Site Identification Analysis for AWE Devices

Contributing to Deliverable: T3.3.2

Revision 01

Abstract

This report details the methodology and results of site identification analysis for Airborne Wind Energy devices undertaken as part of Work Package T3 and contributing to Deliverable T3.2.2.

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Revision History

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1	Final report for issue	LOB	October 2023

Executive summary

The expanding renewable energy sector now has access to promising opportunities and unexplored high-altitude wind resources thanks to airborne wind energy systems (AWES). Implementation of these systems involves complexities and characteristics that cannot (necessarily) be generalized within studies of typical wind turbines. Therefore, it is important to adopt adequate approaches to conduct site identification studies that are suited for both pilot testing and operations at a commercial scale.

Understanding the potential capacity of AWES is essential for assessing the feasibility and economic viability of deploying AWE technologies. By estimating the potential capacity, we can determine the energy generation capabilities of AWE systems and compare them with existing energy sources. This information is vital for decision-making processes and governments, regulatory bodies, and energy stakeholders who can use this information to establish renewable energy goals and implement supportive policies to accelerate the adoption of AWE systems. Moreover, by identifying areas suitable for AWES and with high capacity, developers and investors can focus their efforts on locations that offer the greatest potential for energy generation.

For this reason, site identification plays a crucial role in the successful implementation of AWES. The process involves the integration and evaluation of a variety of geographic characteristics and to the understanding of technological, socioeconomic, environmental, and political constraints.

A total of 12 different parameters were considered in this analysis and several datasets were selected from publicly available sources to populate the complete data repository used in this study. However, collecting accurate, current, and detailed data can be difficult for certain variables, and some data sources present gaps in information or are not available in a workable format. To ensure a rigorous analysis, a thorough exercise was conducted to determine the specific features from each layer that would be included in the input layers for analysis. The data extraction of the relevant categories and features of each raw layer was automatised using the Graphical Modeller in QGIS. The outputs from the data extraction process were 15 layers by region containing the relevant data for each criterion.

Through thorough analysis, it is possible to define a safe operational space for AWE systems. This includes identifying areas with consistent and reliable wind patterns, sufficient space for deploying the Ground Stations (GS) and operating the AWE devices, and minimal risks of collisions with obstacles or other aircraft. By defining this safe operational space, the implementation of AWE systems can be carried out with confidence and minimize potential hazards.

Within the study the base case was defined with an operational radius = 850m, risk buffer = 100m and 200m separation distance to forests. Sensitivity studies were carried out looking at the influence of varying these results on the number and size of sites identified and ultimately the estimated AWE capacity potential for Germany. The base case analysis identified almost 10,000 km^2 of operational area potentially suitable for AWE deployment in Germany, which has potential to support an estimated AWE capacity of up to 12 GW (assuming individual device capacity of 1.5 MW). Of all the scenarios analysed, reducing the operational area to 425 m was the most advantageous. This resulted in an operational area potentially suitable for AWE deployment of 33,000 km^2 and a greater number of devices with a capacity of 14-108 GW depending on the individual device capacity. The site identification analysis also shed light on the potential complementary nature of AWE in comparison to traditional wind energy. The findings indicate that 90% of the base case operational area is not suitable for traditional wind turbines and therefore exclusive to AWE technology[1].

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[1] The information provided here is based on available data from a site identification study on traditional wind turbines, but further research or verification for a comprehensive understanding of the reasons behind why these areas are exclusive to AWE technology is required. Therefore, any figures or details presented should be considered cautiously and used with discretion, pending additional investigation or analysis.

Overall, the analysis carried out during this process shows a large granularity in the identified sites, reveals that some factors such as the tether length have a significant impact on the availability of sites and shows that AWE systems do not necessarily compete spatially with traditional wind turbines in the identified sites.The analysis also proves that even within a densely populated country such as Germany, there are thousands of potential sites capable of accommodating the deployment of several dozen of GW of energy.

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1 Introduction

The renewable energy sector's growth is tapping into new prospects and uncharted high-altitude wind resources, facilitated by airborne wind energy systems (AWES). These systems bring complexities and traits that differ from standard wind turbines in their implementation. Hence, it's crucial to use appropriate methods for site identification studies tailored for both pilot testing and large-scale operations.

Determining the potential output of AWEs is crucial in evaluating their feasibility and economic sustainability for deployment. Estimating this capacity allows us to gauge the energy generation abilities of AWE systems, making comparisons against current energy sources possible. This data is pivotal in decision-making for governments, regulatory bodies, and energy stakeholders, aiding in setting renewable energy objectives and crafting policies to promote AWE system adoption. Additionally, pinpointing areas suitable for AWES and with high capacity, enables developers and investors to concentrate on locations offering the most significant energy generation potential.

Hence, the identification of suitable sites becomes crucial for the effective deployment of AWES. This involves integrating and assessing diverse geographic features and comprehending technological, socioeconomic, environmental, and political limitations in the process.

This report details the steps taken using publicly available data sets and GIS to identify suitable sites for development of AWE farms. The study focuses on a case study for Germany and details the definition of Identification criteria, the data sources used, the analysis methodology, quality control and results.

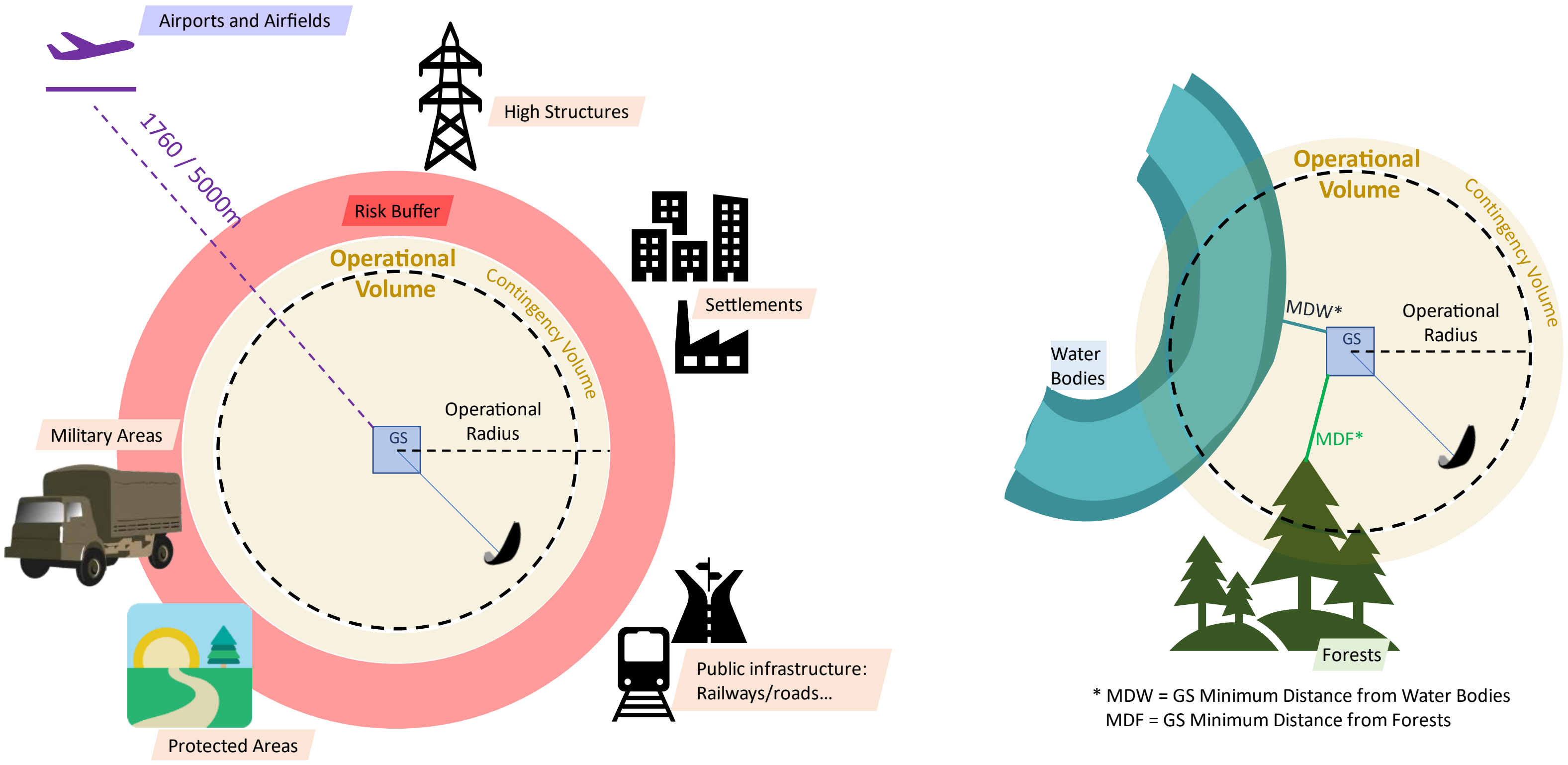
2 Identification Criteria

The criteria selection process was conducted through **extensive consultation with various industry developers**, both within and outside the MegaAWE consortium, to ensure inclusivity of different types of technology. Engagement was undertaken with developers of both fixed wing and kite technologies including: Enerkite, Kitekraft, Kitepower, Skysails, TwingTec, WindFisher and Ampyx Power (now dissolved but core activity continued by Fuchszeug/Mozaero). Given the diverse range of systems and requirements among these developers, the chosen criteria were carefully designed to maintain a technology-agnostic approach. **This approach aims to accommodate the needs and preferences of different technologies without favouring any specific one.** It fosters a fair and unbiased evaluation framework that provides meaningful insights applicable across the industry, promoting innovation and facilitating informed decision-making.

These engagements resulted in the definition of a number of site identification criteria, requirements for AWE devices and definition of variations of key parameters to conduct sensitivity analyses. Table 2.1 below summarises the defined identification criteria which were applied to during this study and the parameters are defined in the diagram presented in Figure 2.1.

Table 2.1. Requirements and sensitivity studies applied to each criterion.

CRITERIA	REQUIREMENT AWE DEVICES	SENSITIVITY STUDIES
Flat in operating and surrounding area	Avoid areas with >30° slope in the deployment areas.	
Co-use, e.g. agricultural land use	Yes	
Operational Radius around ground station	Base Case: 850m	Op. radius: 425, 650 and 1050m.
Inhabited urban area/ Settlements in general/ Publicly used infrastructure (e.g., roads, railways)	Avoid. Apply Operational Area radius. Additionally, add Risk buffer. Risk buffer Base Case: 100m distance from Ground Station	Risk buffers: 0, 50, 150m.
High structures (e.g., wind turbines, power lines, phone, met and radio masts)	Avoid. Apply Operational Area radius. 100m Risk buffer around high structures.	
Airports and Airfields	Avoid. 5000m Risk buffer around Airports. 1760m Risk buffer around Airfields	
Forests	Avoid. Permitted to fly partially over forests. Base Case: 200m distance from Ground Station	Distance from GS: 100 and 300m.
Water bodies	Avoid. Permitted to fly partially over Water Bodies. Base Case Min Distance from Ground Station: 100m.	
Protected Areas Military Areas	Avoid. Apply Operational Area radius	
Wind speed*	Minimum annual average wind speed (m/s) at x altitude. *Base case > 8m/s at 200m.* * This criterion was not applied in the analyses (See Section 4.2.1.1).	Altitudes: 100, 500m.
Solar power plants*	Co-use Accepted (with plant operator approval) * Despite developers accepting the colocation, a suitable layer was not found to allow its appropriate integration and therefore, solar plants were excluded following a conservative approach.	



* MDW = GS Minimum Distance from Water Bodies
MDF = GS Minimum Distance from Forests

Figure 2.1. Diagram on the criteria and requirements applied for the Site Identification process. GS refers to “Ground Station”.

3 Data sources and features selection

Identifying suitable locations for AWE systems involves the gathering of data on environmental, geographical, logistical and on aspects of the site that are relevant to the technologies requirements.

Several datasets were selected from publicly available sources such as GADM (Global Administrative Areas), EU-DEM (European Digital Elevation Model), WDPA (World Database on Protected Areas), DLM250 (Digital Landscape Model 1:250,000 from the Federal Agency for Cartography and Geodesy), OSM (Open Street Map), Reiner Lemoine Institute (layers accessed through Zenodo website) or the NEWA (New European Wind Atlas). Most of the datasets used were accessed as shapefiles, raster/TIFF (Tagged Image File Format) files, GeoPackage or NetCDF (Network Common Data Form). However, collecting detailed, accurate and current data can be difficult for certain variables, and some data sources present gaps in information (e.g., exact and accurate locations of wind turbines) or are not available in a workable format (e.g., German Airspace Restricted Areas, maps on grid connection).

Table 3.1. Main parameters, source and dataset format.

Parameter	Source	Format
Water bodies	DLM250, 2022 and OSM, 2023	Shapefiles
Forests	DLM250, 2022 and OSM, 2023	Shapefiles
Slope	EU-DEM, 2016	TIFF
Settlements	DLM250, 2022 and OSM, 2023	Shapefiles
Roads	DLM250, 2022 and OSM, 2023	Shapefiles
Railways	DLM250, 2022	Shapefiles
Air Traffic (airfields and airports)	DLM250, 2022 and OSM, 2023	Shapefiles
High Structures	DLM250, 2022 and OSM, 2023	Shapefiles
Protected Areas	WDPA, 2022	Shapefiles
Military Areas	DLM250, 2022 and OSM, 2023	Shapefiles
Wind	NEWA, 2022 & 2023	NetCDF
Base map	GADM, 2015	Shapefiles
Suitable areas for traditional Wind Turbines	Reiner Lemoine Institute, 2022	GeoPackage

The analysis relied on the following datasets from which a diverse range of data were extracted and used:

- **The EU-DEM**, version 1.1, is the European Digital Elevation Model and was used for extracting the **Slope information** (See Section 4.1.2). The EU-DEM is a dataset that came from the EU-DEM v1.0 update, which improved the vertical accuracy of EU-DEM and improved the correction of geo-positioning errors[2]. This data has a resolution of 25x25m and was published in 2016 by the European Environment Agency (EEA) under the framework of the Copernicus programme[2].
- Data containing information on **protected areas** was extracted from **The World Database on Protected Areas (WDPA).** The WDPA is a partnership between UNEP and the International Union for Conservation of Nature (IUCN), and collaborates with governments, NGOs, and data providers to compile the most comprehensive global database of protected areas for both marine and terrestrial regions[3]. This dataset is continuously being updated.
- **The Digital Landscape Model** 1:250,000 (Ebenen) from the Federal Agency for Cartography and Geodesy (© GeoBasis-DE / BKG (2022)) contains the **topographic landscape objects** in vector format based on a uniform, redundancy-free geo data model for the Federal Republic of Germany. This dataset was used for a big range of criteria specified, along with their coverage, in Table 3.2.
- **OpenStreetMap** is a freely accessible geographic database that relies on open collaboration, where a community of volunteers continuously updates and maintains its contents. It has

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[2] EU-DEM v1.1 — Copernicus Land Monitoring Service (2016). EU-DEM v1.1 — Copernicus Land Monitoring Service. Retrieved November 2022 from: https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=metadata

[3] UNEP-WCMC (2019). User Manual for the World Database on Protected Areas and world database on other effective area-based conservation measures: 1.6. UNEP-WCMC: Cambridge, UK. Available at: http://wcmc.io/WDPA_Manual

shown high rates of completeness and accuracy, especially in European countries (4, 5, 6). This dataset was used for a **big range of criteria** specified in Table 3.2. such as roads, water bodies, settlements, etc.

- The **New European Wind Atlas** is a free, web-based application developed, owned and operated by the NEWA Consortium that provides is a high-resolution mesoscale dataset. For additional information see www.neweuropeanwindatlas.eu. The data used was the **mean wind speed (m/s)** at different altitudes derived from the Mesoscale modelling. The spatial resolution from this database is 3x3km and it has a temporal resolution of 30 years (1989-2018).
- GADM, the **Database of Global Administrative Areas**, is a high-resolution spatial database with the location of **country administrative areas** for use in GIS and similar software. All base maps used were extracted from the GADM database (www.gadm.org), version 2.5, July 2015.
- The think tank Agora Energiewende commissioned **Reiner Lemoine Institute (RLI)** to develop an online tool that shows where the **potential areas for Photovoltaic and onshore Wind Energy** available in Germany. In 2022 they published the results in form of downloadable GeoPackage layers. The study includes a diverse range of layers, each with unique requirements applied to specific criteria, such as varying distances to settlements or the exclusion of forest areas or protected landscapes.

After accessing the datasets, in some cases, only a portion of the information within the raw layers was utilized. To ensure a rigorous analysis, a thorough exercise was conducted to determine the specific features from each layer that would be included in the input layers for analysis. The initial

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[4] Zhou, Q., Zhang, Y., Chang, K., & Brovelli, M. A. (2022). Assessing OSM building completeness for almost 13,000 cities globally. *International Journal of Digital Earth*, *15*(1), 2400-2421.

[5] Zhou, Q., Wang, S., & Liu, Y. (2022). Exploring the accuracy and completeness patterns of global land-cover/land-use data in OpenStreetMap. *Applied Geography*, *145*, 102742.

[6] Zielstra, D., & Zipf, A. (2010, September). Quantitative studies on the data quality of OpenStreetMap in Germany. In *Proceedings of GIScience* (Vol. 2010, No. 3).

step involved identifying the features of each layer that potentially met the predetermined selection criteria and parameters. Subsequently, a comprehensive visual inspection of the raw layers and their respective features, inspecting a minimum number of 20 features randomly selected in three different states was carried out using GIS and satellite images. This inspection aimed to verify whether the selected features should be included or excluded from the analysis. By combining the outcomes of the visual inspection and the selection criteria, the key features from each layer were extracted and processed to meet the AWE requirements predefined (e.g., selecting relevant high structures and adding a safety buffer around them).

Table 3.2. Table presenting the selected features from each dataset.

CRITERIA	DLM250 (2022)	OSM (2023)	Others
Water Bodies	VEG03 (Vegetation Areas) • 43005 Moor → Area ≥ 40 ha • 43006 Swamp → Area ≥ 40 ha Typical swamp landscapes are recorded, but not the temporarily wet places in the ground after rainfall. GEW01 (Water Bodies) • 44001 Rivers → Complete from a width ≥ 42 m • 44005 Docks • 44006 Standing Water → Area ≥ 10 ha • 44007 Sea → Complete	Waterways • Canal • River Water • Water • Riverbank • Reservoir • Dock • Wetland	N/A
Forests	VEG02 (Forestry Use) ▪ 43002 Forest → Area ≥ 40 ha	Land Use ▪ Forest	N/A
Slope	N/A	N/A	European Digital Elevation Model (EU-DEM), version 1.1. (2016) Processed to extract the Slope. Areas with Slope >30 degrees were excluded.
Settlements	SIE02 (Areas dominated by Buildings) ▪ 41002 Industrial and commercial area → Area ≥ 40 ha, only objects of great topographical importance. ▪ 41003 Stockpile ▪ 41005 Opencast mine, Pit, Quarry → Area ≥ 40 ha ▪ 41007 Area of special functional character → Area ≥ 40 ha. Facilities for public purposes or historical installations.	Land Use • Allotments • Cemetery • Commercial • Farmyard • Industrial • Recreational ground • Residential	N/A

CRITERIA	DLM250 (2022)	OSM (2023)	Others
	▪ 41008 Sport Leisure and Recreation Area ▪ 41009 Cemetery ▪ 41010 Settlement area → Residential areas, urban centres, rural settlements: - Area ≥ 40 ha - All independent municipalities - Parts of the municipality <40ha near area ≥ 40 ha	• Retail • Park	
Roads	VER01 (Road Traffic) • 42003 Roads → Complete recording of inter-urban roads approved for public transport as well as recording of other roads used for the development of settlement or business areas.	Roads • Motorway • Motorway links • Primary • Primary link • Residential • Secondary • Secondary link • Tertiary • Tertiary link • Trunk • Trunk link • Unclassified • Unknown	N/A
Railways	VER03 (Railway) • 42014 Railway → Complete coverage of railways. Trams and subways are not included. • 53005 Cableway, suspension railway	N/A	N/A
Air Traffic (airfields and airports)	VER04 (Aviation)	Transport • Helipad	N/A

CRITERIA	DLM250 (2022)	OSM (2023)	Others
	• 42015 Air traffic → Complete coverage from an area ≥ 40 ha or a length of the longest runway ≥ 455 m	• Airfield • Airport • Apron	
High Structures	SIE03 (Buildings and other facilities) • 51002 field BWF = 1220 Wind Turbines → Objects of great topographical importance or a height ≥ 100 m. • 51005 Overhead Power lines → Complete ≥ 110 kV. SIE05 (Buildings) • 51001 Towers → Objects of great topographical importance or a height ≥ 100 m	Points • Comms Tower • Observation tower • Water Tower • Tower • Windmill • Lighthouse Railways • Funicular Wind Turbines	N/A
Protected Areas	N/A	N/A	WDPA (2022) • National Park • Nature monuments • Nature Reserve • Baltic Sea Protected Area, Marine Protected Area (OSPAR) • Sites of Community Importance (Habitats Directive) • Special Areas of Conservation (Habitats Directive) • Special Protection Area (Birds Directive) • Ramsar Site

CRITERIA	DLM250 (2022)	OSM (2023)	Others
			• Wetland of International Importance • UNESCO-MAB Biosphere Reserve.
Military Areas	GEB03 (Protected Areas) • 71011 Other law → Military training areas	Land Use • Military	N/A
Wind	N/A	N/A	NEWA (2022, 2023). 3x3 km. 30 years coverage (1989-2018) Average wind speed at several altitudes.
Base map	N/A	N/A	GADM database (2015)

4 Data extraction and Site identification methodology using QGIS Models

4.1 Data Collection and Extraction

The data collection for all the different criteria specified in Table 3.1 was carried out utilising various datasets with different characteristics. The EU-DEM, WDPA, DLM250 and NEWA datasets had a coverage for the entirety of Germany, while the OSM datasets were organised in division by state or administrative district level in the case of states with a large territorial extension (E.g., Bayern). Due to the significant size of the OSM datasets, it was not feasible to merge the subregions and obtain the data on a national scale, so all the analyses were carried out at a statal or, in some cases, administrative district level. Different QGIS projects were created for each of the regions and the national datasets were divided into the subregions using the *clip* tool in QGIS and a 5km-buffered base map[7] of the relevant region. The subsections below list every layer, category, and feature utilised for each criterion.

The data extraction of the relevant categories and features of each raw layer was automatised using the Graphical Modeller and batch process tool in QGIS. All the inputs from the batch process were stored as .json files to be able to carry out the Quality Control on this step. The outputs from the Data Extraction process were 15 layers by region containing the relevant data for each criterion. All the layers received a systematic name, containing the criteria, the CRS and the region code ‘XXX’ (E.g, Hessen = HES):

- Slope_3035_XXX
- Protected_Areas_NoLPA_3035_XXX

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[7] A 5 km buffer was added to the base maps of the different regions to account the presence of objects that, even though located outside the state division, could still affect areas within the state or study region due to their predefined range (For example, airports located in an adjacent state, outside the studied region, but which exclusion boundary (5 km) could affect areas within the studied region).

- Water_Bodies_3035_XXX
- Forests_3035_XXX
- Settlements_3035_XXX
- Military_3035_XXX
- High_Structures_Buffered_3035_XXX
- Roads_3035_XXX
- Railways_3035_XXX
- Airports_Riskbuffer_3035_XXX
- Airfields_Riskbuffer_3035_XXX

Three layers with national extent were also produced with Wind data for the different altitudes.

EPSG:3035 (ETRS89, LAEA) was selected as the Coordinate reference system and all layers were transformed to meet this CRS. The data extraction steps adopted are detailed in the subsections below.

4.1.1 Base Map for Germany

All base maps used were extracted from the GADM database. It should be noted that these maps can be used for non-commercial purposes only and cannot be redistributed or used for commercial purposes without prior consent.

Figure 4.1 shows an example of the base map for one region, Schleswig-Holstein.

Figure 4.1. Base map of Schleswig-Holstein.
©GADM

4.1.2 Slope

Slope data (or gradient) was extracted from the EU-DEM dataset. It was accessed and downloaded in November 2022 from the Copernicus programme (https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1).

The requirement applied to this criterion was to avoid areas with a slope >30 degrees (following traditional wind turbines criteria for similar studies in Germany[8]). To cover all of Germany, layers for the regions 'E40N30' and 'E40N20' in raster format were downloaded and loaded in a QGIS project to be able to process them.

The *Slope* tool was used to calculate the slope in both raster layers. Both rasters were reclassified using the *raster calculator* to differentiate between areas with <30 degrees, giving them value of 1, and areas with >30 degrees that were given a value of 0. To transform both raster layers to vectors,

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[8] Reiner Lemoine Institute (2022): *Documentation accompanying the web application "Der Photovoltaik- und Windflächenrechner"*, Version 1.2, DOI: 10.5281/zenodo.4731920

the tool *vectorize* in QGIS was used, and the features with a value equal to 0 were erased. Both vectors were *clipped* to the German Base map, and they were *merged* to obtain an integrated map of Germany with the areas that have a slope <30 degrees.

Note: No buffer was applied around the excluded slope in order to avoid excluding areas where the GS deployment area is at a higher elevation than the terrain surrounding it. It is expected that the farms at a commercial level can control the deployment and landing of the aircrafts and avoid the terrain with steep slope. Further investigation on a case-by-case basis would be required to identify if GS cannot be deployed in an area that has been identified as “deployment area”.

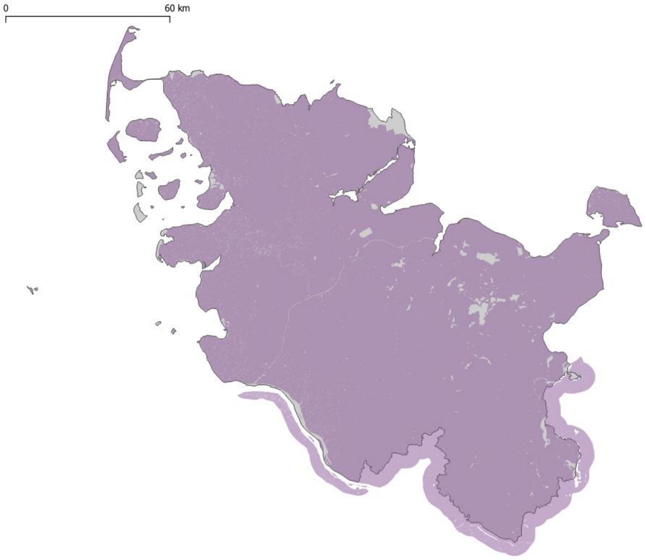

Figure 4.2. Areas meeting the Slope requirement (<30°) in Schleswig-Holstein.
Source Data: ©GADM, ©Copernicus

4.1.3 Protected Areas

Data containing information on protected areas was extracted from WDPA, being accessed and downloaded in November 2022 from Protected planet (www.protectedplanet.net). The protected areas included: Landscape Protection Area, National Parks, Nature monuments, Nature Reserves, Baltic Sea Protected Areas, Marine Protected Areas (OSPAR), Sites of Community Importance (Habitats Directive), Special Areas of Conservation (Habitats Directive), Special Protection Areas

(Birds Directive), Ramsar Sites, Wetlands of International Importance and UNESCO-MAB Biosphere Reserves. The data was available to download in three different polygon vector layers that contained the data for all of Germany[9].

The requirement for this criterion was to avoid the protected areas.

The layers were *merged* in QGIS, excluding in the resulting layer the features with “Landscape Protection Areas” classification. The layer was clipped to the correspondent 5km-buffered base map, and the tool *retain fields* was applied to preserve only the ‘WDPA_ID’ field.

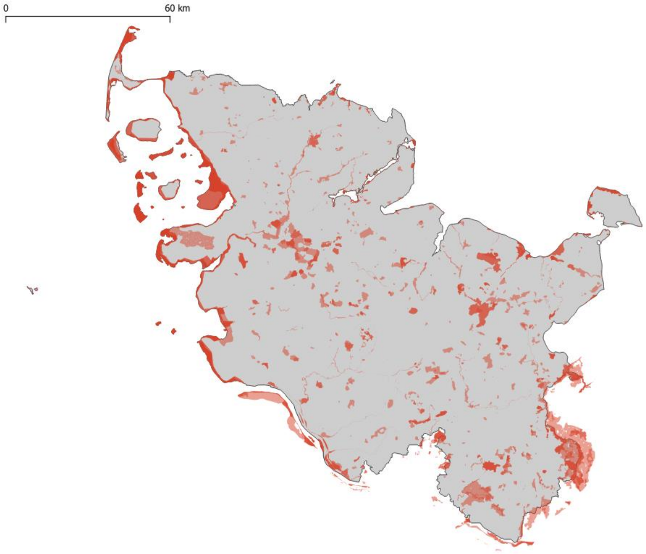

Figure 4.3. Protected Areas (shown in Red. Protected Landscape Areas not included) in Schleswig-Holstein.
Source Data: ©GADM, ©ProtectedPlanet

4.1.4 Water Bodies

The databases used for obtaining data on the water bodies in Germany were:

- DLM250 (2022) – Two polygon shapefile layers from this database were included:

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[9] UNEP-WCMC (2022). Protected Area Profile for Germany from the World Database on Protected Areas, November 2022. Available at: www.protectedplanet.net

  - “GeW01_F” that contains data on water bodies. The categories included were ‘44001 – Rivers’, ‘44005 – Docks’, ‘44006 – Standing Water’, ‘44007 – Sea’.
  - “Veg03_f” that contains data on vegetation areas. Only categories ‘43005 – Moorland’ and ‘43006 – Swamp’ were included in the analysis.

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.

- OSM (2023) - In this case, two layers were used:
  - Water, that contains the categories ‘Water’, ‘Riverbank’, ‘Reservoir’, ‘Dock’ and ‘Wetlands’.
  - Waterways were only the categories ‘Canal’ and ‘River’ were selected.

  OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.

The requirement applied to this criterion was to avoid water bodies and leave 100m distance from the GS to the water bodies.

The first step was to extract the relevant categories from the four layers and transform them to the standard reference system used in this study. In the case of the waterways layer, a 5m *buffer* was added to the canals and rivers so all the vector features were polygons. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area and once this was completed, the four layers were merged. The tool *retain fields* was applied to the resulting layer to preserve only the fields with a unique identifier of each feature and the categories names.

The 200m distance was applied in a later stage, specified in section 4.2.1 - Site Identification

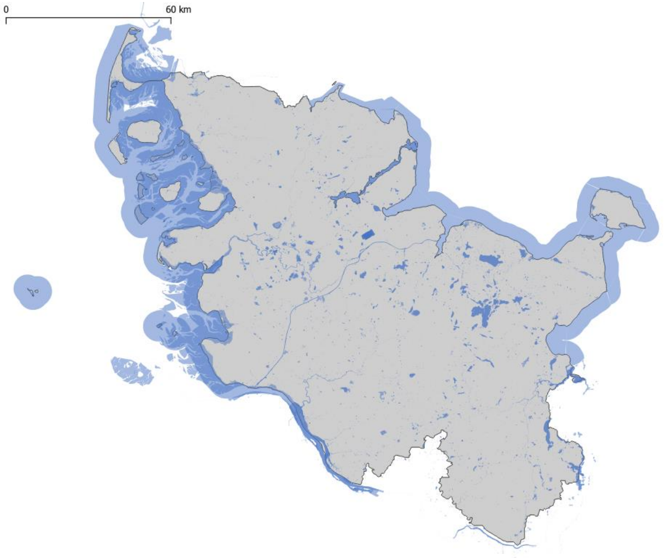

Figure 4.4. Water Bodies (shown in blue) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

4.1.5 Forests

The databases used for obtaining data on the forests in Germany were:

- DLM250 (2022) – The layer used from this database was “Veg02_F”, that contains data on forestry use in polygon shapefile format. The category included was ‘43002 – Forest’.

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.
- OSM (2023) – The layer on Land Use containing the category ‘Forest’ was used.

  OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.

The requirement applied to this criterion was to avoid forests and leave 200m distance from the GS to the water bodies as the base case. Sensitivity analyses were applied to this criterion, applying a distance of 100m and 300m from the GS.

The first step was to extract the relevant categories from the two layers and transform them to the standard reference system used in this study. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area and once this was completed, it was *merged* to the OSM layer. The tool *retain fields* was applied to the resulting merged layer to preserve only the fields with a unique identifier of each feature and the categories names.

The required distance from GS to forests and the sensitivity analysis were applied in a later stage, specified in section 4.2.1 - Site Identification.

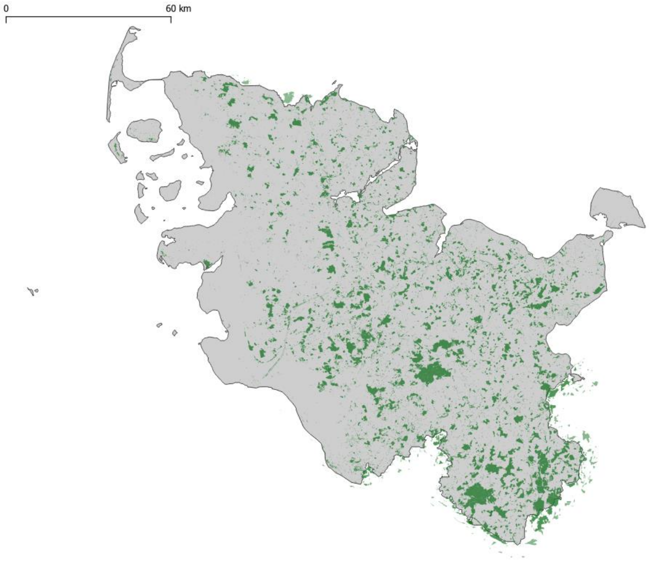

Figure 4.5. Forests (shown in green) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

4.1.6 Settlements

The databases used for obtaining data on the Settlements in Germany were:

- DLM250 (2022) – The layer used from this database was “Sie02_F”, that contains data on areas dominated by buildings in polygon shapefile format. The categories included were ‘41002 – Industrial and commercial area’, ‘41003 – Stockpile’, ‘41005 – Opencast mine, Pit, Quarry’, ‘41007 - Area of special functional character’, ‘41008 - Sport Leisure and Recreation Area’, ‘41009 – Cemetery’ and ‘41010 - Settlement area’.

The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.

- OSM (2023) – The layer on Land Use containing the category ‘Allotments’, ‘Cemetery’, ‘Commercial’, ‘Farmyard’, ‘Industrial’, ‘Recreational ground’, ‘Residential’, ‘Retail’ and ‘Park’ were used.

  OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.

The requirement applied to this criterion was to avoid settlement areas and apply an operational radius around them of 850m as the base case. Sensitivity analyses were applied to this criterion (as part of publicly used infrastructure), applying risk buffers of 250m, 650m and 1050m.

The first step was to extract the relevant categories from the two layers and transform them to the standard reference system used in this study. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area and once this was completed, it was *merged* to the OSM layer. The tool *retain fields* was applied to the resulting merged layer to preserve only the fields with a unique identifier of each feature and the categories names.

The operational radius was applied in a later stage, specified in section 4.2.1 - Site Identification.

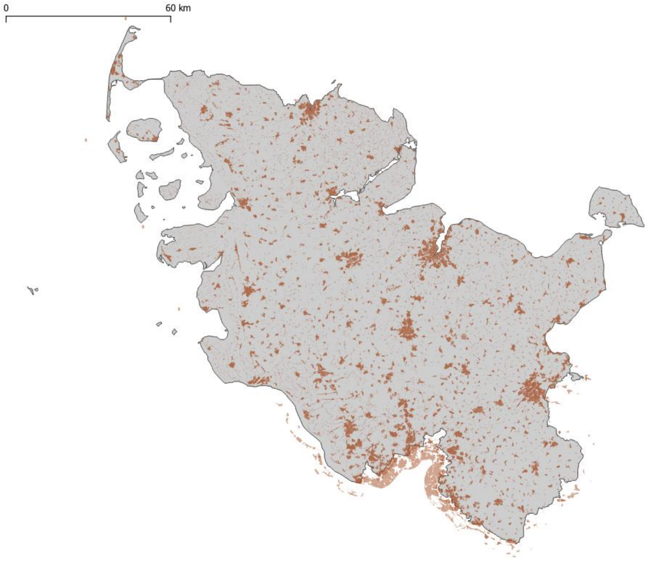

Figure 4.6. Settlements (shown in Orange) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

4.1.7 Military

The databases used for obtaining data on the forests in Germany were:

- DLM250 (2022) – The layer used from this database was "Geb03_F", that contains data on protected areas in polygon shapefile format. The category included was '71001 – Other law: Military training Areas'.

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.
- OSM (2023) – The layer on Land Use containing the category 'Military' was used.

  OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.

The requirement applied to this criterion was to avoid Military areas.

The first step was to extract the relevant categories from the two layers and transform them to the standard reference system used in this study. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area and once this was completed, it was *merged* to the OSM layer. The tool *retain fields* was applied to the resulting merged layer to preserve only the fields with a unique identifier of each feature and the categories names.

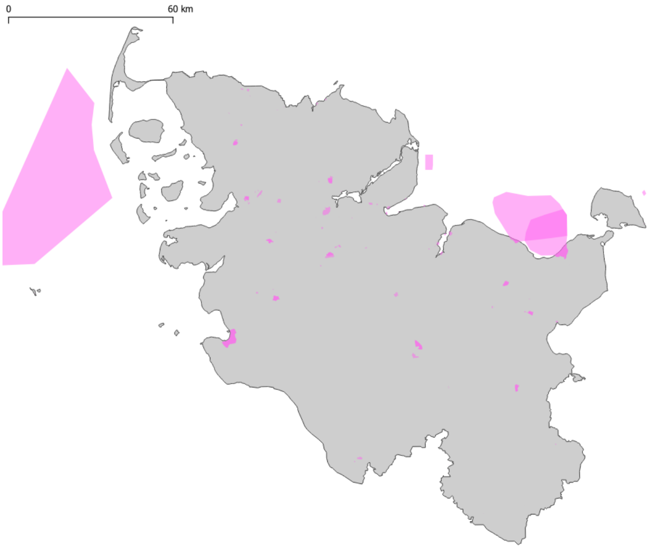

Figure 4.7. Military Areas (shown in pink) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

4.1.8 High Structures

Various objects were included as high structures for these analyses, including three main categories: wind turbines, power lines & power towers, other types of towers (such as communication towers, water towers, lighthouses, and similar entities) and funicular lines. Given the different characteristics of these objects, they were processed individually and finally consolidated into a final 'High Structures' layer.

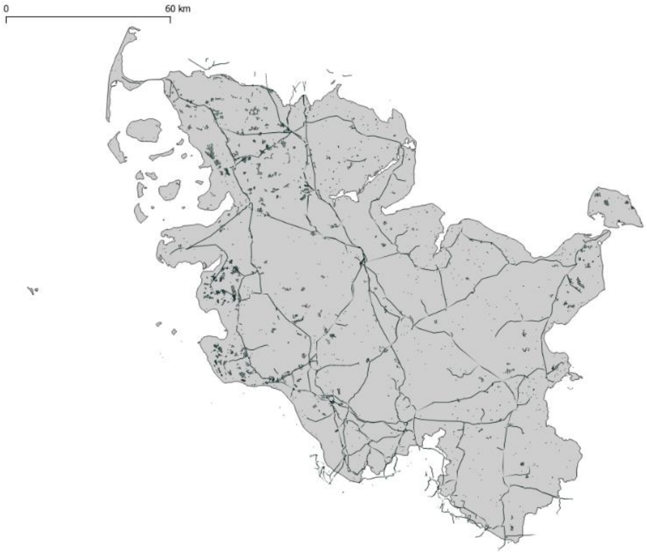

Figure 4.8. High Structures (shown in black) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

The output layers of Wind turbines, Power lines, Towers and Funicular lines were then merged into a single layer and a 100m radius buffer was added as a risk buffer around high structures.

The following subsections give further detail on each of the sub-layers within the high structures layer.

4.1.8.1 Wind Turbines

The databases used for obtaining data on the Wind Turbines in Germany were:

- DLM250 (2022) – The layer used from this database was “Sie03_p”, that contains data on buildings and other facilities in points shapefile format. The category included was ‘51002’, selecting only the field ‘BWF = 1220’ (Wind turbines).

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.
- OSM (2023) – A points shapefile layer containing the location of the wind turbines was used.

> OSM data was accessed and downloaded from the QuickOSM plugin in QGIS in February 2023. The key used for the search and download was “Man Made/Power/Power Generator/Wind Turbine”. The wind turbines were downloaded using the states or administrative districts base maps as the desired extension.

The requirement applied to the wind turbines was to avoid them and a 50m buffer was added as a safety measure.

The first step was to extract the relevant categories from the layers, transform them to the standard reference system used in this study and *retain* the fields with a unique identifier of each feature and the categories names. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area.

Following a thorough visual examination using satellite images, it became evident that both datasets exhibited complementary points. However, there were a few meters difference in points that were marking the same wind turbine. As a result, it was necessary to identify and merge the turbines that were unique to each dataset. To achieve this, a buffer of 100m was created around the OSM points. Subsequently, the *difference* tool was utilized to eliminate the points within the DLM250 dataset that marked the same wind turbine as the OSM dataset. The OSM data and the remaining points from the DLM250 dataset were then *merged*. Furthermore, another visual examination was conducted using satellite imagery to identify any additional turbines that were not originally marked in either of the initial layers[10]. Finally, a 50m buffer was applied to the merged layer containing data on the wind turbines.

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[10] The quality control process for both layers was not exhaustive, which means that some of the points marked in the layers may not accurately represent the position of wind turbines, and there is a possibility that some turbines may have been overlooked and not marked, and others that are marked and are not yet built.

4.1.8.2 Power lines

The database used for obtaining data on the Power lines and Power Towers in Germany was:

- DLM250 (2022) – The layer used from this database was "Sie03_l", that contains data on buildings and other facilities in lines shapefile format. The category included was '51005 – Overhead Power lines'.

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.

The requirement applied to the Power lines was to avoid them. A 10m buffer was added to the power lines to be able to consider the width of structure.

The first step was to extract the relevant categories from the layer, transform it to the standard reference system used in this study and *retain* the fields with a unique identifier of each feature and the category names. The layer was clipped to a 5km-buffered base map of the correspondent area and a 10m buffer was added to the layer.

4.1.8.3 Towers

- DLM250 (2022) – The layer used from this database was "Sie05_p", that contains data on buildings in points shapefile format. The category included was '51001 – Towers'.

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.
- OSM (2023) – The points shapefile layer called Points containing the categories 'Comms Tower', 'Observation tower', 'Water Tower', 'Tower', 'Windmill' and 'Lighthouse' was used.

  OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.
- OSM (2023) – A points shapefile layer containing the location of the power towers was used.

OSM data was accessed and downloaded from the QuickOSM plugin in QGIS in February 2023. The key used for the search and download was "Man Made/Power/Power Tower". The power towers were downloaded using the states or administrative districts base maps as the desired extension.

The requirement applied to the towers was to avoid them and a 10m buffer was added to be able to consider the radius of the structure.

The first step was to extract the relevant categories from the layers, transform them to the standard reference system used in this study and *retain* the fields with a unique identifier of each feature and the categories names. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area.

In the case of the power towers extracted from the OSM data, a 50m buffer was added to the processed layer of Power lines, and only the points that were not within the buffer were retained. Following a similar process as with the wind turbines, a 50m buffer was created around the OSM data containing the points for all the 'other' towers and the DLM250 points that were within these areas were eliminated from the analysis. Finally, the retained points marking power towers, the OSM data with the 'other' towers and the remaining DLM250 points were merged. A 10m buffer around these points were added to account for the space that occupies the structure.

4.1.8.4 Funicular Lines

The datasets used for obtaining data on the Funicular lines in Germany were:

- OSM (2023) – The lines shapefile layer called Railways selecting the category 'Funicular' was used. OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.
- The settlements output layer (See section 4.1.6 - Settlements).

Funicular lines were treated as high structures and the requirement applied to them was to avoid them and a 5m radius buffer was added to be able to consider the width of the structure.

The first step was to extract the relevant categories from the OSM layer, transform it to the standard reference system used in this study and *retain* the fields with a unique identifier of each feature and the categories names.

A buffer of 100m radius was applied to the settlements layer and the difference tool was applied to obtain the funicular lines that are outside settlements. A 5m radius buffer around the remaining lines was added to account for the space that occupies the structure.

4.1.9 Roads

The databases used for obtaining data on the Roads in Germany were:

- DLM250 (2022) – The layer used from this database was “Ver01_l”, that contains data on road traffic in lines shapefile format. The category included was ‘42003 – Roads’.

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.
- OSM (2023) – The layer on Roads containing the categories 'motorway', 'motorway_link', 'primary', 'primary_link', 'residential', 'secondary', 'secondary_link', 'tertiary', 'tertiary_link', 'trunk', 'trunk_link', 'unclassified' and 'unknown' was used. This layer is on lines shapefile format. OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.

The requirement applied to this criterion was to avoid roads and apply an operational buffer around them of 850m as the base case. Sensitivity analyses were applied to this criterion (as part of publicly used infrastructure), applying risk buffers of 250m, 650m and 1050m.

The first step was to extract the relevant categories from the two layers and transform them to the standard reference system used in this study. The DLM250 data was clipped to a 5km-buffered base map of the correspondent area. After a visual inspection of the datasets and using satellite images, discrepancies between the two layers of a few meters for some roads were identified. To avoid including twice the same road, a 100m buffer around the OSM data was created and using the *difference* tool, only the roads in the DLM250 dataset that were outside the boundaries of the 100m buffer were retained. Both layers were then *merged* and the tool *retain fields* was used to preserve only the fields with a unique identifier of each feature.

The operational radius was applied in a later stage, specified in section 4.2.1 - Site Identification.

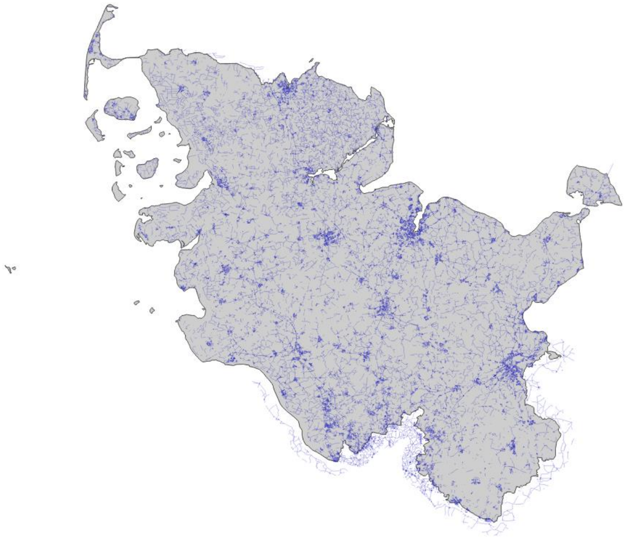

Figure 4.9. Roads (shown in lilac) in Schleswig-Holstein.

Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

4.1.10 Railways

The database used for obtaining data on the Railways in Germany was the DLM250 (2022) dataset. The layer used from this database was “Ver03_l”, that contains data on railways in lines shapefile format. The categories included were ‘42014 – Railway’ and ‘53005 – Cableway, suspension railway’.

The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.

The requirement applied to this criterion was to avoid roads and apply an operational radius around them of 850m as the base case. Sensitivity analyses were applied to this criterion (as part of publicly used infrastructure), applying risk buffers of 250m, 650m and 1050m.

The first step was to extract the relevant categories from the layer, transform it to the standard reference system used in this study and *retain* the fields with a unique identifier of each feature and the category name. The layer was clipped to a 5km-buffered base map of the correspondent area and a 5m buffer was added to the layer to account for the width of the structure.

The operational radius was applied in a later stage, specified in section 4.2.1 - Site Identification.

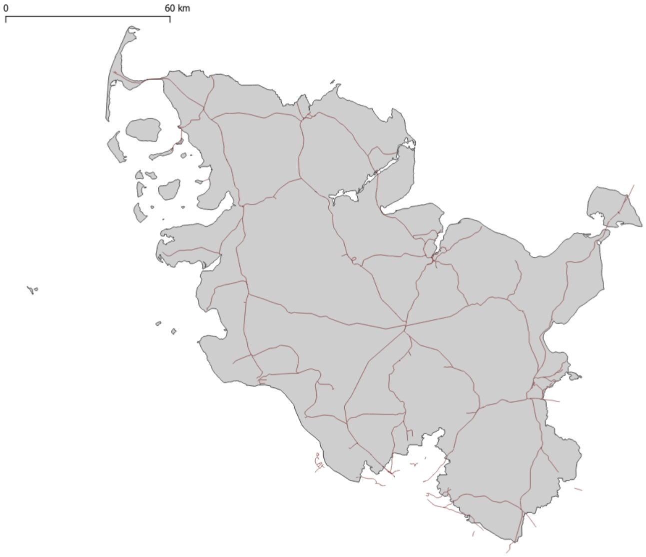

Figure 4.10. Railway lines (shown in red) in Schleswig-Holstein.

Source Data: ©GADM, ©GeoBasis-DE/BKG

4.1.11 Airports

Defining Airport as a place with primarily paved runways where planes may take off and land while also giving people access, the database used for obtaining data on Airports in Germany was the

DLM250 (2022) dataset. The layer used from this database was “Ver04_F”, that contains data on aviation in polygon shapefile format. The categories included were ‘42015 – Air traffic’ selecting only the fields ‘ART = 5511, 5512, 5513’ [11](Airport, International Airport and Regional Airport).

The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.

The requirement applied to this criterion was to avoid airports and apply a risk buffer around them of 5000m.

The first step was to extract the relevant categories from the layer, transform it to the standard reference system used in this study and *retain* the fields with a unique identifier of each feature and the category name. The layer was clipped to a 5km-buffered base map of the correspondent area and a 5000m buffer was added to the layer.

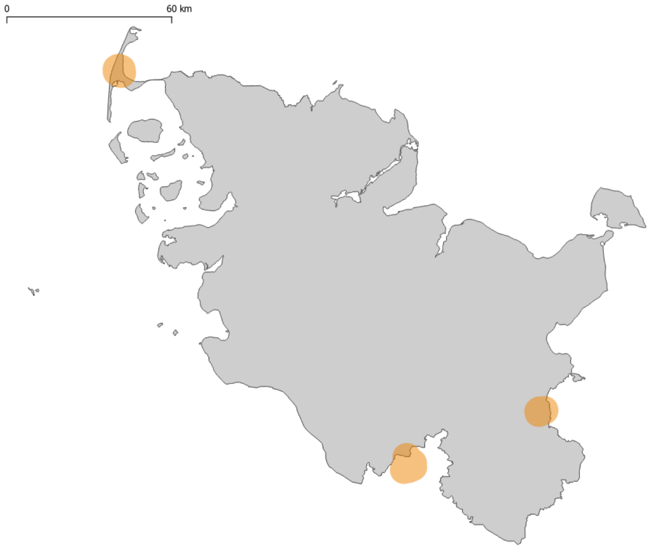

Figure 4.11. Airports (shown in orange) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG

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[11] There is discrepancy between the category numbers in the attribute table and the metadata. In the metadata it seems that airports are 5510, 5511 and 5512. After visual inspections the numbers in the attribute table were selected.

4.1.12 Airfields

In this study Airfields are defined as an area designated expressly for aircraft to take off and land; however, this does not imply that the space is paved. It is possible that the allotted space will be a grass, gravel, or dirt strip.

The databases used for obtaining data on the airfields in Germany were:

- DLM250 (2022) – The layer used from this database was “Ver04_F”, that contains data on aviation in polygon shapefile format. The categories included were ‘42015 – Air traffic’ selecting only the fields ‘ART = 5521, 5522, 5530, 5550’ (Aerodrome, Heliport, Landing Field and Glider airfield).

  The data was accessed and downloaded from the German Federal Agency for Cartography and Geodesy website (https://gdz.bkg.bund.de/) in October 2022. The coverage of the different categories of the dataset is listed in Table 3.2.
- OSM (2023) – The polygon shapefile layer on Transport containing the categories ‘helipad’, ‘airfield’, ‘airport’ and ‘apron’ was used. Visual investigation revealed that the OSM data's category Airport was incorrectly identifying airfields as airports. OSM airports’ category was included in the study, but as airfields, given that different requirements applied to the two criteria. Moreover, the DLM250 coverage of airports was highly comprehensive.

  OSM data was accessed and downloaded from Geofabrik's free download server (https://download.geofabrik.de/) in April 2023.

The requirement applied to this criterion was to avoid airfields and apply a risk buffer around them of 1760m.

The first step was to extract the relevant categories from the layers and transform them to the standard reference system used in this study. The DLM250 layer was clipped to a 5km-buffered base map of the correspondent area and DLM250 and OSM layers were *merged*. A 1760m buffer was added to the merged layer and *retain fields* tool was used to maintain only the unique identifier of each feature and the category names.

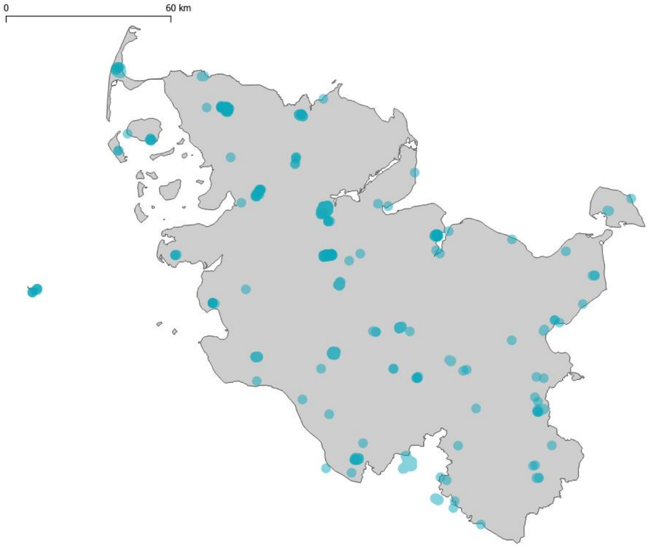


Figure 4.12. Airfields (shown in blue) in Schleswig-Holstein.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors

4.1.13 Wind Resource

Data containing information on Wind Resource was accessed and downloaded in November 2022 from NEWA (https://map.neweuropeanwindatlas.eu/). The downloaded layers (one layer for each required altitude) were in NetCDF format.

The requirement applied to this criterion was to avoid areas with lower mean wind speed than 8m/s at 100m, 200m and 500m altitudes.

The layers were reclassified using the *raster calculator* tool and the areas with a wind speed ≥8m/s were given a value = 1 and a value= 0 was given to the areas with wind speed <8m/s. The layers were later *vectorized* and the features with value=0 were erased. The three layers were then transformed to the standard reference system used in this study.

This criterion was not applied in the analyses (See Section 4.2.1.1).

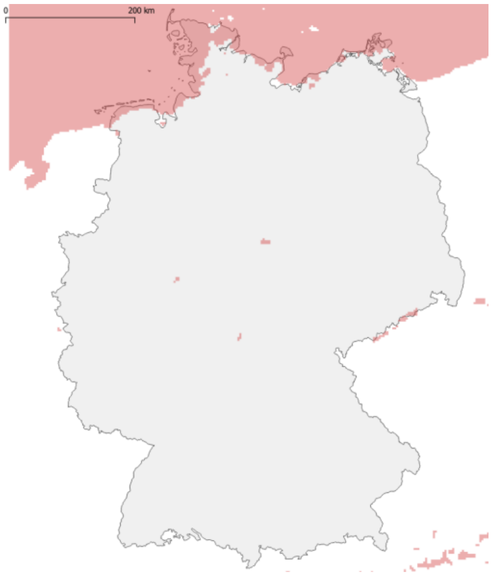


Figure 4.13. Areas with Wind speed >8m/s at 100m altitude (in red) in Germany.
Source Data: ©GADM, ©NEWA

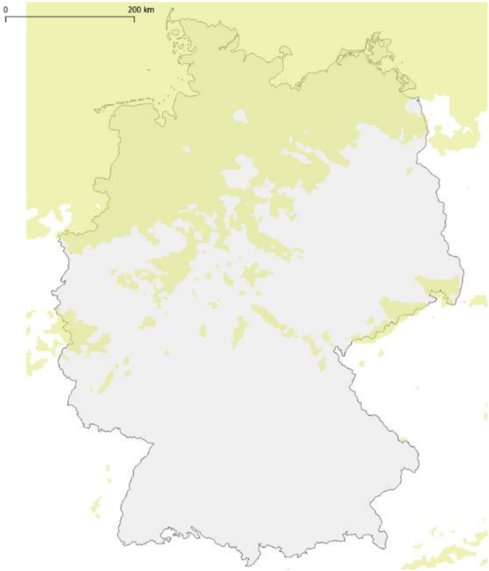


Figure 4.14. Areas with Wind speed >8m/s at 200m altitude (in yellow) in Germany.
Source Data: ©GADM, ©NEWA

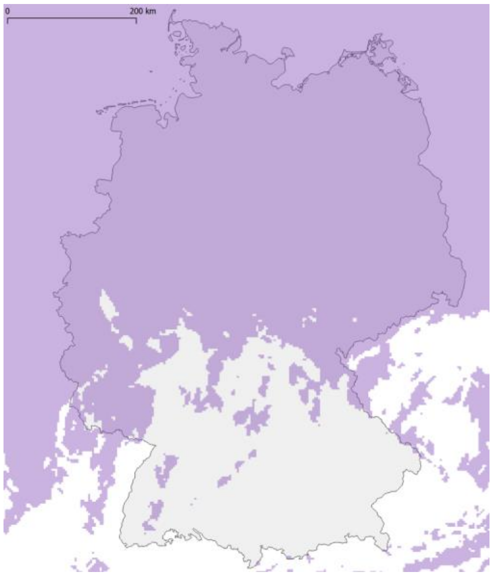


Figure 4.15. Areas with Wind speed >8m/s at 500m altitude (in purple) in Germany.
Source Data: ©GADM, ©NEWA

4.2 Data Processing

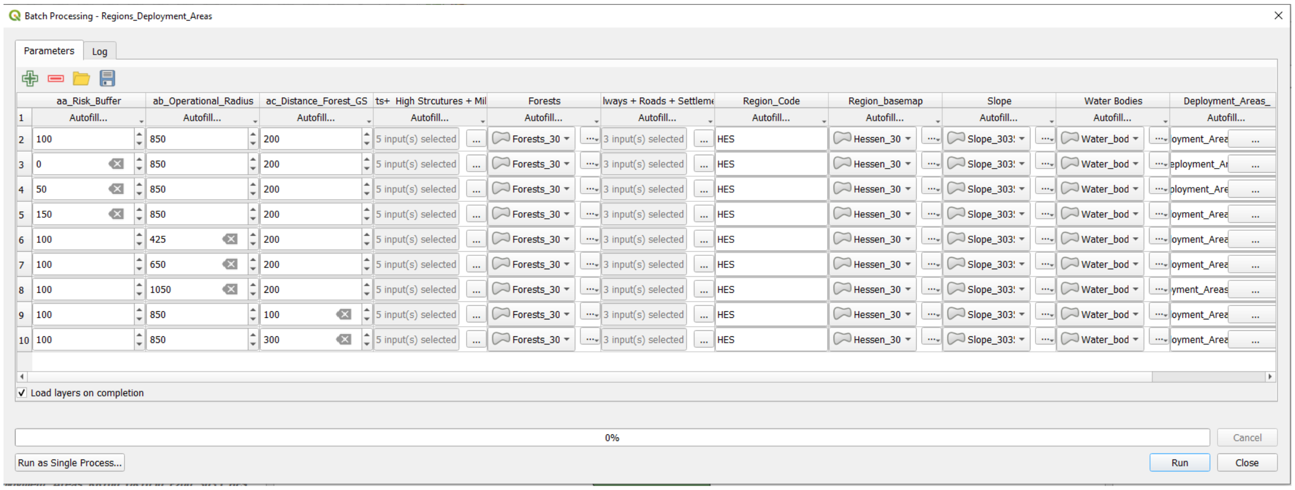
4.2.1 Site Identification

For the site identification process, new QGIS projects were created for all states and districts, and the analysis was applied individually to each region. The results were eventually integrated to generate final maps including information for the whole country of Germany.

A model was constructed in the Graphical Modeller to incorporate various parameters and conduct sensitivity analysis on the criteria. All the input layers consisted of the layers obtained through the Data Collection and Extraction procedure (See section 4.1).

1. Railways, Roads and Settlements were *merged* and a risk *buffer* was applied to them. The magnitude of this "Risk Buffer" varied according to the applied scenario (0m, 50m, 100m, or 150m), using 100m as the base case.
2. Airfields, Airports, High Structures, Military and Protected Areas were also *merged* into a single layer.
3. The outputs from steps 1 and 2 were *merged* and subjected to an "Operational Radius" *buffer*. The size of the operational area buffer depended on the applied scenario (250m, 650m, 850m, or 1050m), using 850m as the base case.
4. Water Bodies were given a 200m *buffer*.
5. A *buffer* to determine the distance from the GS to forests was applied to the Forests layer. The scenarios explored were 100, 200 and 300m, using 200m as the base case.
6. Outputs from steps 3, 4 and 5 were *merged* into one single layer.
7. The merged layer from step 6 was *clipped* to the Slope layer.
8. The resulting layer from step 7 was *clipped* to the base map layer from the corresponding region.
9. The tool *multiparts to singleparts* was applied to the output layer from the previous step and the output layer was saved.

Thanks to the *batch processing* tool, it was possible to iterate the analysis applying the different sensitivity analysis on the layers (See Figure 4.16). Moreover, all the batch process inputs were saved as .json files to allow validation and quality control.



	aa_Risk_Buffer	ab_Operational_Radius	ac_Distance_Forest_GS	ts+ High Strcutures + Mil	Forests	lways + Roads + Settleme	Region_Code	Region_basemap	Slope	Water Bodies	Deployment_Areas_
1	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...	Autofill...
2	100	850	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	oyment_Area
3	0	850	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	eployment_Ar
4	50	850	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	ployment_Are
5	150	850	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	oyment_Area
6	100	425	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	oyment_Area
7	100	650	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	oyment_Area
8	100	1050	200	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	yment_Areas
9	100	850	100	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	oyment_Area
10	100	850	300	5 input(s) selected	Forests_30	3 input(s) selected	HES	Hessen_30	Slope_303	Water_bod	oyment_Area

☑ Load layers on completion

Figure 4.16. Image showing the batch processing for the site identification analysis.

The final deployment area layers for each region (see Figure 4.17) were saved with a systematic name that would allow the identification of each scenario: “Deployment_Areas_RBxxx_ORxxx_Fxxx_3035_XXX”.

RBxxx = ‘RB’ stands for Risk Buffer and xxx for the number indicating the scenario applied.

ORxxx = ‘OR’ stands for Operational Radius and xxx for a number indicating the sensitivity analysis applied.

Fxxx = ‘F’ stands for Forest and xxx for the number indicating the sensitivity analysis applied (distance from forests to the GS).

3035 = indicates the projection.

XXX = Indicates the region code.

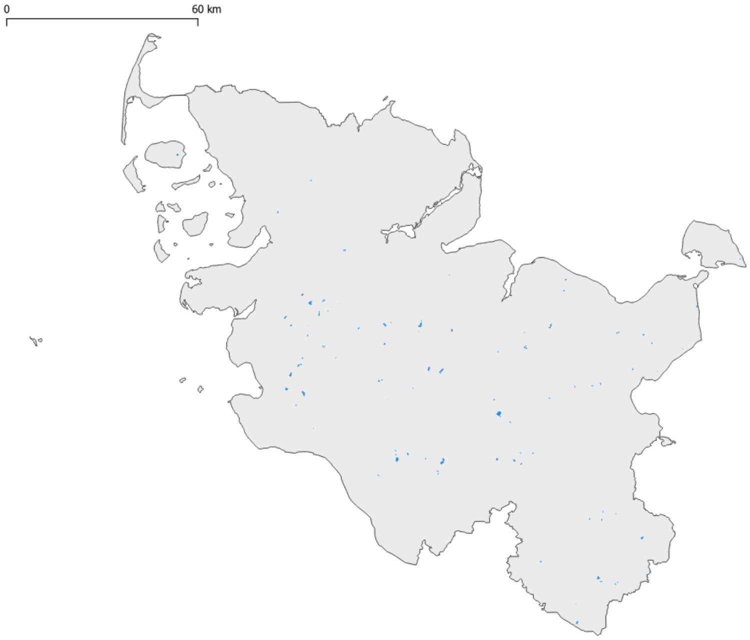


Figure 4.17. Ground Station Deployment Areas (in blue) in Schleswig-Holstein using the base case scenario.
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

To obtain the final available sites for AWE deployment and operation at a national level (see example in figure Figure 4.18), one QGIS projects were created for each scenario (nine in total), and all the Deployment Areas layers that were generated by region were merged following the next steps:

1. *Merge* all the layers in the project.
2. *Dissolve* the merged layers.
3. Add *auto incremental field* to have a unique identifier for each feature.
4. *Retain* only the field that was created in step 3.
5. Add *geometry attributes* (area and perimeter).
6. *Extract* only the features with Area ≥ 700m^2 (See section 4.2.3).
7. Add the Operational Radius *Buffer* specific to each scenario with “dissolve result” activated.
8. Apply the *Multipart to Singlepart* tool.
9. Repeat steps 3 to 5.
10. Export the outputs of step 6 (Deployment Areas) and 9 (Operational Areas), both in shapefile and spreadsheet format.

Both the ‘Deployment areas’ and ‘Operational Areas’ layers were named with the same systematic name as explained above.

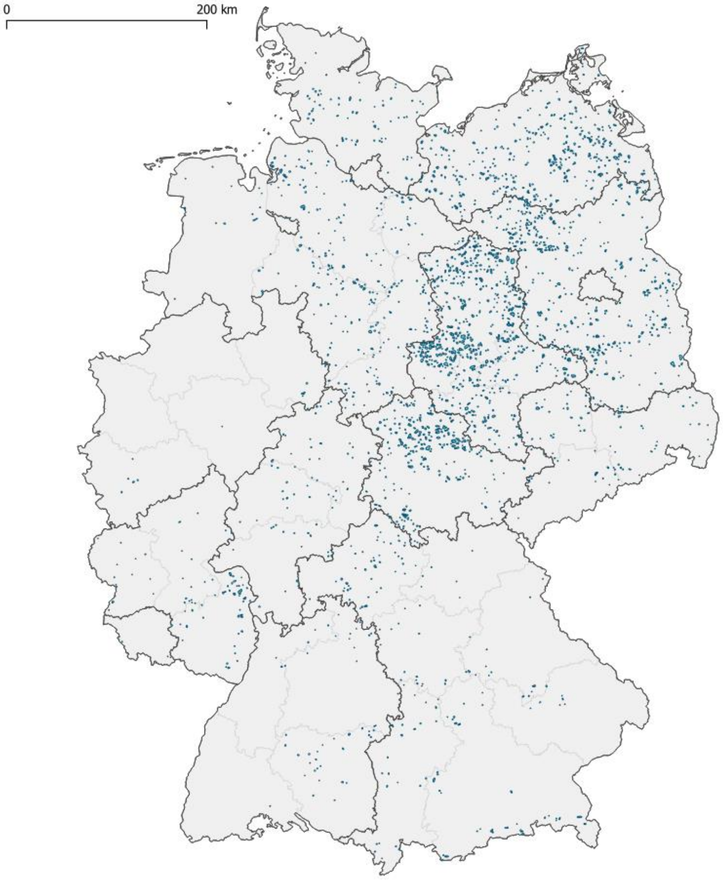


Figure 4.18. Ground Station Deployment Areas and Operational Areas (in blue) in Germany using the base case scenario requirements.

Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

4.2.1.1 Wind Speed Parameter Exclusion

The analysis conducted for this report did not incorporate the Wind Resource criterion for three reasons:

1. **Restrictive Nature of the Criterion:** One of the primary reasons for not including the Wind Resource criterion from the model is its restrictive nature in Germany. For instance, when considering factors such as a mean wind speed exceeding 8m/s at a height of 100m, the criterion becomes overly stringent. Applying such a strict criterion would result in the majority of the German territory failing to meet the requirement. Consequently, the areas identified based on the other criteria would have been overlooked, leading to a significant omission of potential locations.
2. **Diverse Wind Requirements of Developers**: Another important factor contributing to the exclusion of the Wind Resource criterion is the varying wind requirements among different developers. Each developer may have distinct preferences or specific criteria for wind conditions suitable for their projects. Incorporating a standardized Wind Resource criterion would not adequately account for these variations in developer preferences and may not align with their specific project requirements.
3. **Limited scope of the Criteria:** The criterion used in the analysis was relatively simplistic and did not capture the full complexity of wind resource assessment. By solely relying on simple metrics, such as mean wind speed at a specific height, the analysis may overlook important aspects of wind utilization. To obtain a more comprehensive and realistic estimation of wind utilization, it is crucial to conduct a thorough wind profile analysis. Such an analysis would provide a more nuanced understanding of wind conditions, taking into account factors such as wind direction, turbulence, and variations at different heights. Integrating a wind profile analysis would enhance the informativeness and accuracy of the identification process.

Considering these reasons, the decision was made not to include the Wind Resource criterion in the analysis.

4.2.2 Comparison to traditional wind

The RLI analysis was employed as the database for comparing the results with potential traditional wind locations. Data was accessed and downloaded in November 2022 from zenodo.org website (https://zenodo.org/record/6728382#.Yvto4N9CQ2w)[12].

The layer from RLI that was used to conduct a comprehensive comparison with the results obtained for the deployment of AWE systems had the following criteria:

- 800m distance to settlements.
- Excluded forests as suitable areas for wind turbines deployment.
- Allowed the utilization of areas with protected landscapes categorization[13].

In order to evaluate the coexistence of AWE technology with traditional wind turbines, an analysis was undertaken to identify areas capable of accommodating AWE systems while being unsuitable for traditional wind turbines. Three scenarios were compared against the areas identified by the Rainer Lemoine Institute:

- Base case
- 50m Risk Buffer scenario
- 650m Operational Radius scenario

This evaluation involved the utilization of the tool *difference*, which was applied by incorporating the RLI layer in conjunction with the final maps generated from the afore mentioned scenarios (See Figure 4.19). As part of this process, areas smaller than 700m^2 were discarded (see Section 4.2.3),

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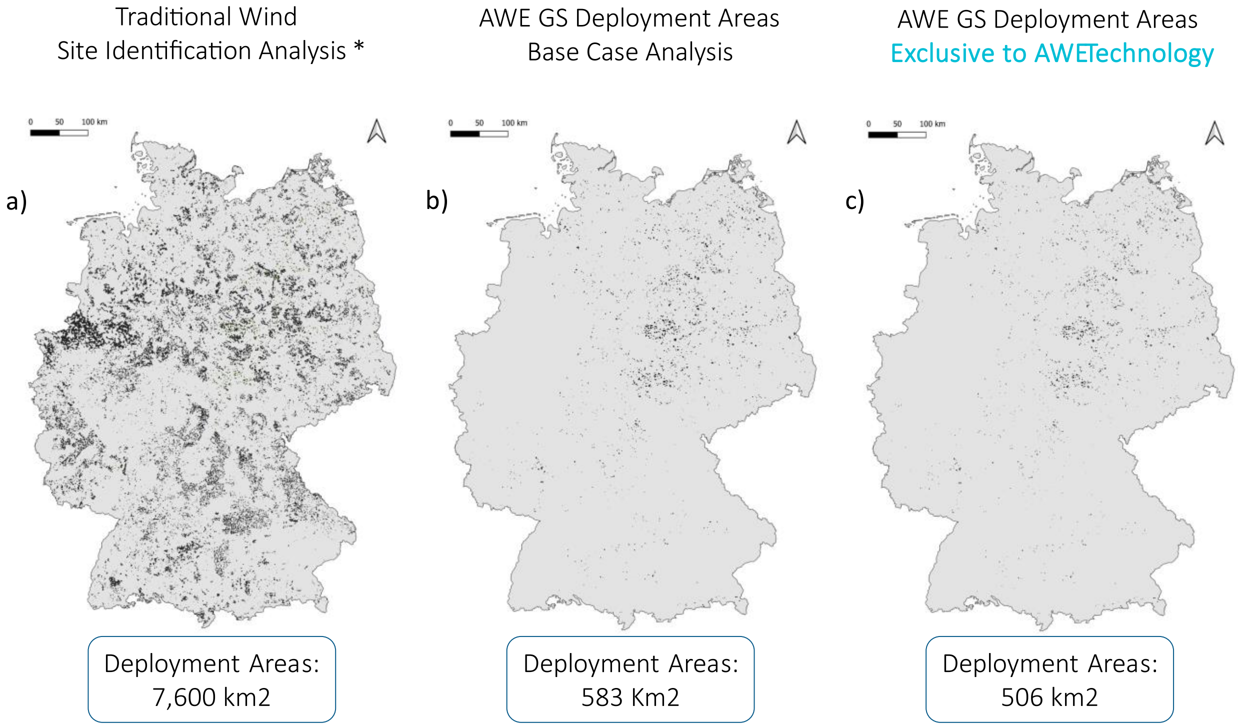
[12] Amme, Jonathan. (2022). Der Photovoltaik- und Windflächenrechner - Geodaten Potenzialflächen (v1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.6728382

[13] To gain a deeper understanding of the criteria utilized in that study, please refer to Reiner Lemoine Institute (2022): *Documentation accompanying the web application "Der Photovoltaik- und Windflächenrechner"*, Version 1.2, DOI: 10.5281/zenodo.4731920

ensuring that only suitable and adequately sized locations were considered for AWE deployment (See results in Section 6.2- Areas exclusive to AWE).



Traditional Wind
Site Identification Analysis *

AWE GS Deployment Areas
Base Case Analysis

AWE GS Deployment Areas
Exclusive to AWETechnology

Deployment Areas:
7,600 km2

Deployment Areas:
583 Km2

Deployment Areas:
506 km2

Sources: ©GADM, ©Photovoltaik- und Windflächenrechner
*Reiner Lemoine Institute, 2022[12]

Sources: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Sources: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet, ©Photovoltaik- und Windflächenrechner

Figure 4.19. Maps showing the Identified areas suitable for: a) Traditional wind; b) AWE GS; and c) Areas exclusive to AWE GS.

4.2.3 Capacity calculation

Upon completion of the generation of maps encompassing different scenarios and the areas exclusive to AWES, which depict the German extent and incorporate the area attribute of each site, the acquired data was exported to a spreadsheet format. This facilitated the calculation of various parameters such as the total area available for AWE GS deployment, the total operational area, the total number of viable sites and the capacity of those sites.

A triangulation method was employed to estimate the maximum number of devices or GS that could be efficiently installed within each designated deployment area.

The triangulation method assumes that the optimum layout for maximising the number of objects (total number >3) within a given area is to place objects in a triangular pattern. In order to apply this method, it is necessary to define the minimum separation distance between objects and the footprint of individual object (i.e., the ground station). In this case the footprint of the ground station was taken as 30m while the minimum separation distance was taken to be 400m.

For N devices > 3 the minimum area required was found to follow a straight line ($R^2 = 0.9992$)

The trendline equation obtained was:

$$y = 15{,}7151x - 472{,}874$$

where y = minimum area and x = the number of devices.

Note: The triangulation method is a simple technique to estimate the number of devices for a large number of identified sites in an automatic way where the number of sites is too great to define manually or to run layout optimisation techniques. This method works best for sites which are regular in shape and is less accurate for long, elongated or irregular shapes. However, at this scale it seems to give a good first estimate of the number of devices. A comparison was done with the *Random points in polygons* algorithm within GIS on a subset of sites and it was found that, while both tools give over and underestimates for different sites, on average the triangulation method give results closest to a manual technique. With almost 7,000 sites identified in this analysis the method above was selected as suitable to give initial estimations of site capacity.

In order to estimate the number of devices that could be hosted within the identified areas, specific criteria were applied. Areas ranging from 700m^2 to 13,800m^2 were determined suitable for hosting one device[14], while areas ranging from 13,800m^2 to 91,540m^2 could host up to two devices. For areas larger than 91,540m^2, the trendline equation was utilized to calculate the maximum number of devices that could be supported.

To ensure practicality and realism in the estimation process, all calculated numbers on the number of devices were rounded down to obtain whole numbers. This approach provides a more precise and realistic estimation of the actual number of devices that could be hosted within each respective area.

Once the total number of devices was determined, a direct calculation was conducted to ascertain the potential capacity of the AWE system. This calculation was based on a straightforward conversion rate of either 200 kW or 1.5 MW per device, allowing for a comprehensive assessment of the potential capacity range which is technology specific. The former rate provided a conservative estimate, while the latter yielded a more optimistic estimation, considering power generation capability of different technologies and devices (See results in Section 6.1 - Site Identification).

---

[14] Areas smaller than 700m^2 (minimum area for a ground station with 30m diameter footprint) were discarded. The shape of certain polygons could have led to overestimation in total deployment area, as the threshold for discarding areas smaller than 700m^2 may not account for elongated or irregular shapes that meet the minimum required area but that cannot accommodate a 30m diameter device. Developers with smaller diameter requirements may still consider these areas for potential use.

5 Quality Control

5.1 Data Selection

Quality control for the data extraction process was implemented by an independent team member who had not been previously involved in the data extraction. This person conducted a visual inspection of all the selected features in each layer of the datasets. At least 20 features in three different states from each dataset were randomly chosen and carefully cross-referenced with corresponding satellite images.

Through this validation procedure, we aimed to ascertain the consistency and accuracy of the extracted data. Any discrepancies or potential errors on the features selection identified during this inspection were promptly rectified through further investigation and refinement of the data selection process.

5.2 Data Extraction and Site Identification

Both the data extraction and the site identification models underwent a validation process that included comparisons with previous analyses conducted manually on two different German States. To establish the models’ accuracy and efficacy, we leveraged a dataset of layers and identified sites that had been previously identified through manual analysis. These layers along with manually identified sites served as a gold standard or benchmark against which the model's performance was measured. The outcomes of the validation process were highly promising, as the model displayed a perfect correlation of 100% with the manually identified sites.

After successfully validating the models, and with the data extraction and site identification stages executed using models developed in the QGIS Graphical Modeller and batch process tools (See Figure 4.16), we were able to monitor and verify the input data for each batch process following the completion of the analysis. This served as a robust quality control mechanism.

Following the generation of output layers from the data extraction and site identification processes, an impartial team member conducted thorough cross-checks to ensure each layer proper generation. Additionally, all saved batch processes were reloaded and meticulously examined to verify the accurate completion of input field information. This scrutiny of the outputs and inputs served to uphold the integrity and precision of the entire analysis.

After generating the final layers, an AWE developer cross-referenced certain locations previously identified during a site identification and selection exercise they conducted, noting a remarkably high correlation of suitable sites with this analysis.

6 Results

6.1 Site Identification

Following the completion of the site identification process, we have generated nine distinct scenarios by considering variations in the risk buffer, operational radius, and distance from the GS to the forest. These scenarios allow us to evaluate the impact of these criteria on the available areas that are suitable for installing AWE devices.

The results of the calculations performed on the results obtained from the site identification analysis are presented in Table 6.1. The table showcases the outcomes derived from each scenario applied, allowing the recognition of the significant impact that arises from the use of different requirements.

Table 6.1. Results of the site identification analysis applying different scenarios. Base Case highlighted in orange.

Test Case	Outer Operational Area (km^2)	GS Deployment Area (km^2)	N° of Sites	N° of devices	Min Capacity*	Max Capacity**	Max. Capacity/ Unit Area (MW/km^2)
Base Case	9,503	583	2,673	8,491	1,698	12,737	1.34
0m Risk Buffer	12,153	894	4,033	12,903	2,581	19,355	1.59
50m Risk Buffer	12,153	755	3,435	10,884	2,177	16,326	1.34
150m Risk Buffer	7,762	469	2,178	6,884	1,377	10,326	1.33
425m Op. Radius	33,034	5,152	22,017	71,908	14,382	107,862	3.27
650m Op. Radius	18,011	1,649	7,318	23,533	4,707	35,300	1.96
1050m Op. Radius	4,658	196	975	2,958	592	4,437	0.95
100m Distance to forests	13,186	789	4,175	12,199	2,440	18,299	1.39
300m Distance to forests	7,207	454	1,899	6,366	1,273	9,549	1.32

*Minimum capacity contemplates a capacity of 200 kW per device.

** Maximum capacity contemplates a capacity of 1.5 MW per device.

All scenarios exhibit a high number of potential sites in Germany, varying from 975 to 22,000 potentially suitable locations. The base case analysis identified approximately 10,000 km^2 of operational space in Germany suitable for potential AWE deployment. This area has the potential to support an estimated AWE capacity of up to 12 GW (assuming an individual device capacity of 1.5 MW). Among the scenarios evaluated, the most advantageous involved reducing the operational area to 425m. As a result, this adjustment yielded an operational space of roughly 33,000 km^2 suitable for AWE deployment, allowing for a greater number of devices with a potential capacity of up 14-108 GW, contingent upon the capacity of each individual device.

Across the base case, the 50m risk buffer, the 150m risk buffer, and scenarios altering the distance to forests, a similar capacity per unit area is evident (ranging from 1.32 to 1.59 MW/km^2). Notably, the primary influencing factor on this metric is the tether length. The scenario featuring a 425m tether demonstrates a notably higher capacity per unit area (3.27 MW/km^2) compared to others, while the 1050m tether displays the lowest capacity per unit area of all scenarios analysed (0.95 MW/km^2). Furthermore, a slight increment in capacity per unit area is observed upon reducing the risk buffer to 0m. This results in the capacity per unit area aligning with the power density capacity calculated in other studies on AWE Power Potential conducted by TU Delft within the JustWind4All project. These studies assumed a power density of 2 MW/km2 for onshore AWE soft wing technology.

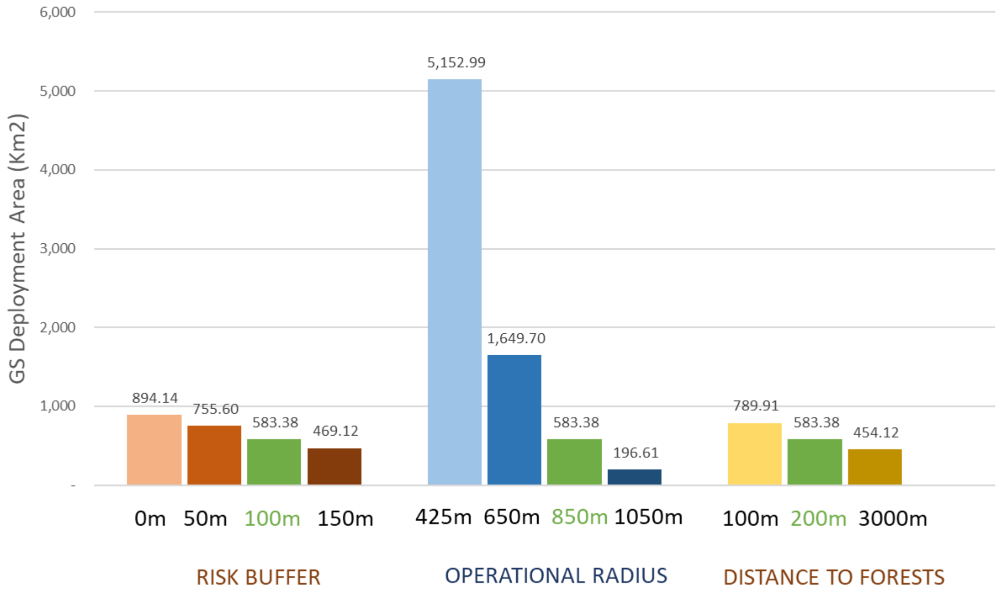


Figure 6.1. Total area (km^2) suitable for GS deployment in the scenarios studied. The results are grouped by modified parameters to assist with the visualization. To facilitate comparison, the base case (in green) is present in the three groups.

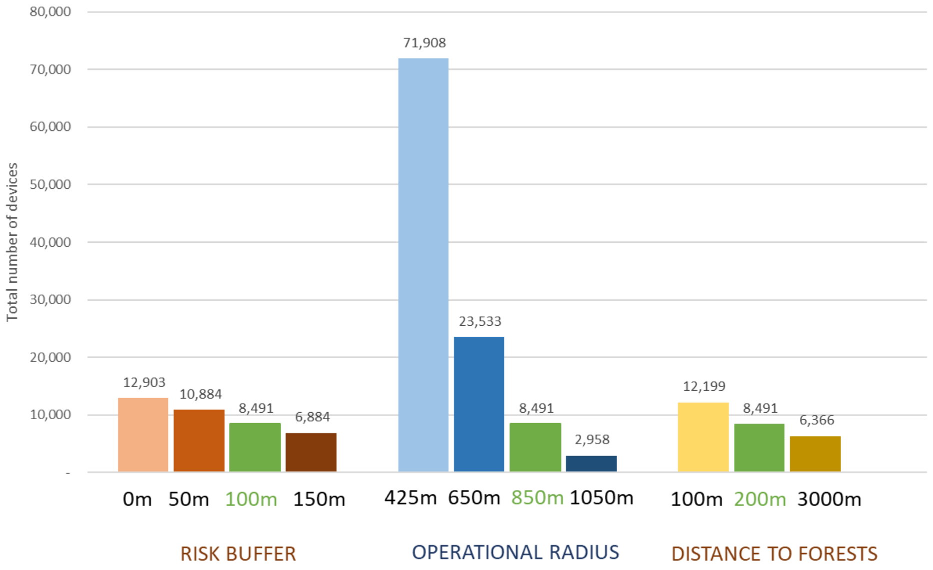


Figure 6.2. Total number of devices that can be deployed in each of the scenarios studied.

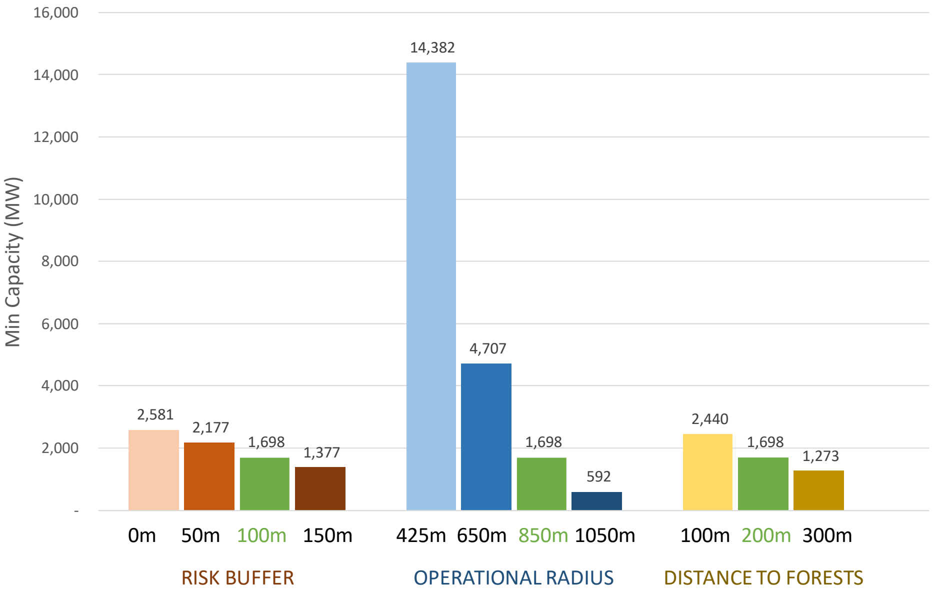


Figure 6.3. Capacity in MW that can be deployed in each of the scenarios studied (<u>based on devices with a 200kW capacity</u>).

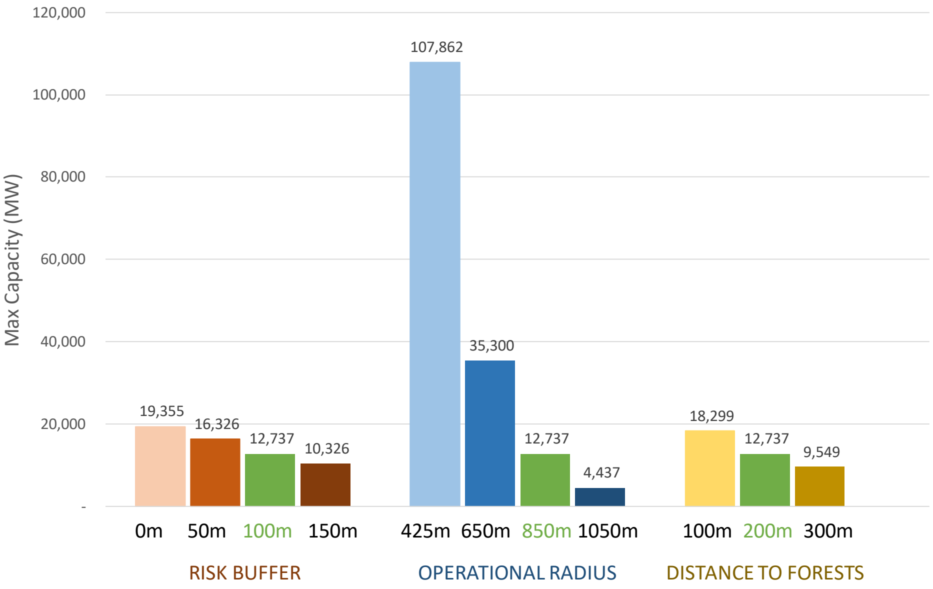
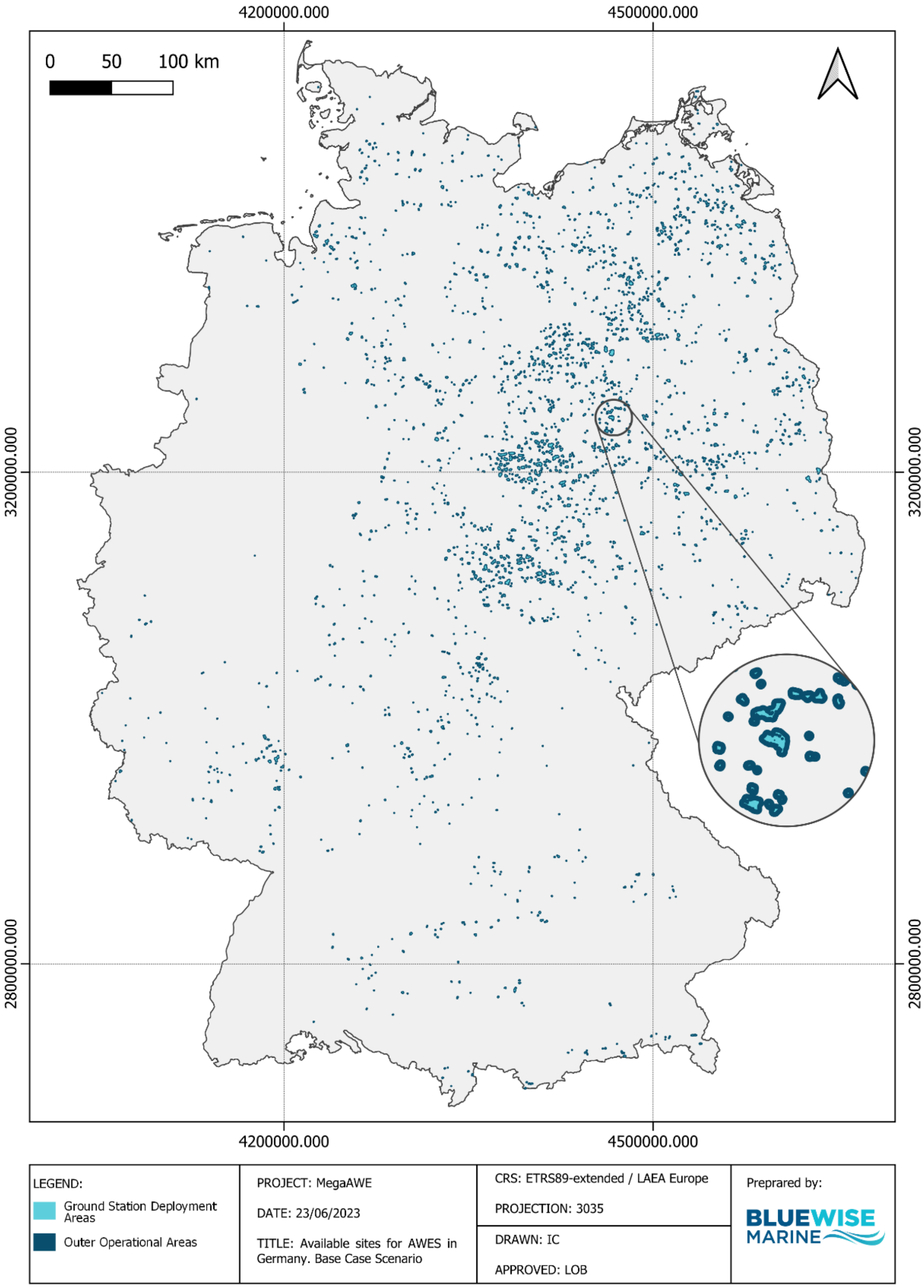


Figure 6.4. Capacity in MW that can be deployed in each of the scenarios studied (<u>based on devices with a 1.5MW capacity</u>).

The maps showcasing the identified areas corresponding to each scenario are presented below:



PROJECT: MegaAWE

DATE: 23/06/2023

TITLE: Available sites for AWES in Germany. Base Case Scenario

CRS: ETRS89-extended / LAEA Europe

PROJECTION: 3035

DRAWN: IC

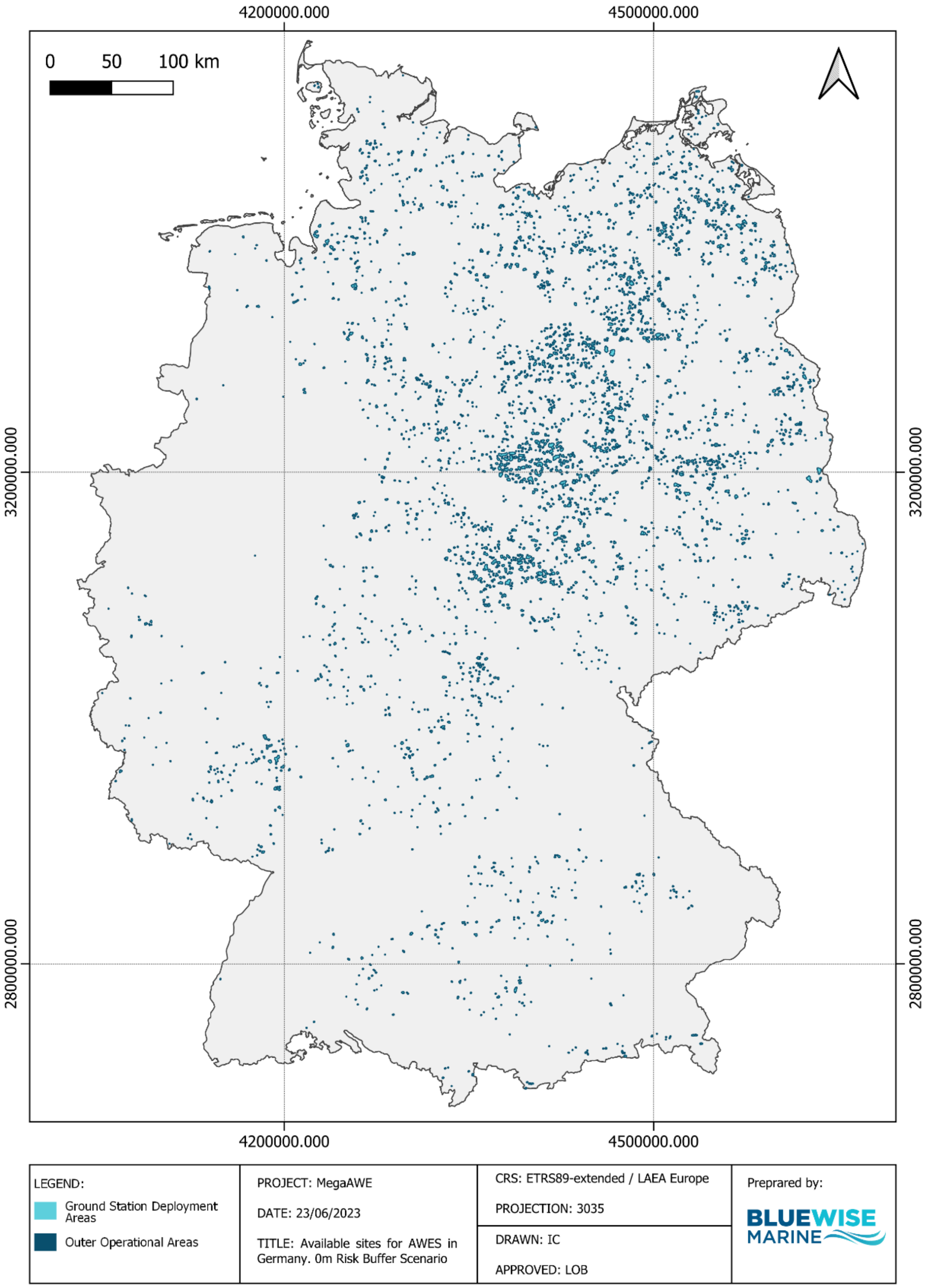
APPROVED: LOB

Preprared by:

BLUEWISE MARINE

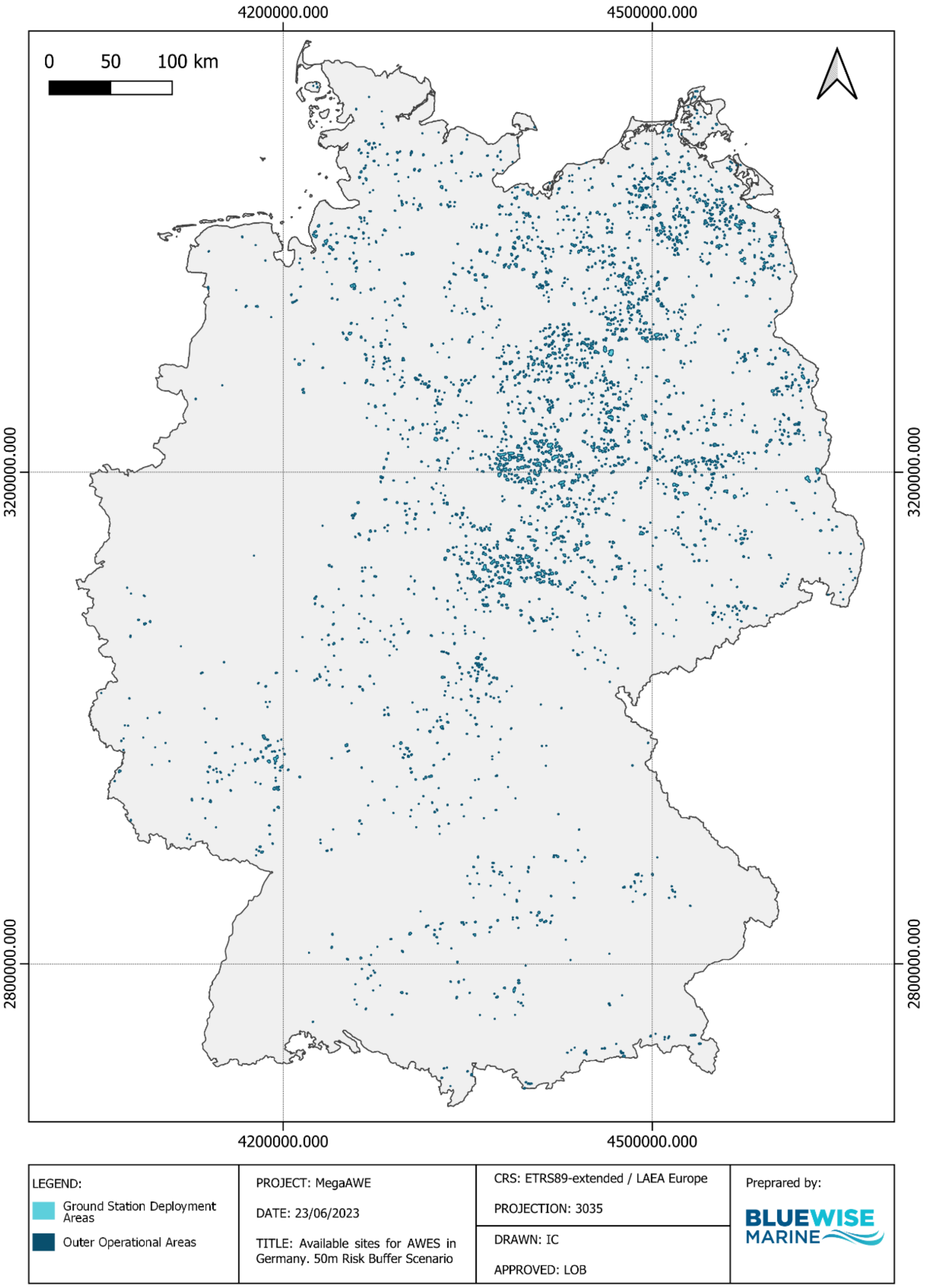
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.5. Map showing suitable sites in Germany after applying the base case scenario requirements. Zoom in to show the granularity of the identifies sites.



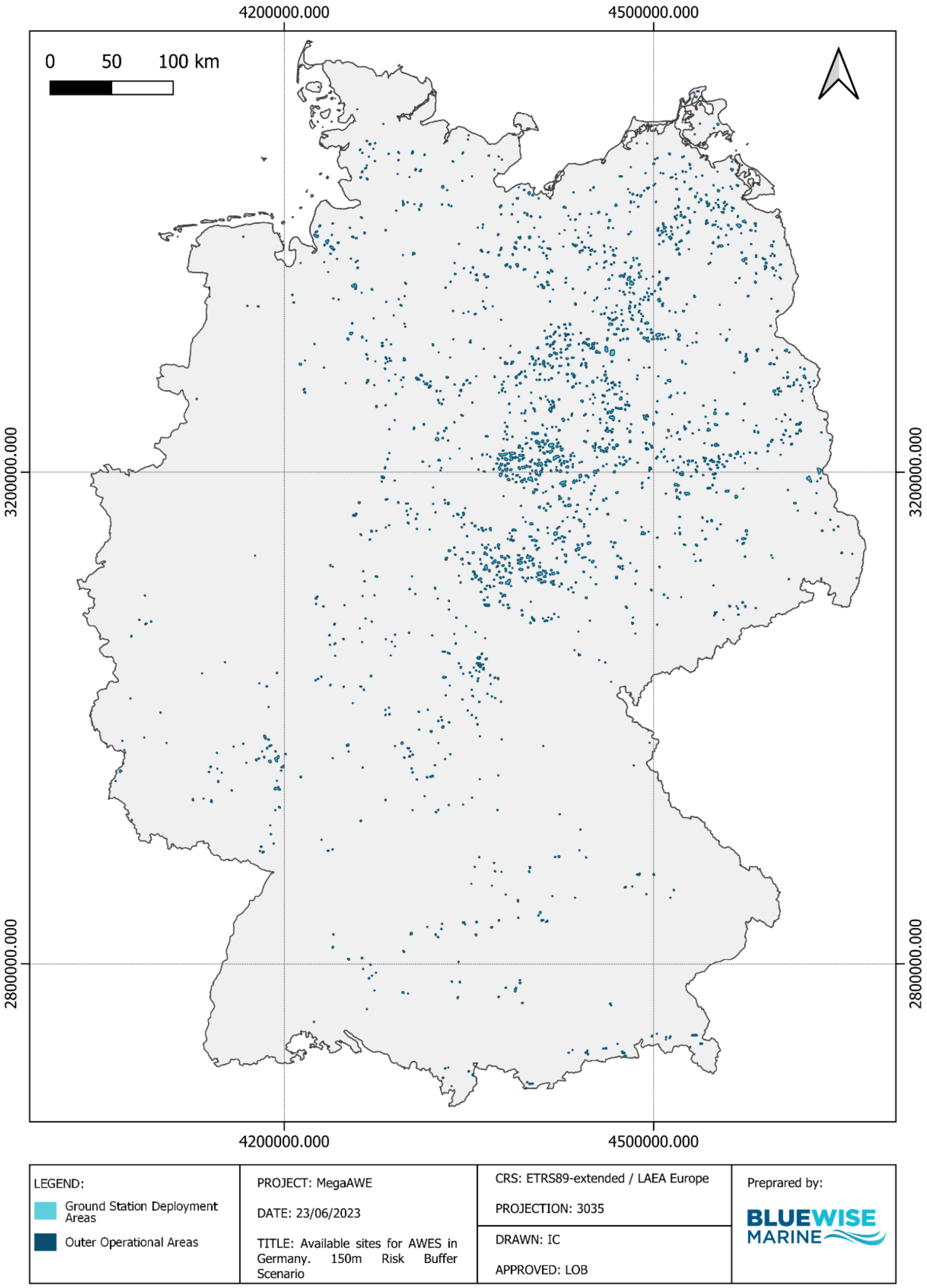
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.6. Map showing suitable sites in Germany after applying the 0m Risk Buffer scenario requirements.



Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.7. Map showing suitable sites in Germany after applying the 50m Risk Buffer scenario requirements.



LEGEND:

🟦 Ground Station Deployment Areas

🟦 Outer Operational Areas

PROJECT: MegaAWE

DATE: 23/06/2023

TITLE: Available sites for AWES in Germany. 150m Risk Buffer Scenario

CRS: ETRS89-extended / LAEA Europe

PROJECTION: 3035

DRAWN: IC

APPROVED: LOB

Preprared by:

BLUEWISE MARINE

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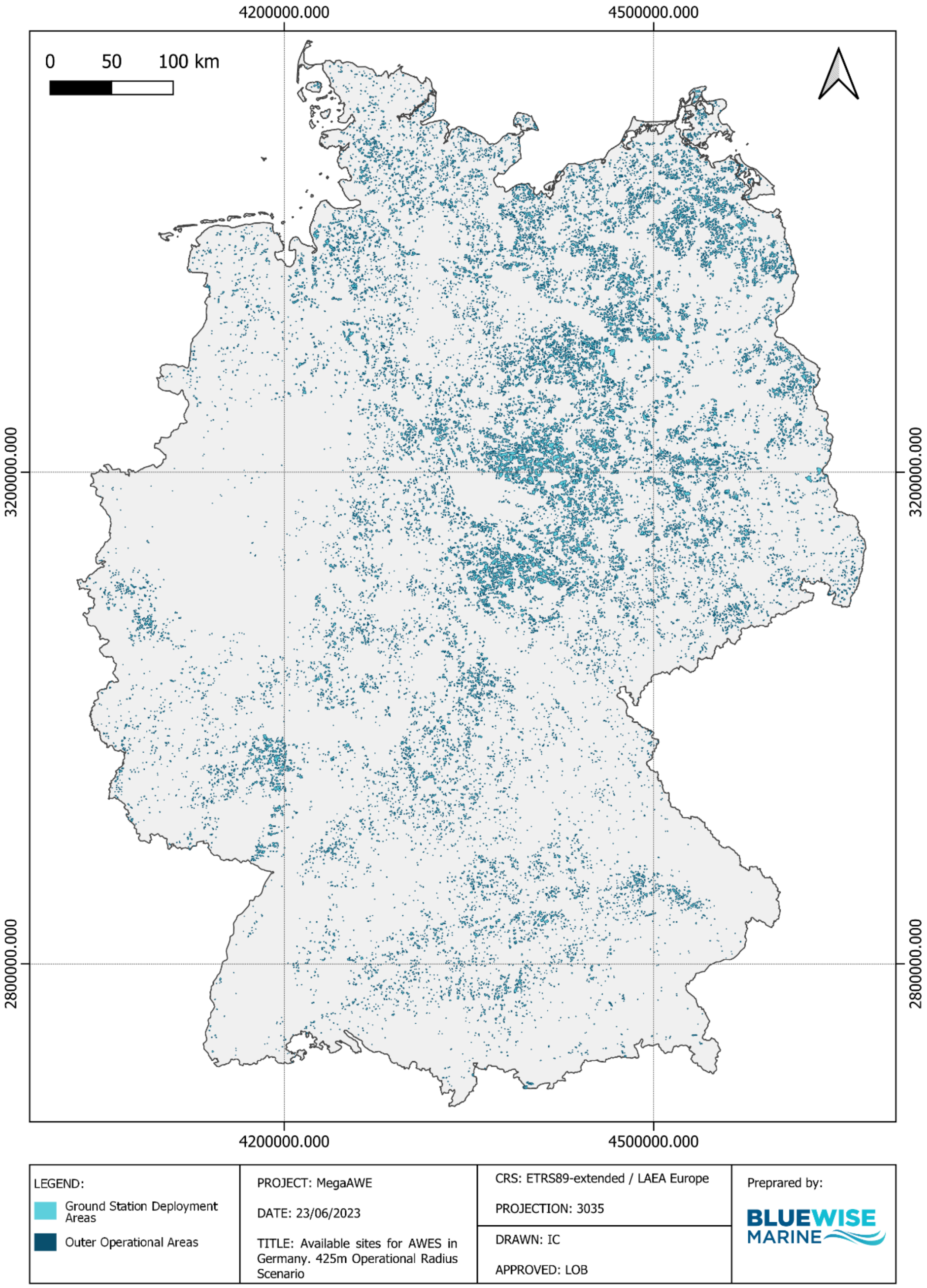
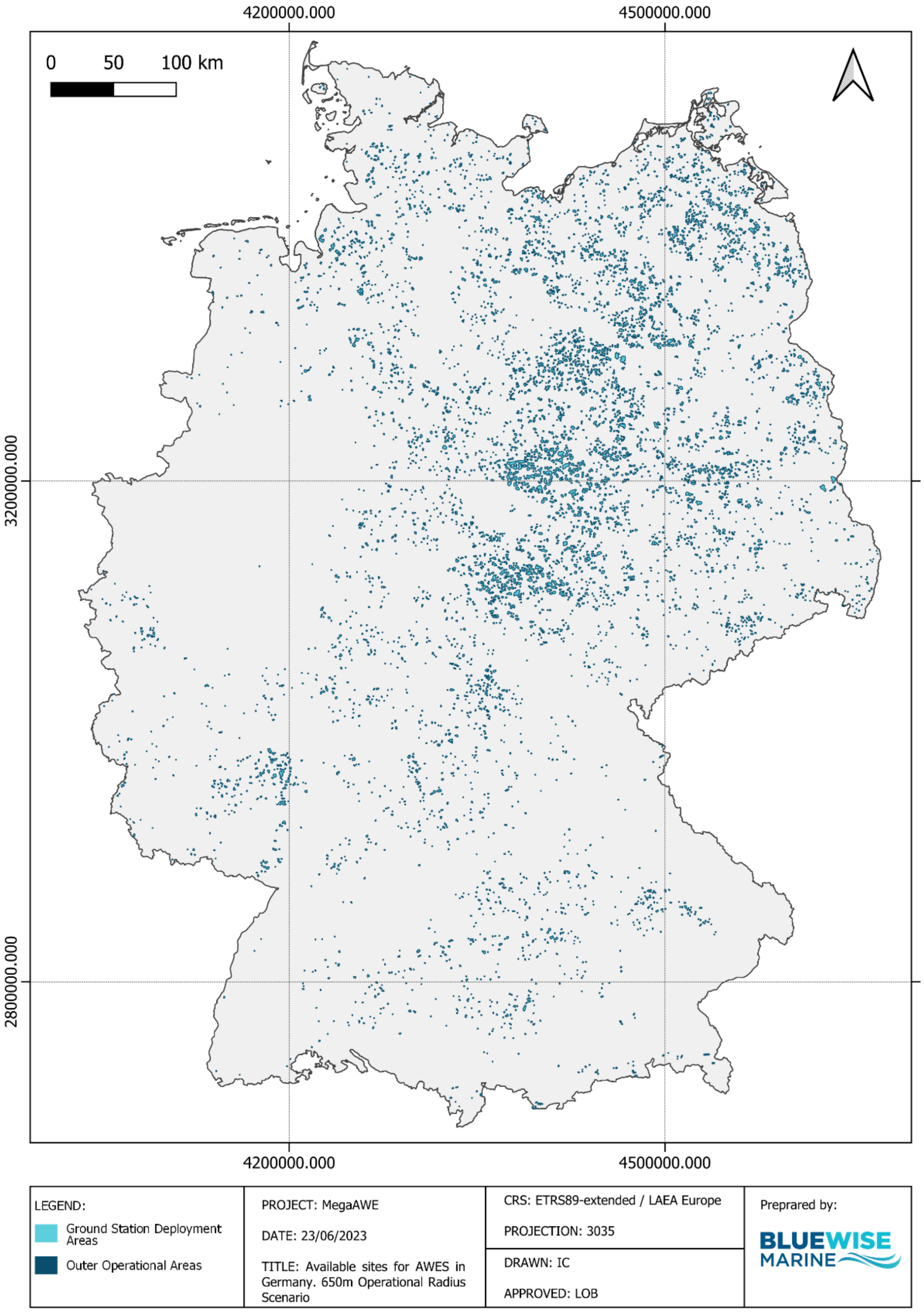
Figure 6.8. Map showing suitable sites in Germany after applying the 150m Risk Buffer scenario requirements.



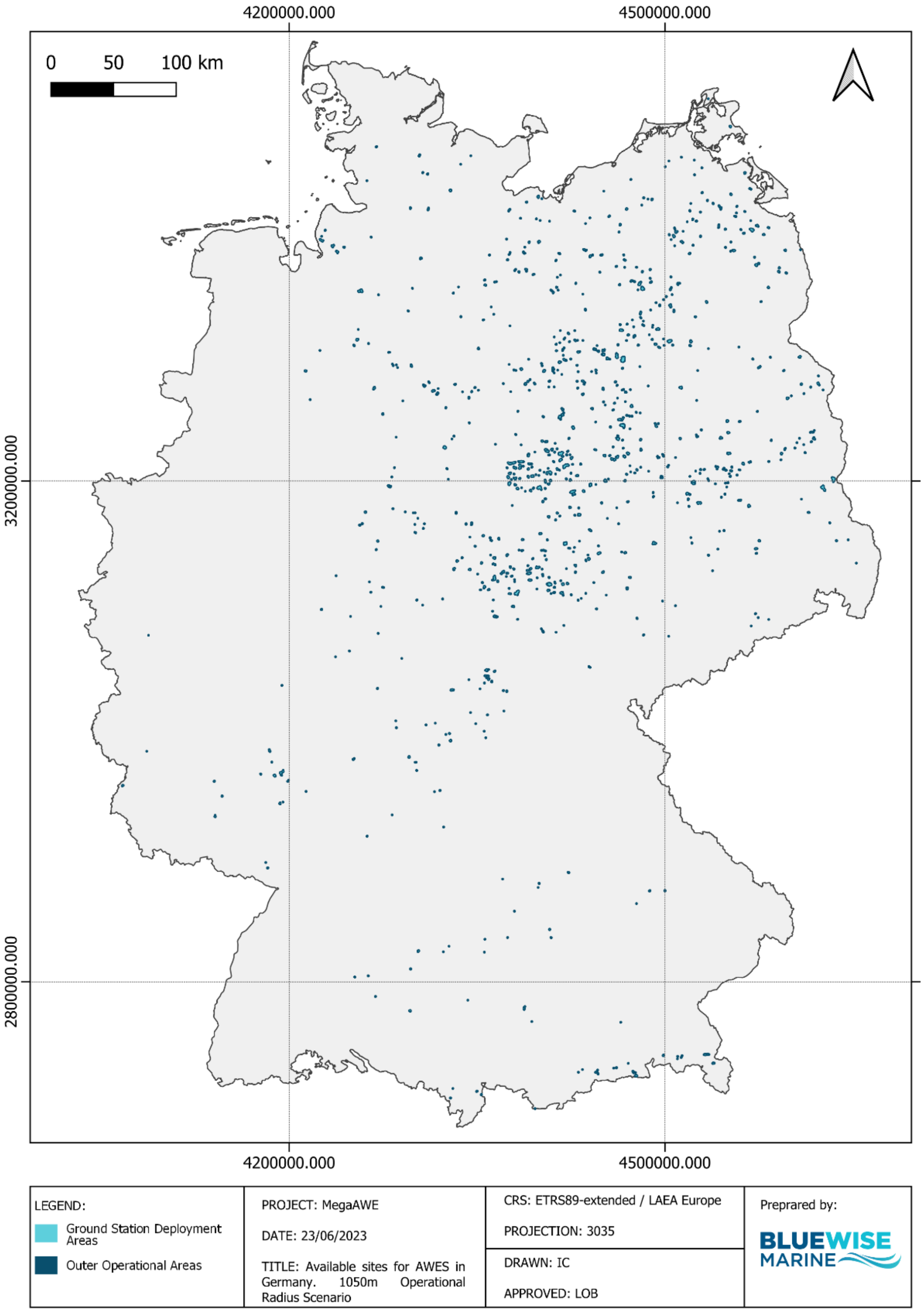
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.9. Map showing suitable sites in Germany after applying the 425m Operational Radius scenario requirements.



Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

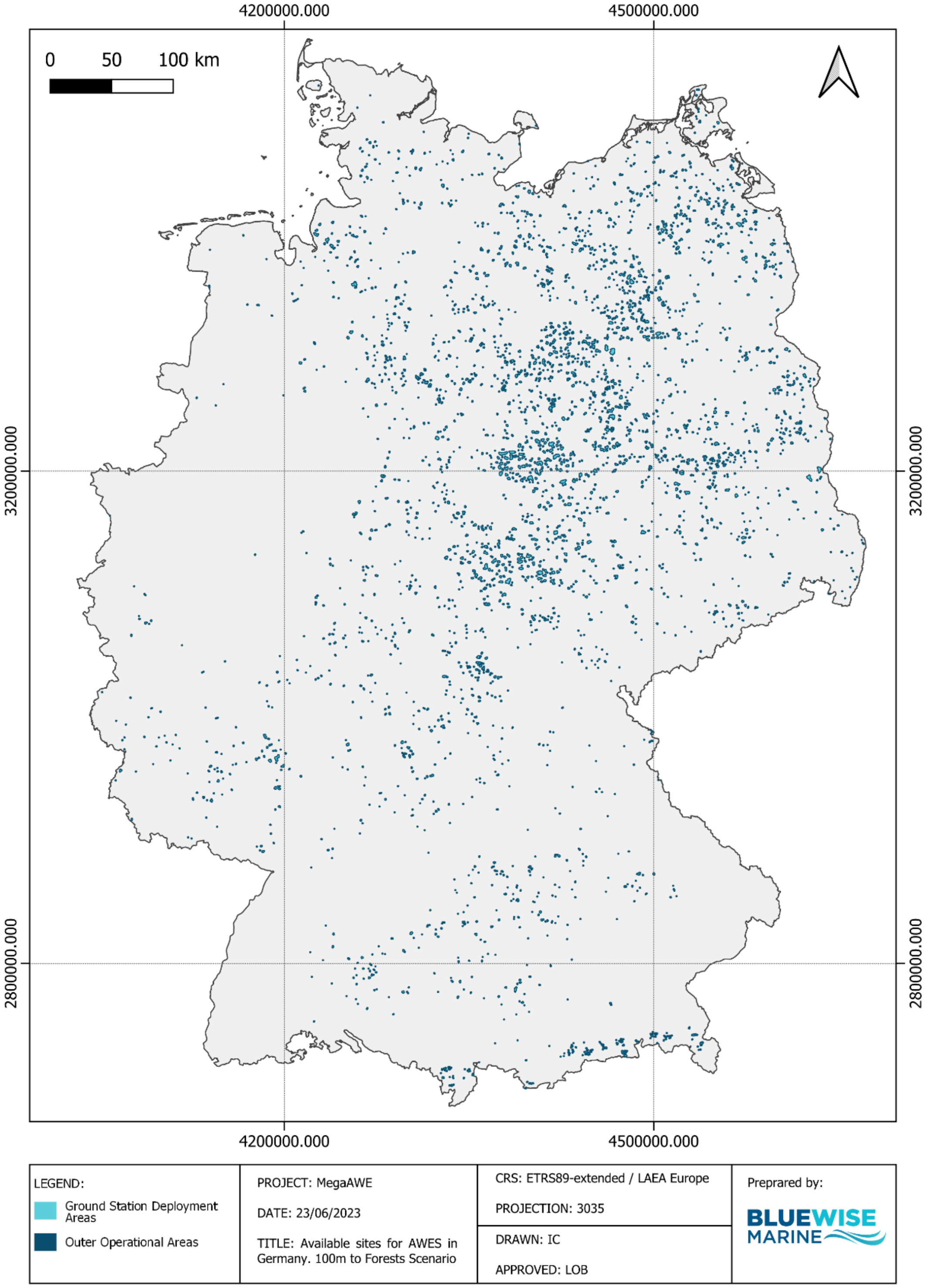
Figure 6.10. Map showing suitable sites in Germany after applying the 650m Operational Radius scenario requirements.



LEGEND: ▨ Ground Station Deployment Areas ■ Outer Operational Areas	PROJECT: MegaAWE DATE: 23/06/2023 TITLE: Available sites for AWES in Germany. 1050m Operational Radius Scenario	CRS: ETRS89-extended / LAEA Europe PROJECTION: 3035 DRAWN: IC APPROVED: LOB	Preprared by: BLUEWISE MARINE

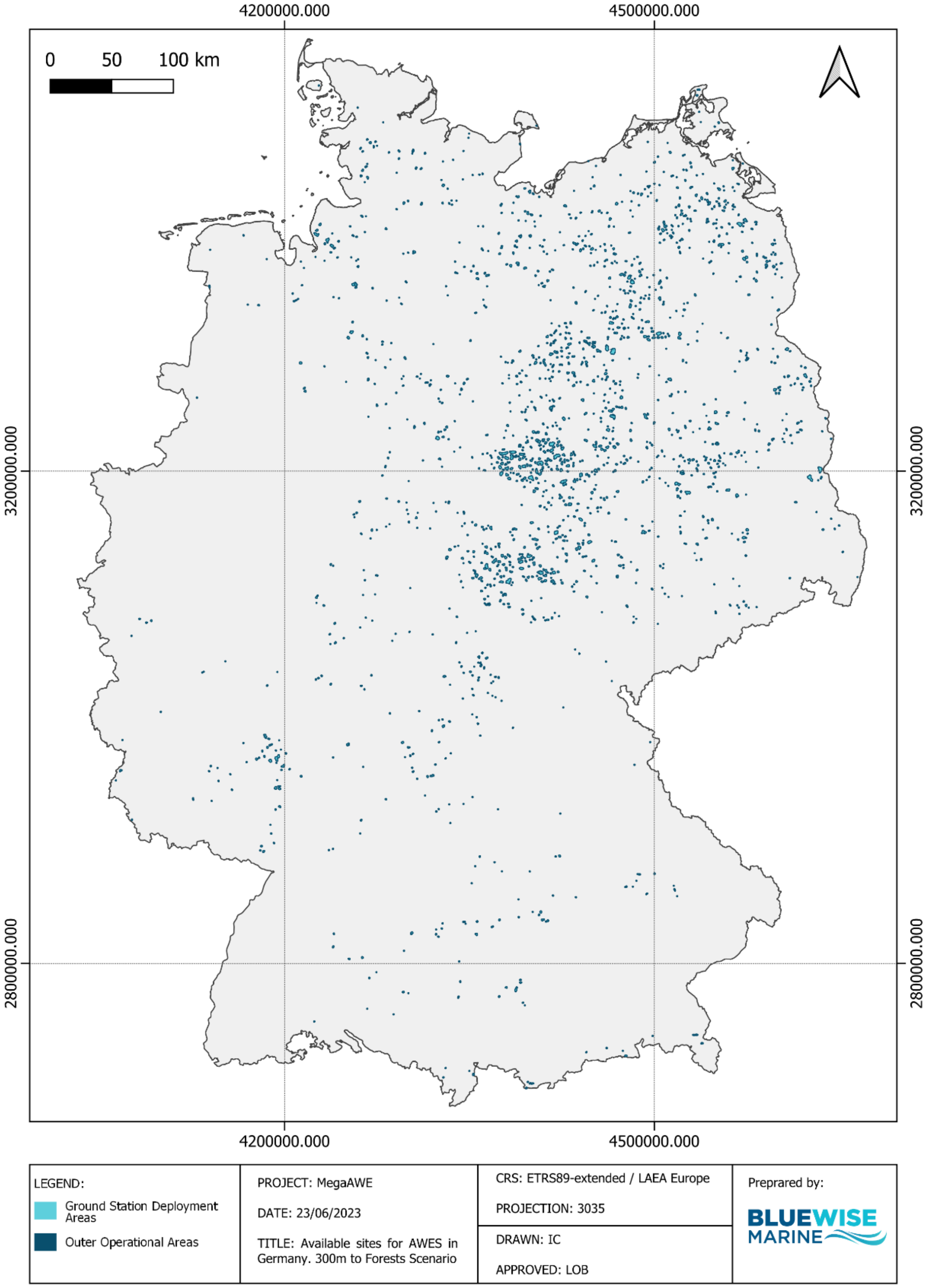
Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.11. Map showing suitable sites in Germany after applying the 1050m Operational Radius scenario requirements.



Sources Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.12. Map showing suitable sites in Germany after applying the 100m from GS to forests scenario requirements.



Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet

Figure 6.13. Map showing Suitable sites in Germany after applying the 300m from GS to forests scenario requirements.

6.2 Areas exclusive to AWE

The analysis comparing the site identification analysis with site analysis conducted for traditional wind energy, shed light on the potential complementary nature of AWE in comparison to traditional wind energy.

The results of the calculations performed on the results obtained from the site identification analysis for areas exclusive to AWE devices are presented in Table 6.2. The table presents the results of the three scenarios that were used. A graph showing the comparison between the base case Scenario and the sites identified exclusive to AWE is presented on Figure 6.14.

Table 6.2. Results of the areas exclusive to AWE systems in different scenarios.

Areas exclusive To AWE devices	Outer Operational Area (km^2)	GS Deployment Area (km^2)	N° of Sites	N° of devices	Min Capacity*	Max Capacity**	Max. Capacity/ Unit Area (MW/km^2)
Base Case	8,292	506	2,299	7,338	1,468	11,007	1.33
50m Risk Buffer	10,646	661	2,963	9,438	1,888	14,157	1.33
650m Op Radius	16,706	1,452	6,782	21,121	4,224	31,682	1.90

*Minimum capacity contemplates a capacity of 200 kW per device.
** Maximum capacity contemplates a capacity of 1.5 MW per device.

The findings indicate that approximately 90% of the operational area, number of sites available and potential capacity are exclusive to AWE technology in the three scenarios analysed.

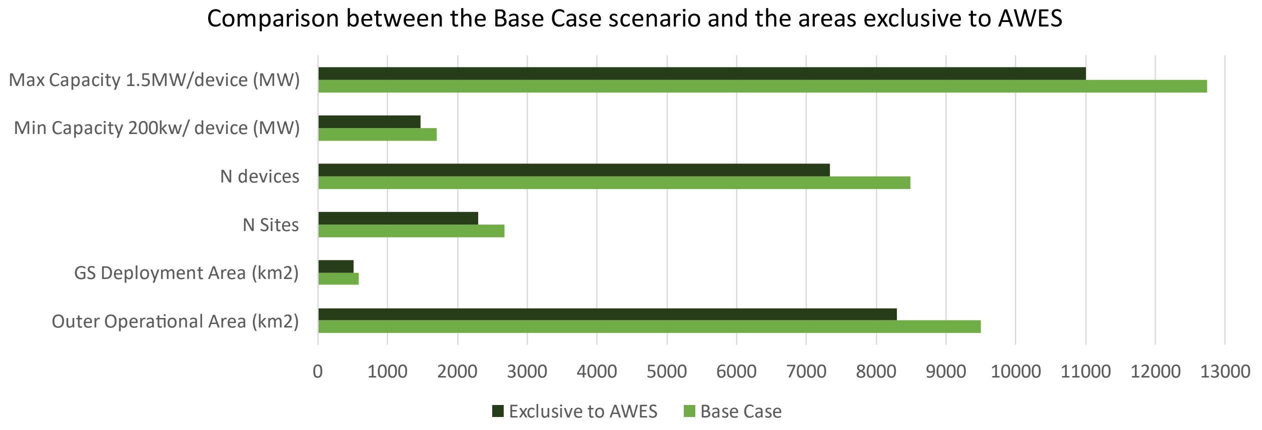


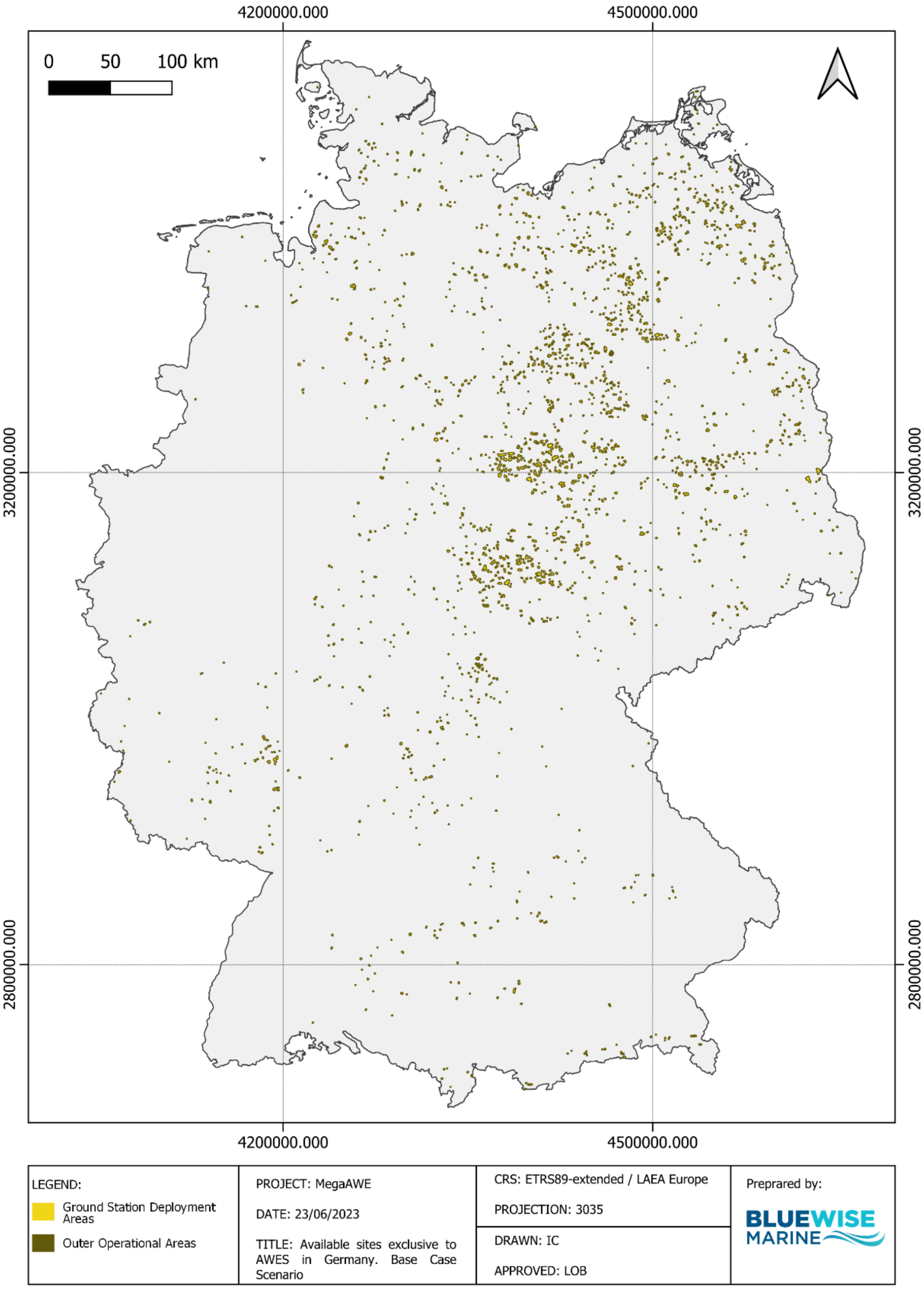
Figure 6.14. Comparison between the base case Scenario and the sites identified exclusive to AWE after combining the base case scenario results and RLI data.

The information provided here is based on available data from a site identification study on traditional wind turbines, but further research or verification for a comprehensive understanding of the reasons behind why these areas are exclusive to AWE technology is required. Some of the areas identified as exclusive to AWE were inspected and all the patches aligned with classifications found in the OSM (Open Street Map) land-use dataset, specifically labelled as "farmland," "meadow," and "scrub". It's unclear why these regions were excluded in the RLI analysis. Upon visual inspection using satellite imagery and an alternative land-use dataset, these areas appear suitable, and their methodology lacks explicit exclusion criteria for farmlands. Notably, analogous areas were deemed suitable in their analysis, prompting two potential explanations:

1. The datasets they utilized might have categorized these areas differently, leading to their exclusion.
2. They might have applied additional criteria not incorporated in our analysis, such as roads under construction or drinking water protection areas.

Therefore, any figures or details presented should be considered cautiously and used with discretion, pending additional investigation or analysis.

The maps showing the areas exclusive to AWE systems are presented below:



PROJECT: MegaAWE

DATE: 23/06/2023

TITLE: Available sites exclusive to AWES in Germany. Base Case Scenario

CRS: ETRS89-extended / LAEA Europe

PROJECTION: 3035

DRAWN: IC

APPROVED: LOB

Preprared by:

Source Data: ©GADM, ©GeoBasis-DE/BKG, ©OpenStreetMap Contributors, ©Copernicus, ©ProtectedPlanet, ©Photovoltaik- und Windflächenrechner

Figure 6.15. Map showing Suitable sites exclusive to AWE technology in Germany after applying the base case scenario requirements and comparing with RLI data.

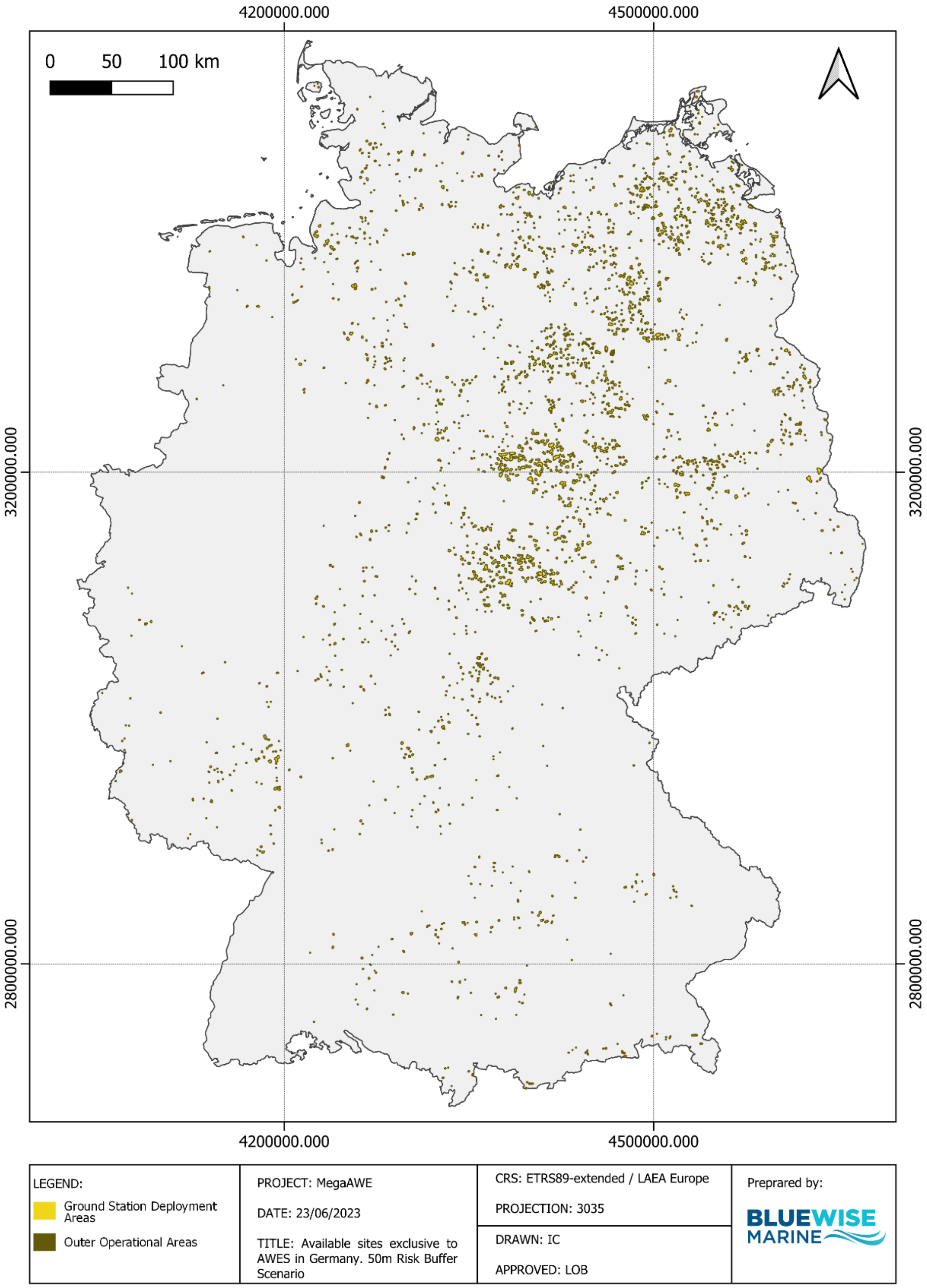


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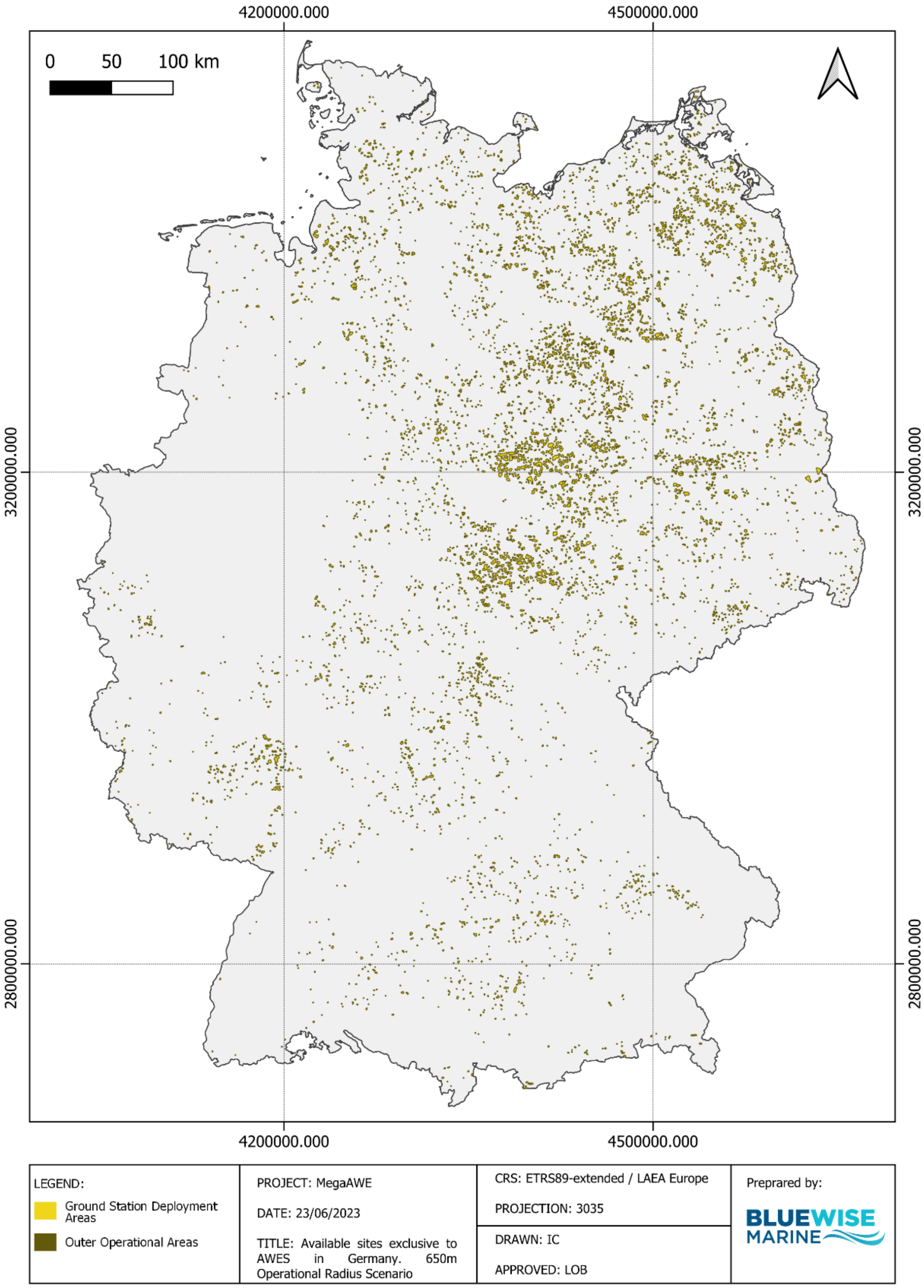
Figure 6.16. Map showing Suitable sites exclusive to AWE technology in Germany after applying the 50m Risk Buffer scenario requirements and comparing with RLI data.



LEGEND:
🟨 Ground Station Deployment Areas
🟫 Outer Operational Areas

PROJECT: MegaAWE
DATE: 23/06/2023
TITLE: Available sites exclusive to AWES in Germany. 650m Operational Radius Scenario

CRS: ETRS89-extended / LAEA Europe
PROJECTION: 3035
DRAWN: IC
APPROVED: LOB

Preprared by:

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Figure 6.17. Map showing Suitable sites exclusive to AWE technology in Germany after applying the 650m Operational Radius scenario requirements and comparing with RLI data.

7 Summary

7.1 Main insights

Learnings from the site identification and sensitivity analyses encompass a comprehensive understanding of the key factors influencing site selection, providing valuable insights and crucial information that inform decision-making processes. The key factors identified in this study are:

- **Data availability**: One significant learning from the site identification analysis was the challenge of obtaining up-to-date data with the appropriate resolution or level of detail for certain criteria. This limitation in data availability can affect the accuracy and reliability of the analysis results, so it is important to be aware of the input data utilized to carry out the analysis. Moreover, it was observed that the resolution of the input data had a substantial impact on the results of the analysis. The analysis highlighted the importance of using data with a sufficiently high resolution to capture the nuances and intricacies of the study area accurately. Inadequate resolution could lead to oversimplification or generalization of the data, potentially resulting in misleading or inaccurate conclusions regarding the suitability of ground station deployment. The level of detail in the input data needs to be assessed for each project, depending on the extension studied and the objectives set.

- **Complementarity of AWE:** The site identification analysis also shed light on the potential complementary nature of AWE in comparison to traditional wind energy. The findings indicate that AWE, which utilizes higher-altitude wind resources, can serve as a valuable addition to conventional wind energy sources. The analysis suggests that AWE can contribute to the overall energy generation and diversification of renewable energy portfolios. However, further research or verification for a comprehensive understanding of the reasons behind why there are areas are exclusive to AWE technology is required.

- **Definition of parameters:** The sensitivity analysis emphasized the crucial role played by the careful definition and selection of requirements. The analysis revealed that the specific requirements chosen impact significantly the outcomes and conclusions of the assessment. It is important to define the criteria and requirements accurately, considering their relevance and weighting appropriately. The thoughtful selection of criteria and requirements ensures that the site identification analysis provides reliable and meaningful insights for decision-making.

- **Impact of operational radius:** Among the parameters examined, the sensitivity analysis identified the operational radius as having the most substantial effect on the results. The operational radius is directly correlated to the tether length used by AWE developers. Adjusting the operational radius can lead to notable variations in the outcomes of the analysis, highlighting the need for careful consideration and optimization of this parameter to ensure accurate and effective decision-making regarding GS deployment. It is important for developers to find the right balance between their technology's ideal operational requirements for exploiting high-altitude wind and the availability of suitable sites. They will need to carefully study and assess the trade-offs associated with different operational radius to optimize the deployment potential while considering factors such as wind resource availability, airspace constraints, and technological limitations. Striking the right balance ensures that AWE technology can effectively harness high-altitude wind resources while maximizing the number of viable deployment sites.

- **Value of site identification analysis:** Site identification analysis focuses on understanding the fundamental characteristics of feasible locations, providing a broad overview of factors like geographical features, potential capacity, and regulatory aspects. It helps identify regions with the highest energy generation capacity, minimizing risks and maximizing the feasibility and economic viability of AWE technologies and its purpose is to lay a foundation for decision-making by offering preliminary insights. It is important not to mistake the results as a site *selection* exercise, which would involve a more precise evaluation of the sites.

7.2 Recommendations

After conducting in-depth site identification and sensitivity analyses, along with extracting key insights from the process and results, the subsequent recommendations have been developed to provide guidance for future analysis and site identification projects. These recommendations aim to serve as a roadmap, offering valuable direction and insights for undertaking similar initiatives in the future.

1. It is highly recommended to **expand these studies to other European countries** due to their significant value in providing valuable insights and informing decision-making processes. By conducting these studies in additional countries, a broader perspective can be gained, allowing for a better understanding of the factors influencing site selection across different regions. Moreover, this expansion would enable organisations to identify trends, similarities, and differences in site suitability, considering diverse geographical, economic, and regulatory contexts. Ultimately, such comprehensive studies across multiple countries can help optimize resource allocation, minimize risks, and maximize the potential for successful deployments. Additionally, understanding the capacity of AWEs at a European level will facilitate assessing feasibility and economic viability. It will help comparing energy generation capabilities with existing sources and guide decision-making. Governments, regulators, and stakeholders can set goals and policies based on this information. Identifying high-capacity areas can enable focused efforts for maximum energy generation potential.

2. **Inclusion of additional layers that are not currently considered in the analysis** is highly recommended. Data gaps related to airspace restricted areas and grid availability should be addressed to understand potential limitations and opportunities regarding the deployment

of the studied technology. Exploring colocation possibilities with PV plants as suitable locations can provide valuable synergies and optimize resource utilization. Additionally, incorporating data on population density will allow for a more comprehensive understanding of the potential impact and feasibility of the technology in densely populated areas. These additional layers will enhance the accuracy and completeness of the analysis, offering more nuanced insights and enabling better-informed decisions.

3. **Future studies should adopt a more flexible approach that considers varying developer requirements.** Each developer or organization may have unique preferences, priorities, or constraints that influence site selection. Therefore, it is recommended to develop a framework that allows for customization and adaptation to individual developer needs. Moreover, incorporating a comprehensive wind profile analysis is crucial to improve the accuracy and applicability of the results. By considering detailed wind profiles, including factors such as wind direction, speed, and turbulence, the analysis can provide more precise estimations of energy generation potential. This information is vital for optimizing the layout and positioning of the technology, leading to more effective and efficient deployments.

4. To calculate the total ground station (GS) deployment potential accurately, it is advised to **develop and apply a more complex and adequate layout algorithm** that accounts for the intricate shapes and characteristics of the available areas. The current analysis might oversimplify the deployment potential by not considering the complexities and constraints of the site geometry. By utilizing a more sophisticated algorithm, the analysis can provide a more realistic estimation of the GS deployment potential, taking into account factors such as land shape, topography, and other site-specific considerations. This will ensure that the results are more reliable and representative of the actual possibilities for deployment, enabling better planning and decision-making.

5. The evolution of AWE technology holds the potential for flying over specific roads or other infrastructure, potentially expanding capacity. However, this advancement may require increased risk buffers. Therefore, **conducting periodic studies** every few years becomes essential to adapt to technological advancements and regulatory changes, ensuring safe and effective integration within evolving landscapes of regulations and technology.