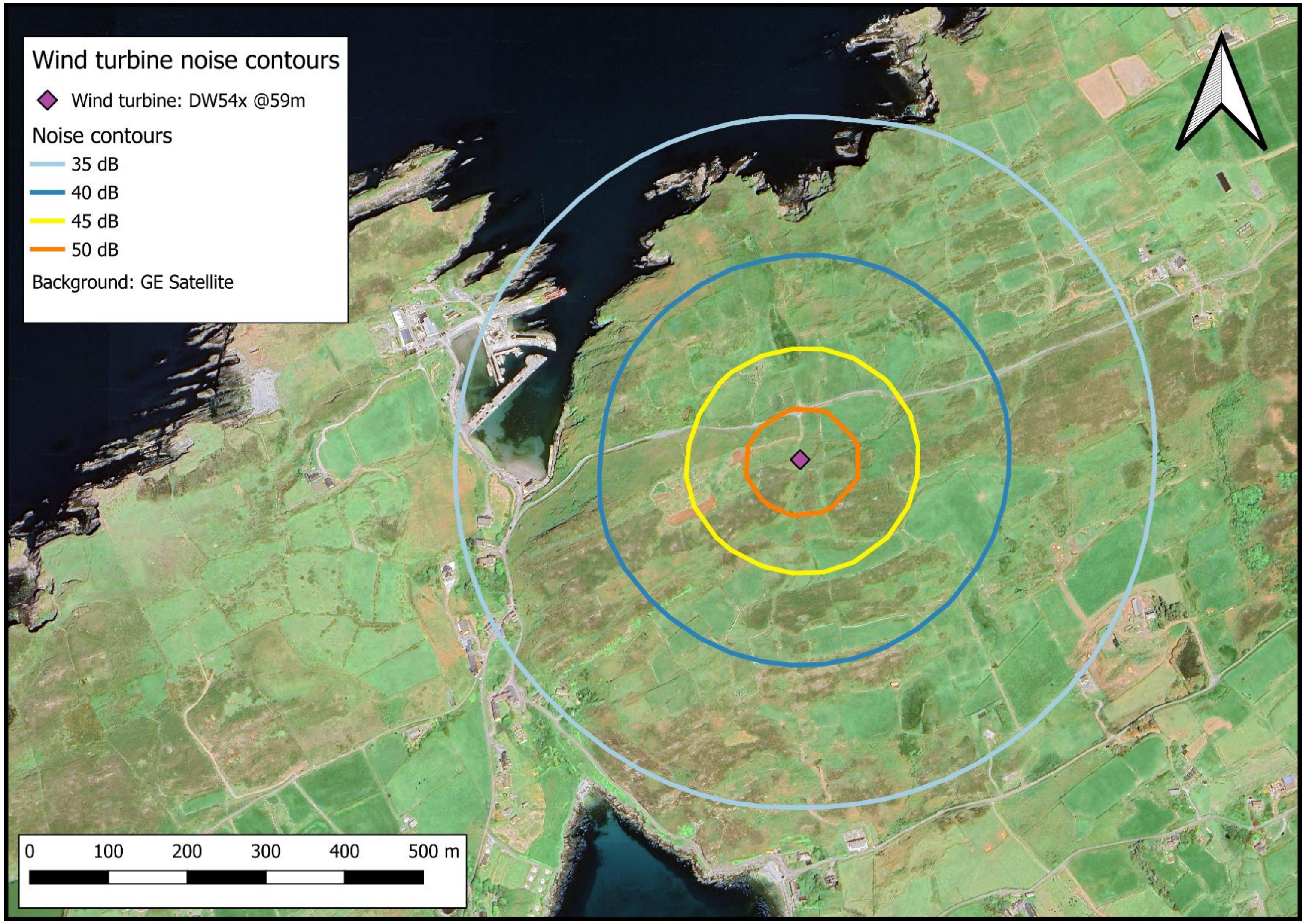

Figure 20: Noise contours for the DW54x 0.5 MW @59 m.

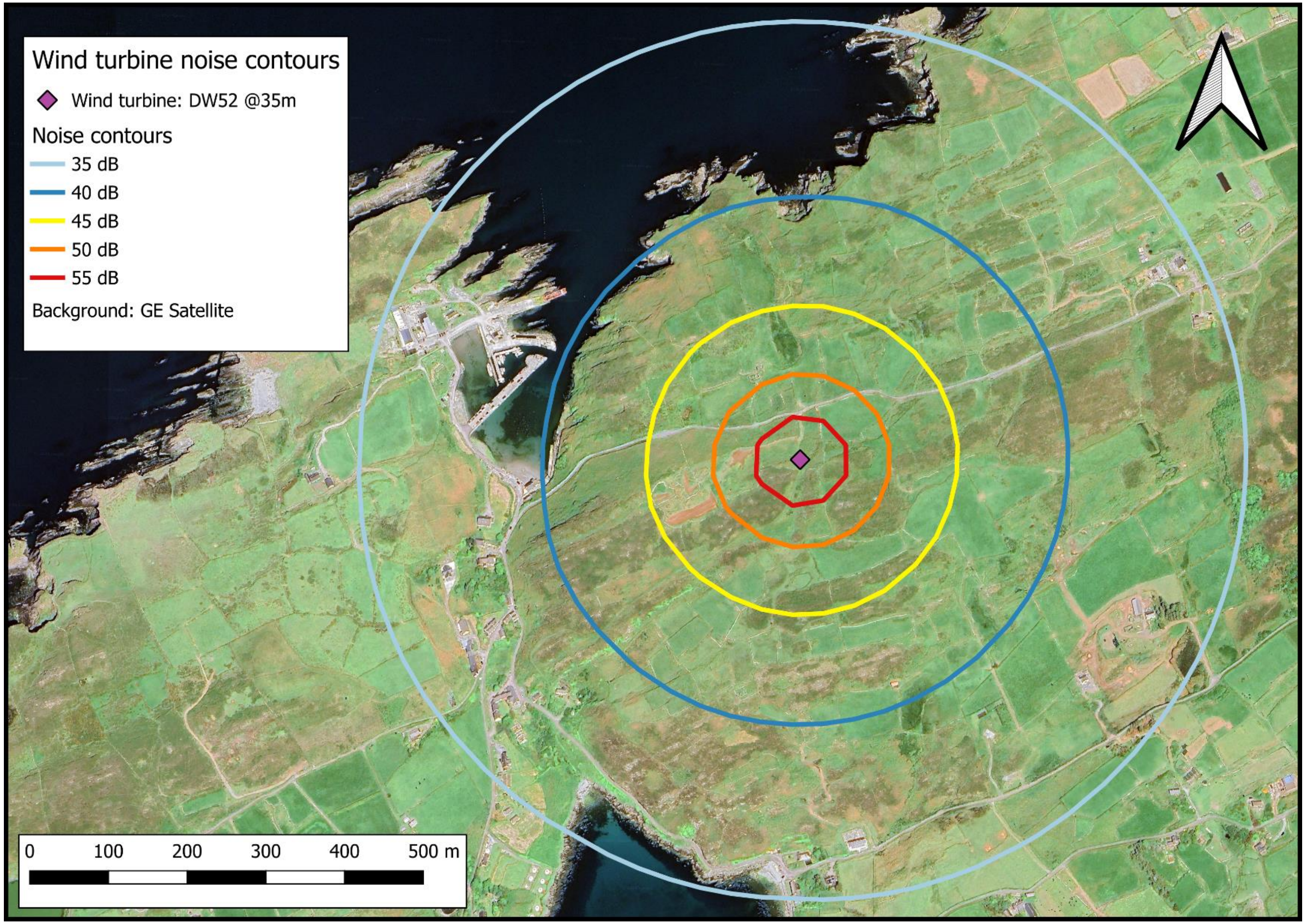

Figure 21: Noise contours for the DW52 0.5 MW @35 m.

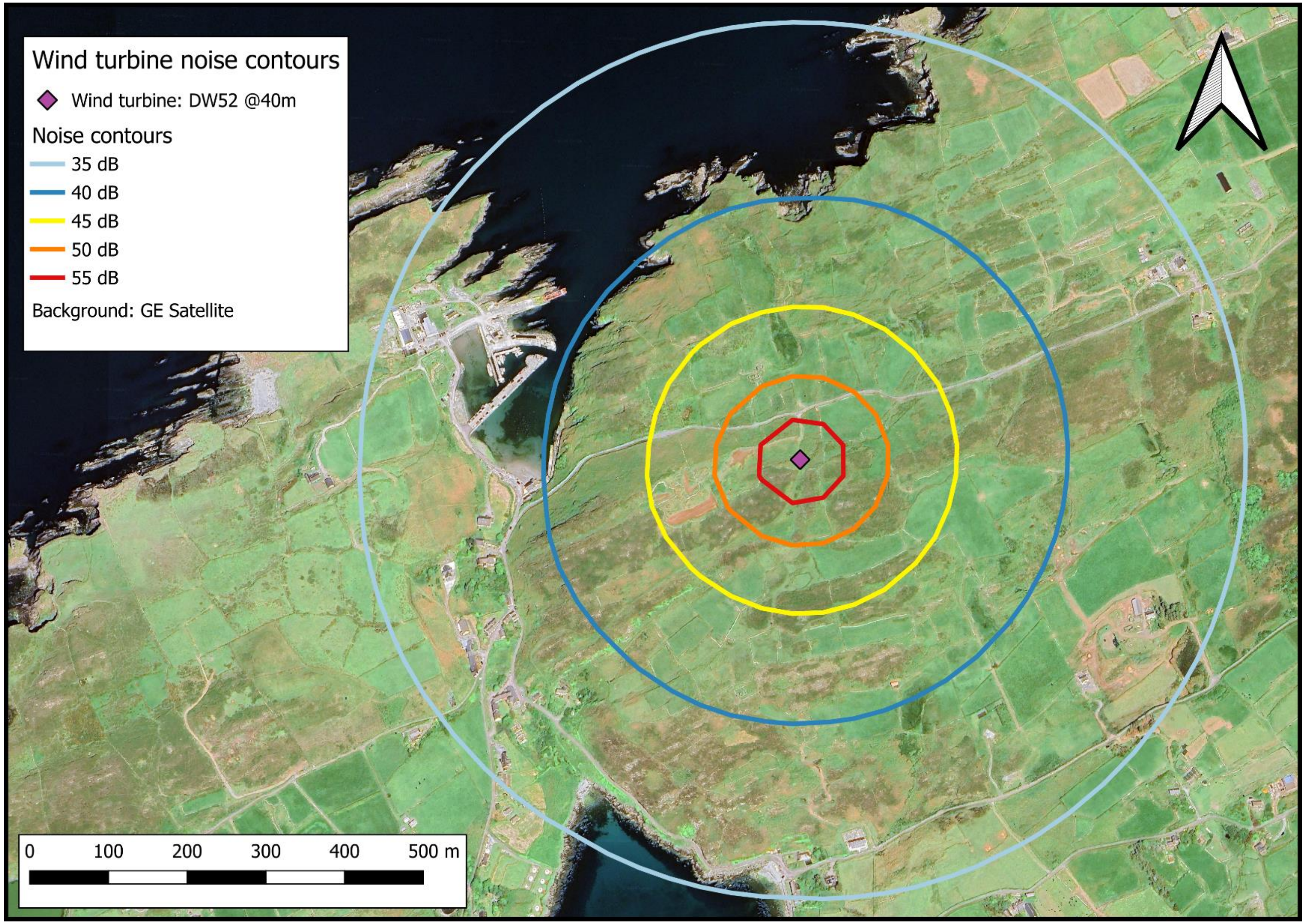

Figure 22: Noise contours for the DW52 0.5 MW @40 m.

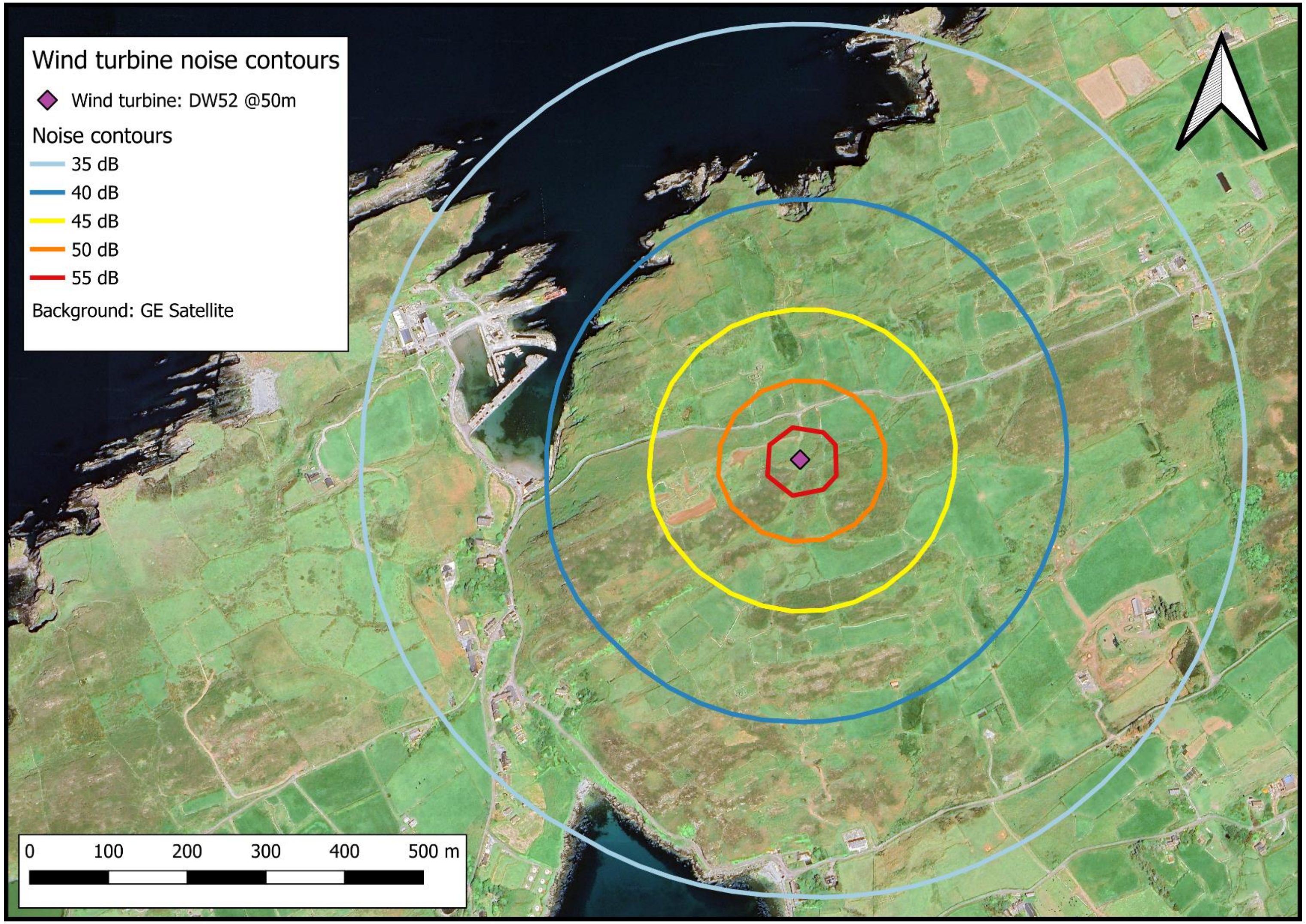

Figure 23: Noise contours for the DW52 0.5 MW @50 m.

ANNEX H Shadow flicker contours

The full results of the shadow flicker analysis, discussed in Section 7.2, are presented in the following charts:

- Figure 24 for the DW54x 0.5 MW @ 40 m.
- Figure 25 for the DW52 0.5 MW @ 50 m.
- Figure 26 for the DW52 0.5 MW @ 59 m.
- Figure 27 for the DW52 0.5 MW @ 35 m.
- Figure 28 for the DW52 0.5 MW @ 40 m.
- Figure 29 for the DW52 0.5 MW @ 50 m.

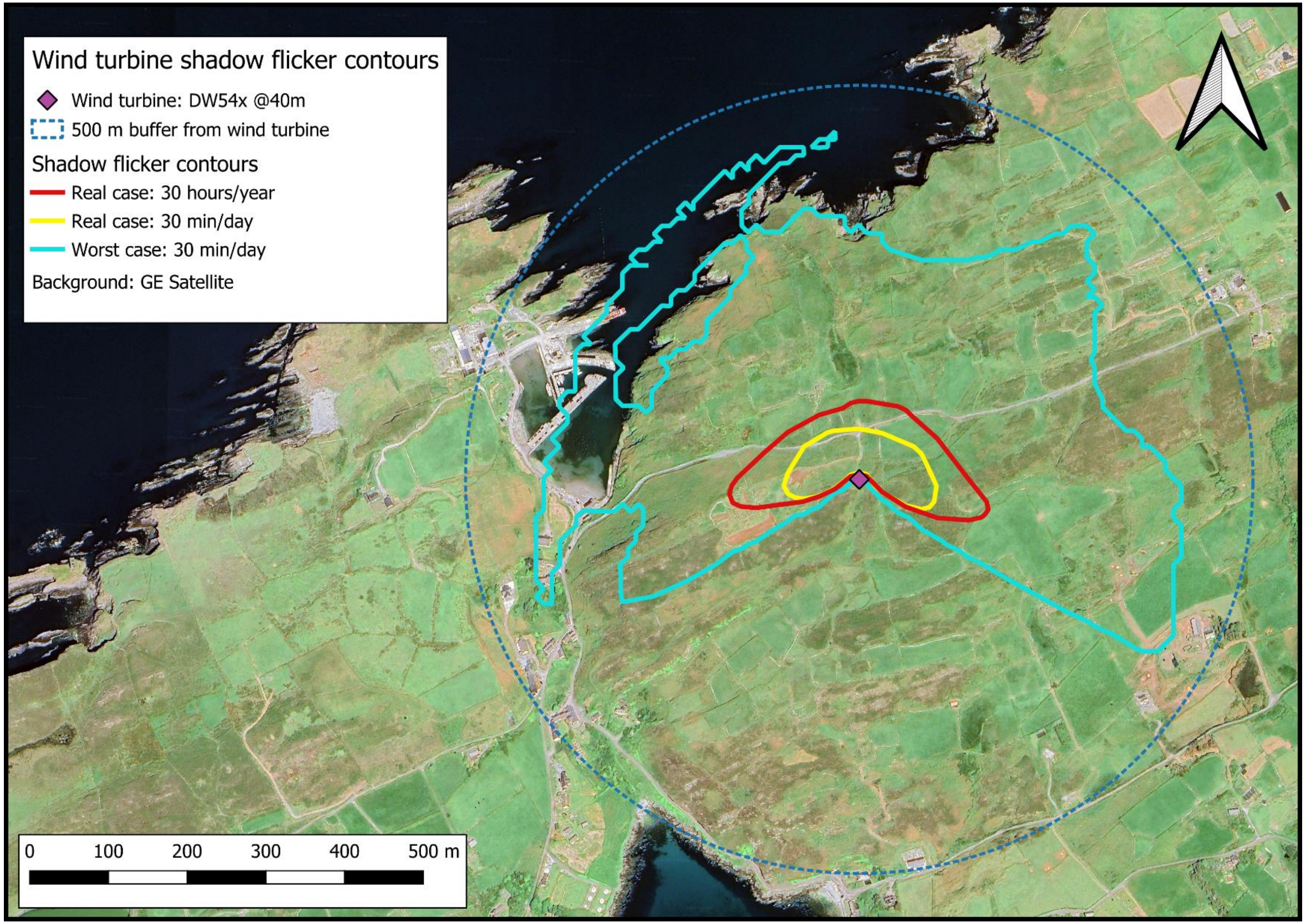

Figure 24: Shadow flicker contours for the DW54x 0.5 MW @40 m.

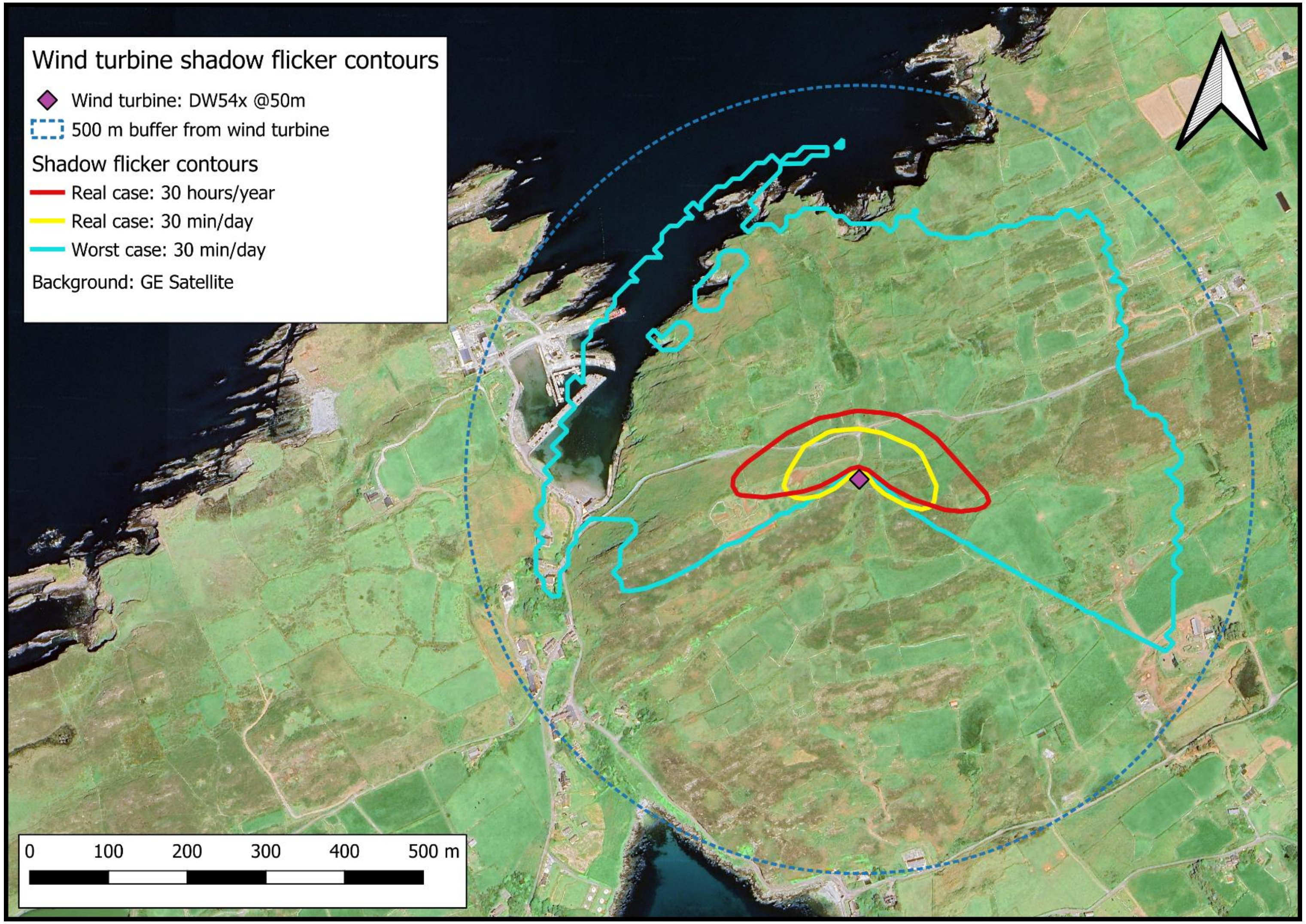

Figure 25: Shadow flicker contours for the DW54x 0.5 MW @50 m.

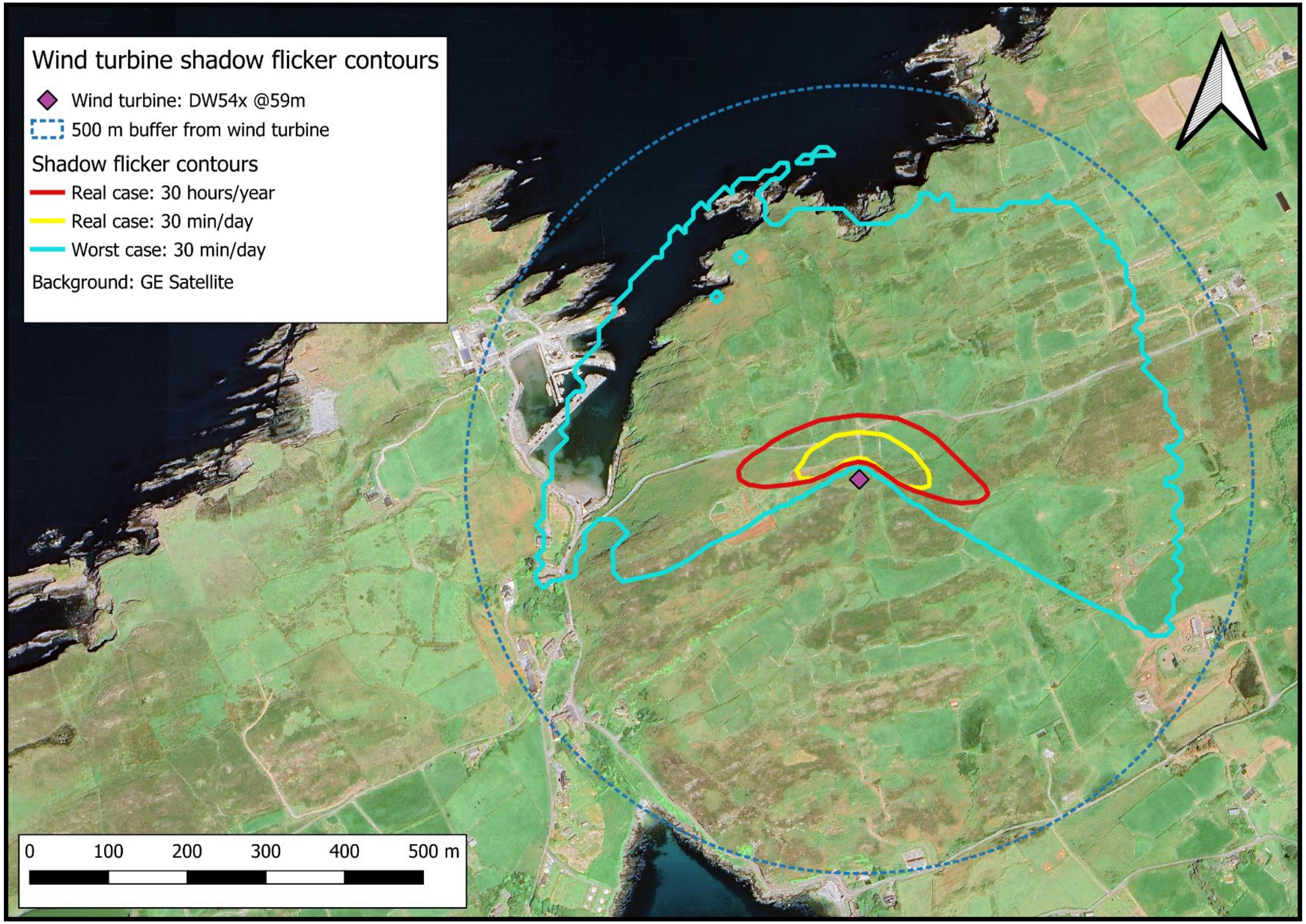

Figure 26: Shadow flicker contours for the DW54x 0.5 MW @59 m.

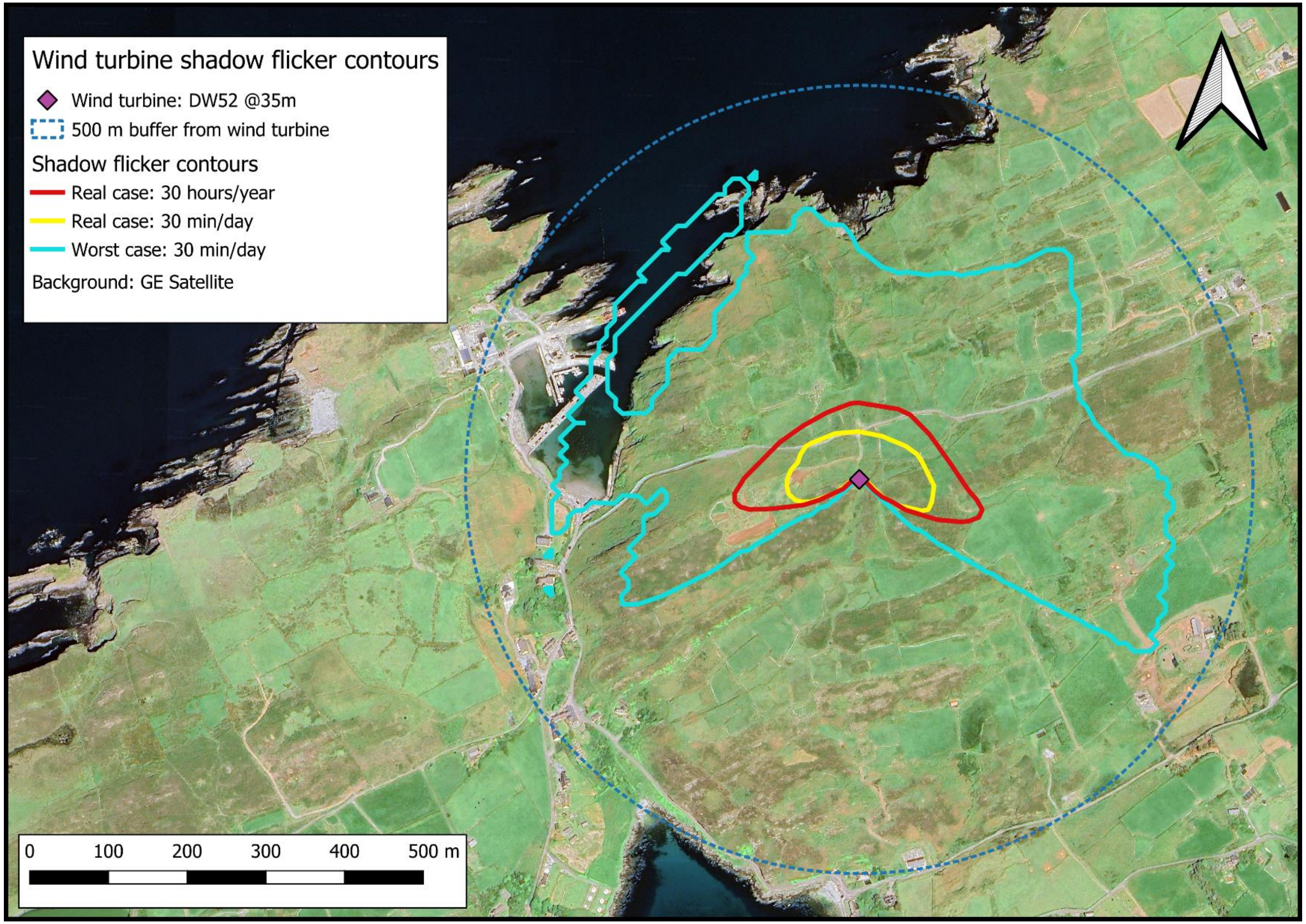

Figure 27: Shadow flicker contours for the DW52 0.5 MW @35 m.

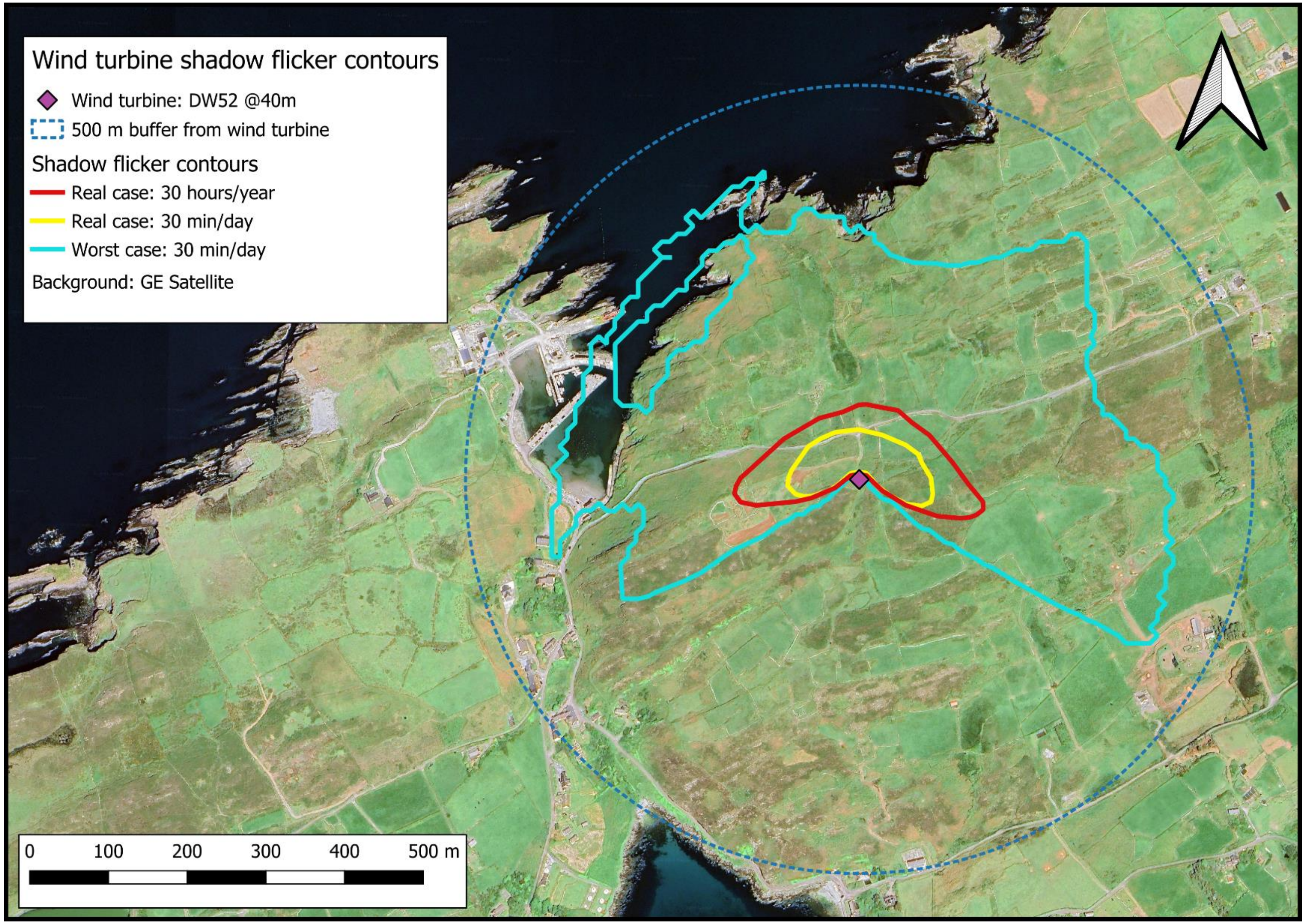

Figure 28: Shadow flicker contours for the DW52 0.5 MW @40 m.

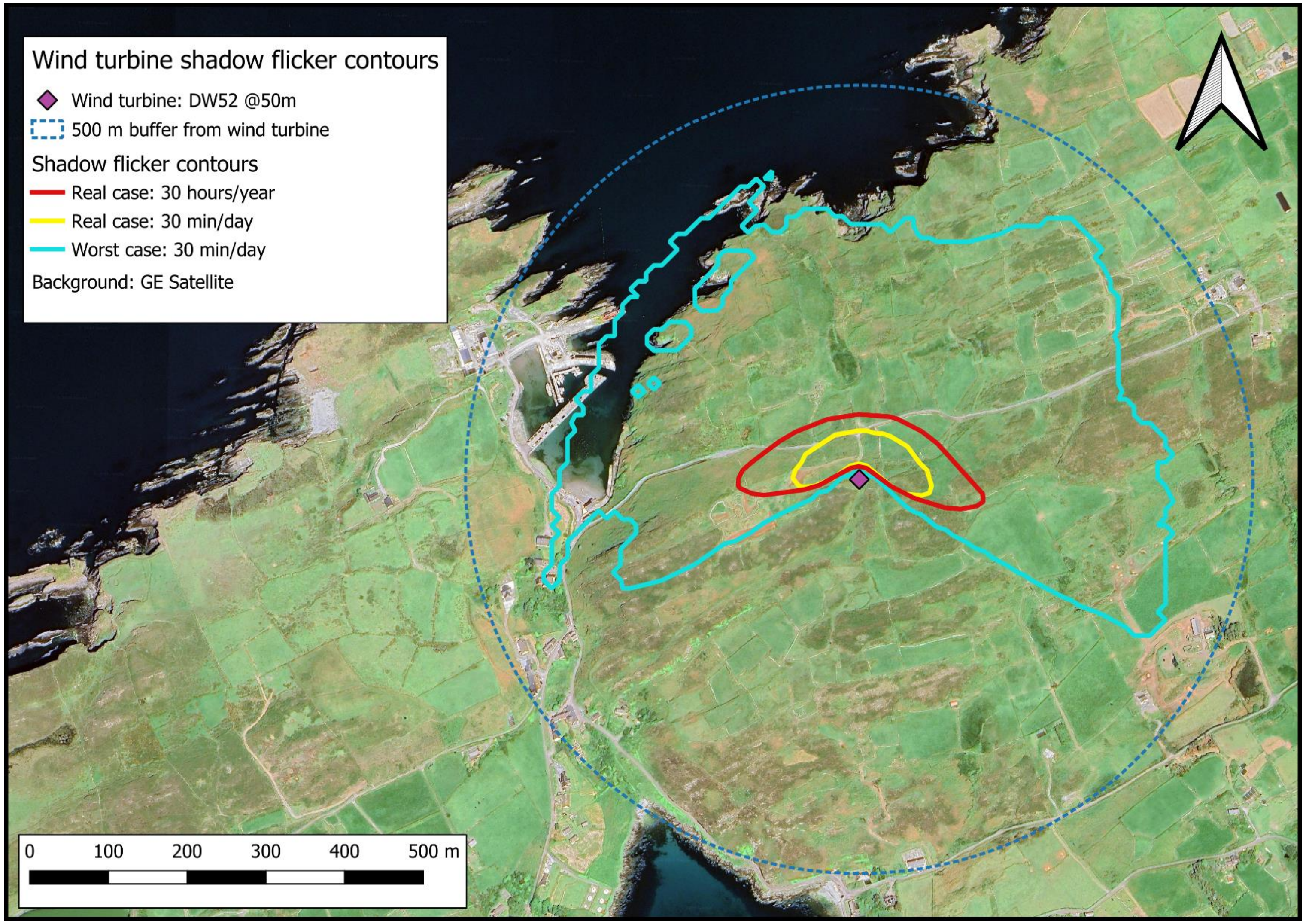

Figure 29: Shadow flicker contours for the DW52 0.5 MW @50 m.

ANNEX I Zone of theoretical visibility

The results of the visual influence analysis discussed in Section 9.1.2, consisting in maps on the zone of theoretical visibility within a radius of 15 km from the site, are presented in the following charts:

- Figure 30 for the DW54x 0.5 MW @ 40 m.
- Figure 31 for the DW52 0.5 MW @ 50 m.
- Figure 32 for the DW52 0.5 MW @ 59 m.
- Figure 33 for the DW52 0.5 MW @ 35 m.
- Figure 34 for the DW52 0.5 MW @ 40 m.
- Figure 35 for the DW52 0.5 MW @ 50 m.

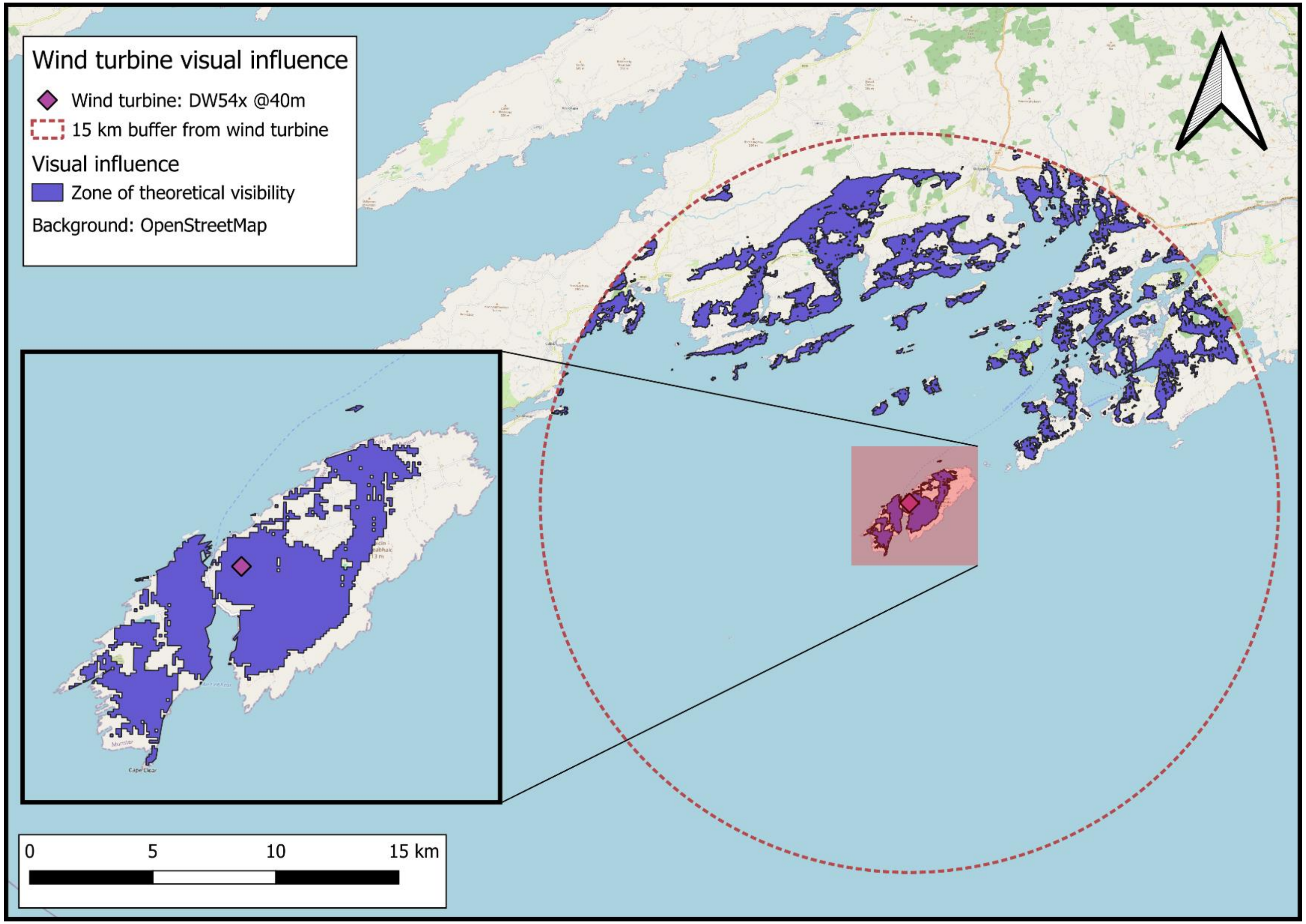

Figure 30: Zone of theoretical visibility for the DW54x 0.5 MW @40 m.

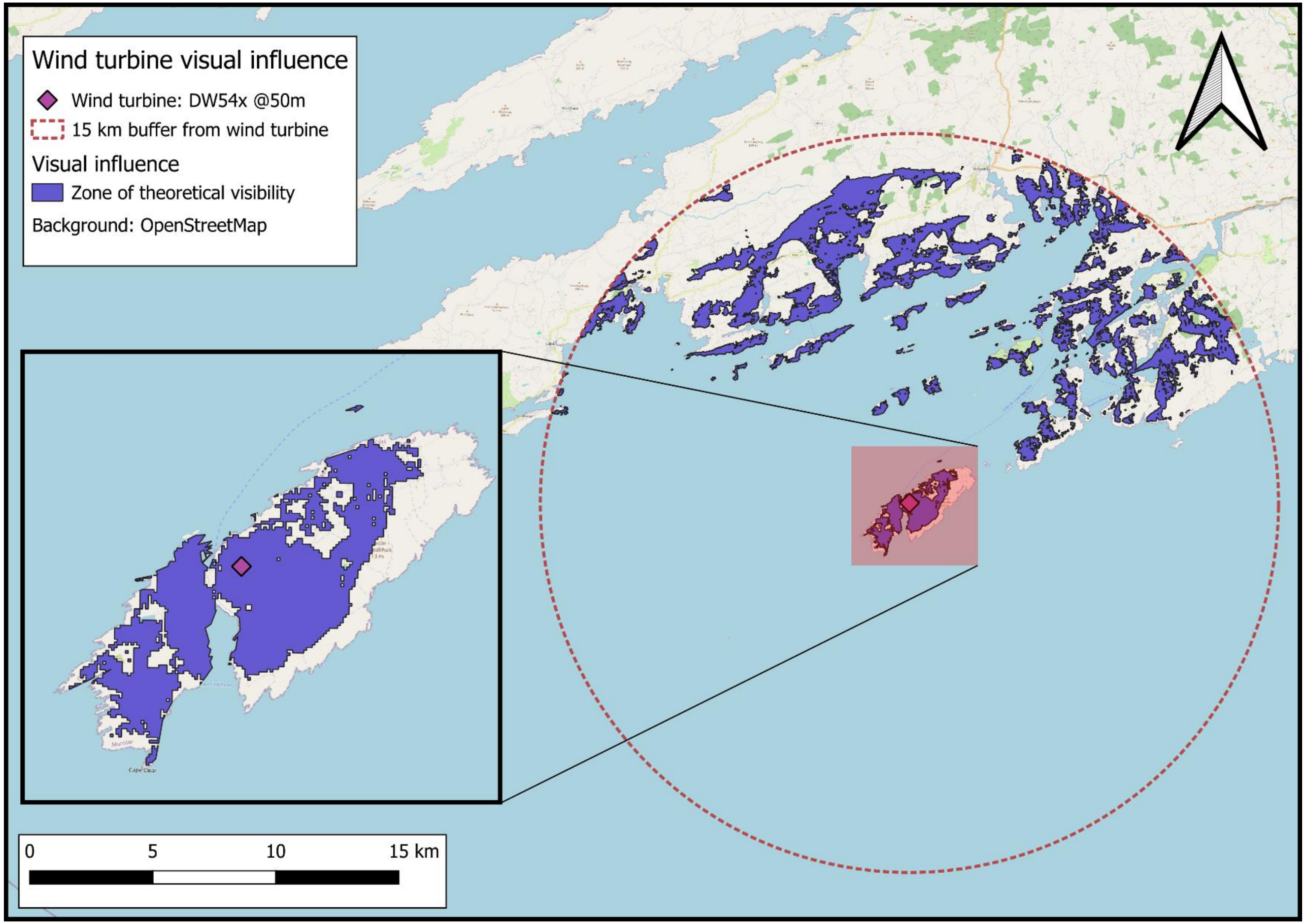

Figure 31: Zone of theoretical visibility for the DW54x 0.5 MW @50 m.

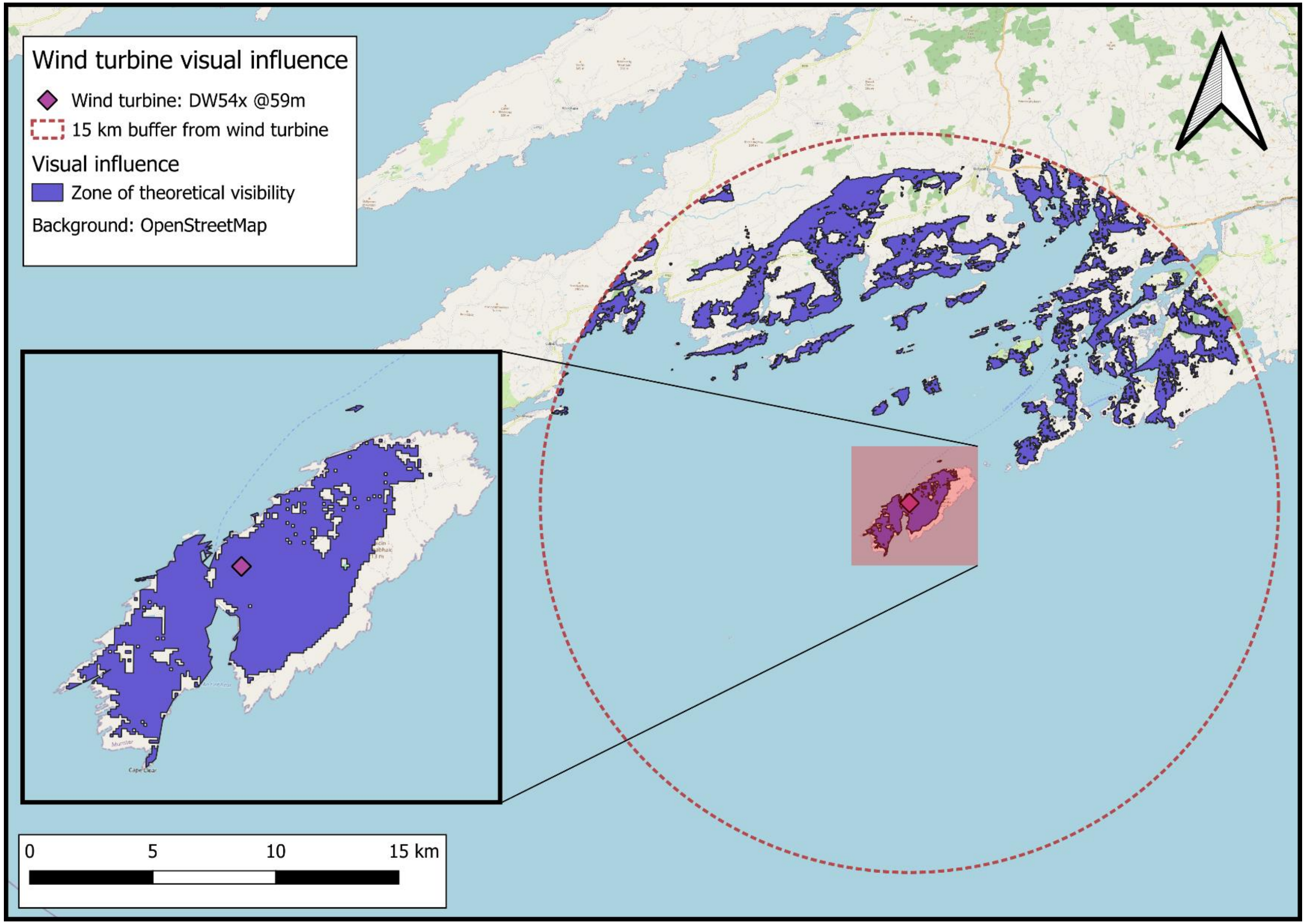

Figure 32: Zone of theoretical visibility for the DW54x 0.5 MW @59 m.

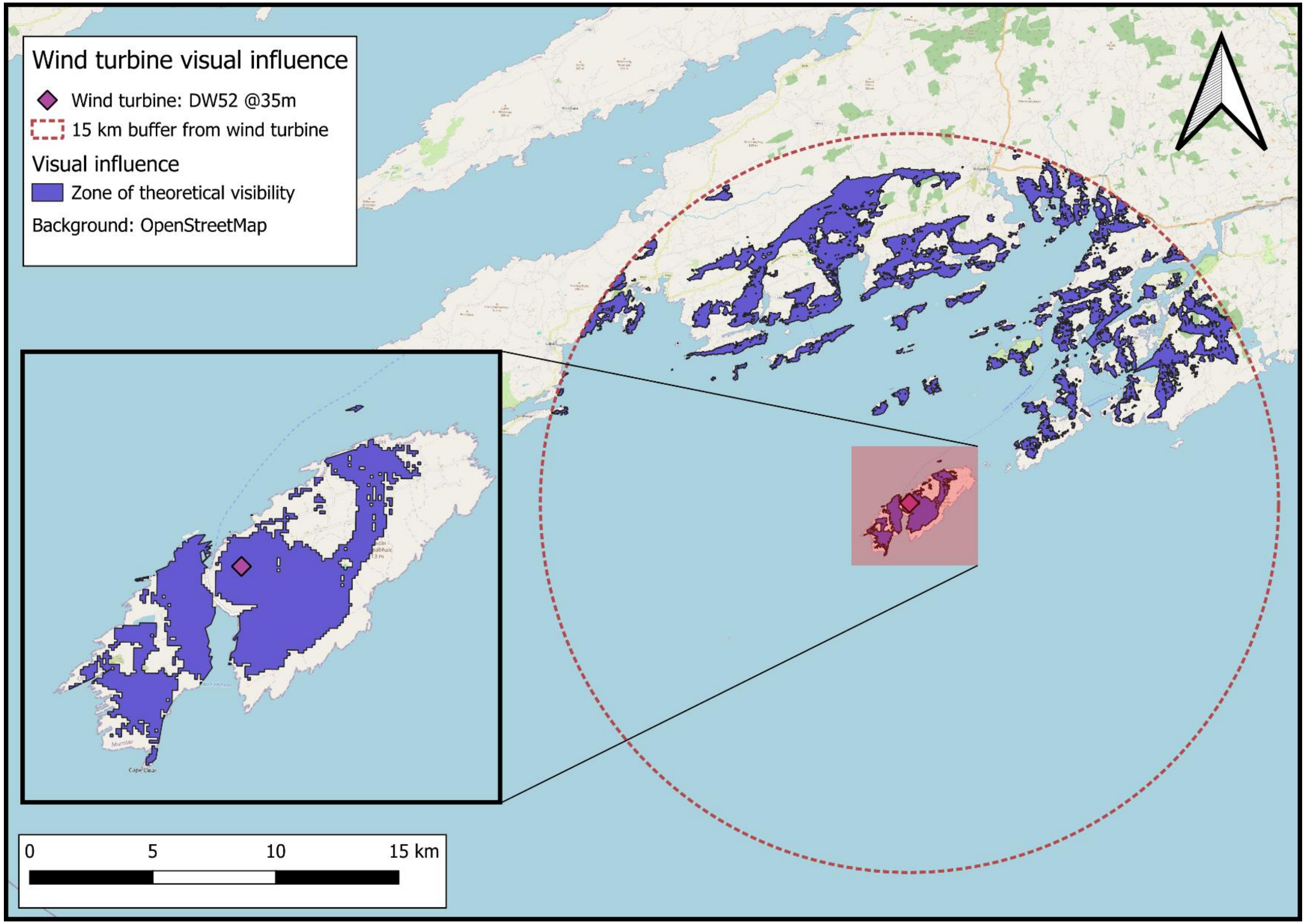

Figure 33: Zone of theoretical visibility for the DW52 0.5 MW @35 m.

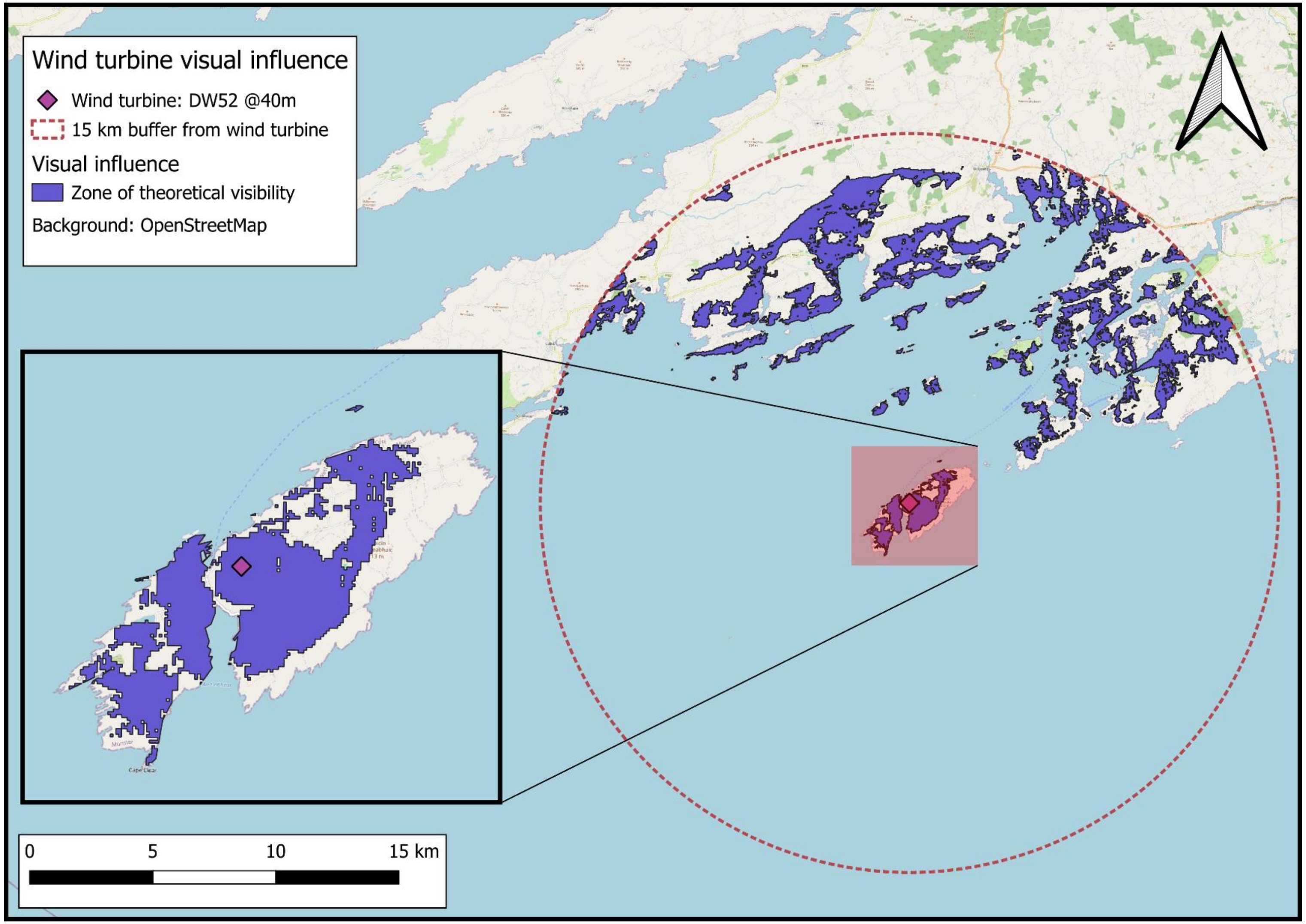

Figure 34: Zone of theoretical visibility for the DW52 0.5 MW @40 m.

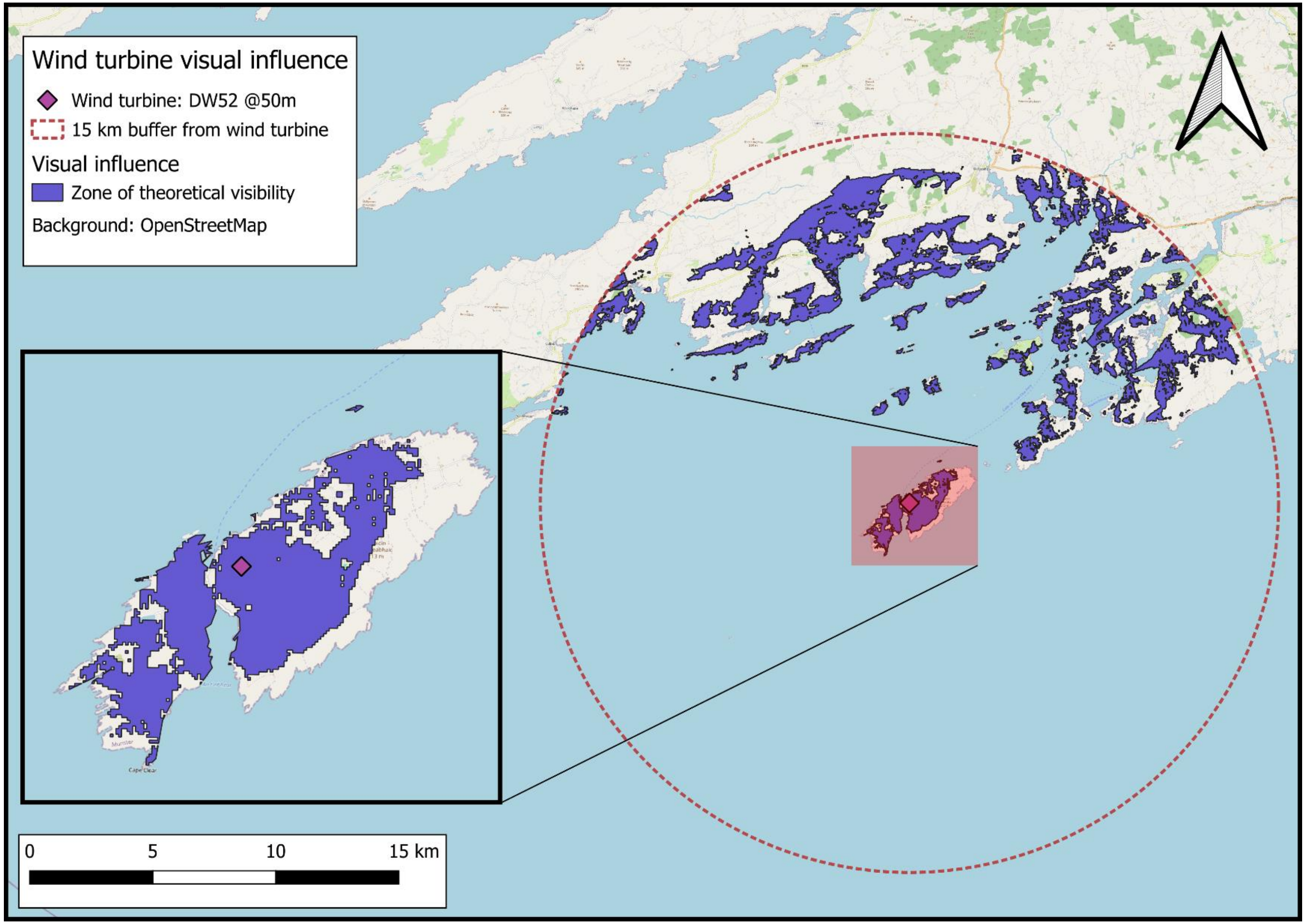

Figure 35: Zone of theoretical visibility for the DW52 0.5 MW @50 m.

ANNEX J Photomontage

The full results of the photomontage analysis, discussed in Section 9.2, are presented in the following charts.

- Figure 36 for the DW54x 0.5 MW @ 40 m from the “Old turbine” site.
- Figure 37 for the DW54x 0.5 MW @ 50 m from the “Old turbine” site.
- Figure 38 for the DW54x 0.5 MW @ 59 m from the “Old turbine” site.
- Figure 39 for the DW52 0.5 MW @ 35 m from the “Old turbine” site.
- Figure 40 for the DW52 0.5 MW @ 40 m from the “Old turbine” site.
- Figure 41 for the DW52 0.5 MW @ 50 m from the “Old turbine” site.
- Figure 42 for the DW54x 0.5 MW @ 40 m from the “Windsock” site.
- Figure 43 for the DW54x 0.5 MW @ 50 m from the “Windsock” site.
- Figure 44 for the DW54x 0.5 MW @ 59 m from the “Windsock” site.
- Figure 45 for the DW52 0.5 MW @ 35 m from the “Windsock” site.
- Figure 46 for the DW52 0.5 MW @ 40 m from the “Windsock” site.
- Figure 47 for the DW52 0.5 MW @ 50 m from the “Windsock” site.

Figure 36: Photomontage from the “Old turbine” site for the DW54x 0.5 MW @40 m.

Figure 37: Photomontage from the “Old turbine” site for the DW54x 0.5 MW @50 m.

Figure 38: Photomontage from the “Old turbine” site for the DW54x 0.5 MW @59 m.

Figure 39: Photomontage from the “Old turbine” site for the DW52 0.5 MW @35 m.

Figure 40: Photomontage from the “Old turbine” site for the DW52 0.5 MW @40 m.

Figure 41: Photomontage from the “Old turbine” site for the DW52 0.5 MW @50 m.

Figure 42: Photomontage from the “Windsock” site for the DW54x 0.5 MW @40 m.

Figure 43: Photomontage from the “Windsock” site for the DW54x 0.5 MW @50 m.

Figure 44: Photomontage from the “Windsock” site for the DW54x 0.5 MW @59 m.

Figure 45: Photomontage from the “Windsock” site for the DW52 0.5 MW @35 m.

Figure 46: Photomontage from the “Windsock” site for the DW52 0.5 MW @40 m.

Figure 47: Photomontage from the “Windsock” site for the DW52 0.5 MW @50 m.