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Pan-European Catalogue of Key Parameters for Offshore Wind Farm Siting – v2

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It is important to note that the information provided in this report, the Geo-Assessment Matrix and the derived map-based products, are based on preliminary data. They are intended for regional-scale information and screening purposes only. The report, Matrix and map-based products associated with this study are not a substitute for a comprehensive site investigations. Site conditions and technology also change over time because of natural or human activities. Therefore, updates and revisions are required to reflect the latest site conditions and data available.

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Executive Summary

The European Commission is committed to transforming Europe into a clean, resource-efficient and competitive economy, with the European Green Deal designed to make Europe the first climate-neutral continent in the world (European Green Deal – European Commission). Offshore renewable energy is a major source of green energy significantly contributing to the EU's 2050 Energy Strategy.

The foundation design of Wind Turbine Generators (WTGs) is impacted by a range of geological and geomorphological constraints at and near the seabed. The offshore geological landscape is highly variable, shaped by both modern and ancient sedimentary, igneous and metamorphic processes. This results in complex lateral and vertical variability of seabed and shallow subsurface conditions, directly influencing the siting and feasibility of Offshore Wind Farm (OWF) developments, and associated infrastructure. The design, development and installation of foundations, including piles, cables, suction caissons and Gravity-Based Structures (GBS), requires a robust understanding of the geological ground conditions. Integrating geological knowledge with geotechnical and engineering principles is essential to reduce risk (technical and financial) and optimise the design and geospatial layout of WTGs. There is currently no universally adopted methodology or classification system to assess ground conditions at OWF sites. This lack of standardisation makes it difficult to compare siting conditions across different regions in Europe. In this report, we introduce a unified methodology designed to address these challenges.

This report presents the pan-European catalogue of key parameters for offshore windfarm siting, termed the 'Geo-Assessment Matrix' (or herein as 'the Matrix'), including the methodology behind the development of the Matrix, which describes geo-engineering implications for OWF development and associated infrastructure. The Matrix bridges the gap between geology and engineering by highlighting key geological features and constraints, such as lithology, morphology and geomorphology, associated with different geological settings and provides a suite of possible associated engineering implications. Designed as a screening tool for flexibility and scalability, it can be adapted to both broad and fine-scale geological features, making it a valuable tool throughout the Geological Service for Europe (GSEU) and other OWF projects. It uses a three-tiered scoring system to classify relative geological constraints: Higher, Moderate, and Lower constraint, based on the suitability of features for offshore infrastructure.

Designed as a screening tool for flexibility and scalability, the Matrix represents a valuable tool for a wide range of stakeholders, including the European Commission, the future Geological Service for Europe, national governments and for commercial OWF projects. The regional outputs from the Matrix can help to inform early decision-making and spatial planning by highlighting areas of relative geological constraints in countries during the early stages of development. Finally, it enables the re-attribution of existing datasets with examples from the European Marine Observation and Data network (EMODnet), the Norwegian offshore mapping programme (MAREANO) and the Irish Shelf Seabed Geomorphological Map (ISSGM). Basin-scale case study examples of data attribution are presented within.

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Abbreviations	
CBRA	Cable Risk Assessment
CCRS	Combined Common Risk Segment Map
D5.4	Deliverable 5.4 (this report and the Geo-Assessment Matrix)
EC	European Commission
EEA	European Economic Area
EGDI	European Geological Data Infrastructure
EU	European Union
EMODnet	European Marine Observation and Data network
GBS	Gravity-based Structures
GGM	Geological Ground Model
GSEU	Geological Service for Europe
GSO	Geological Survey Organisation
H2020	Horizon 2020
IGM	Integrated Ground Model
ISSGM	Irish Shelf Seabed Geomorphological Map
LGM	Last Glacial Maximum
MAREANO	Norway's Offshore Mapping Programme
NGDC	National Geoscience Data Centre
OM	Organic Matter
OWF	Offshore Wind Farm
SPIAM	Poland Spatial Information System of the Maritime Administration
TV	Tunnel Valley
WP	Work Package
WTG	Wind Turbine Generator

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1. Introduction

1.1. Background

Ambitious European energy and climate targets require an increase in wind capacity of at least 60 GW by 2030 (42.5% of renewable energy sources in the EU's energy mix), and 300 GW by 2050 (Renewable energy targets, 2023). As governments develop their road maps for renewable energy from offshore wind around the UK, continental Europe and neighbouring regions, countries are seeing a major expansion in the number of offshore wind farm licenses granted. In preliminary studies, Geological Survey Organisations (GSOs) are often the first port of call regarding external queries for information on the availability of baseline data in the form of geological maps, and some GSOs provide geological expertise to characterise the subsurface (Finlayson et al., 2025). The design and marine spatial planning of foundations for offshore wind turbines require detailed analysis of the seabed and up to 100 m of sediment or rock below the seabed surface (Velenturf et al., 2021; Petrie et al., 2022, Gourvenec, 2024; Lipp et al., 2025). Prior to detailed site characterisation, marine spatial planners, governmental agencies and OWF developers require baseline geological knowledge to understand the seabed and subsurface complexity.

This presents an opportunity to establish and promote standardised practices for assessing geological suitability at a pan-European scale. At present, the assessment of ground conditions between OWF sites vary significantly, with no consistent methodology or classification system. This lack of harmonisation limits the ability to compare geological ground conditions across regions. This report introduces a unified methodology, designed to enable consistent, cross-border geological assessments that can inform strategic decision-making throughout the accelerated development of offshore wind infrastructure.

As part of the Geological Service for Europe (GSEU) project, GSOs share their expertise as part of the group "Coastal Vulnerability Assessment and Optimised Offshore Wind Farm Siting". Twenty-two countries are participating in in the OWF sub-group (Appendix IV), with each country at a different stage of offshore wind farm development, from the preparation of regional desk studies to the establishment of protocols or development of procedures for various stakeholders (Van Heteren et al. 2024). This group aims to allow nations to effectively communicate scientific concepts using standardised geological nomenclature, presenting an opportunity of knowledge sharing between GSOs by integrating datasets and establishing scientific baselines intended to support informed decisions.

1.2. Outputs

This report presents the development methodology of the 'Geo-Assessment Matrix' (Appendix I), or referred to as 'the Matrix', also downloadable on the European Geological Data Infrastructure (EDGI) platform and BGS' National Geoscience Data Centre (NGDC) – Dakin (2025). Examples of reattributed maps derived from the Matrix are presented in Section 2, and form the basis of the first example of pan-European products specific to offshore wind farm siting. Appendix II provides a glossary of terms used within the Geo-Assessment Matrix.

A web-based user interface is in development to enhance the accessibility and clarity of the Geo-Assessment Matrix, providing users with a concise summary of key subsurface geological and engineering information. This will provide an interactive, user-friendly interface for exploring the Matrix data (Figure 1-1 and Figure 1-2). The initial prototype was created in Figma to visualise the concept and user interface design (Figure 1-1), followed by a more functional Streamlit application once the final dataset became available (Figure 1-2). The application enables users to select and compare two geological features side-by-side, examining their characteristics, constraints, and foundation assessment criteria in an intuitive format. This is due to be available via the EGDI platform ahead of the final phase of the current GSEU programme, scheduled for completion in 2027.

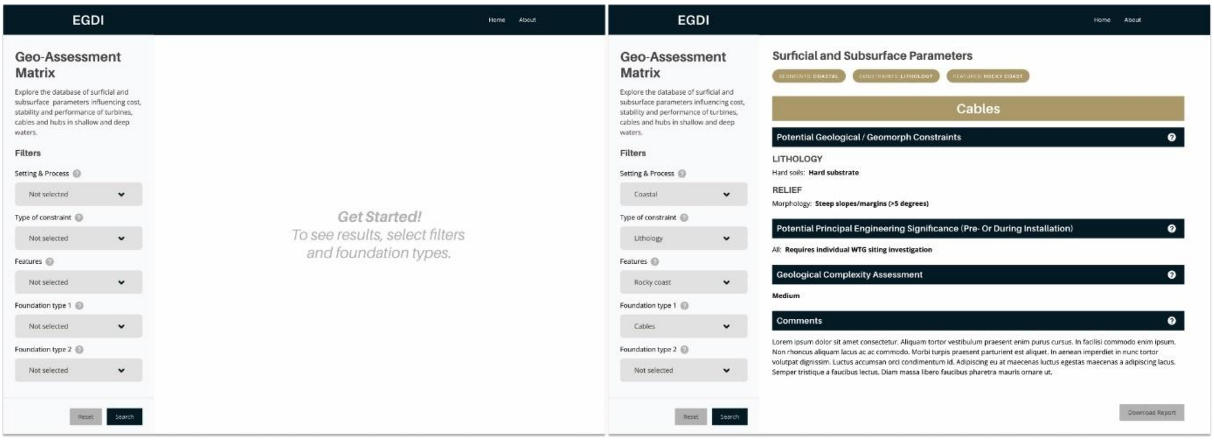

Figure 1-1. Prototype developed testing the usability of the Geo-Assessment Matrix (Figma)

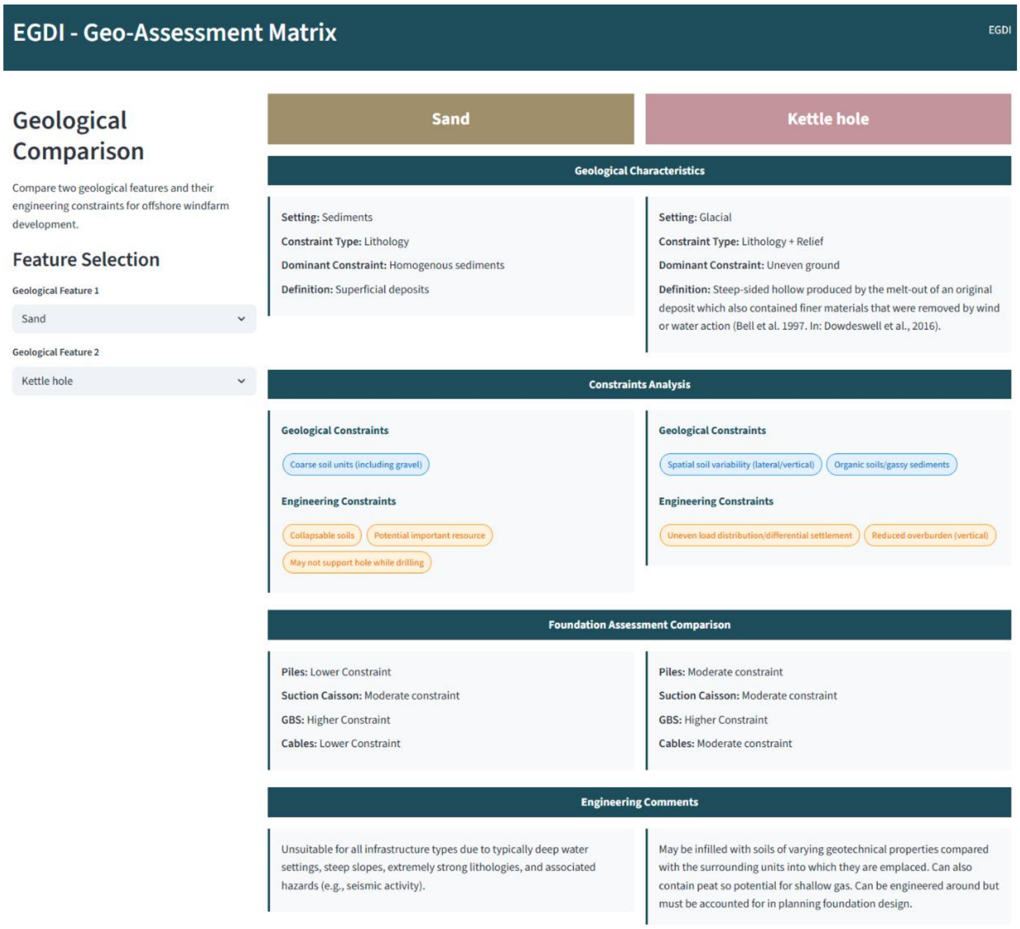

Figure 1-2. Example of data from the Geo-Assessment Matrix integrated into a web-based application under development using Streamlit.

Typical considerations for all foundations include water depth, soil conditions (seabed and subsurface geology), susceptibility to seafloor mobility and the uniformity of design versus optimisation of foundations for each location (Cook et al., 2022, Finlayson et al., 2025). The Geo-Assessment Matrix assesses the suitability of these geological features for the following fixed foundation types: piles (drilled/grouted), gravity-based structures (GBS), suction caisson and associated infrastructure (export and inter-array cables) - Figure 1-3. The subsurface depth of interest varies from:

- Shallow sub-seafloor (0-5 m) for inter-array and export cables
- Intermediate sub-seafloor (5-10 m) for anchoring and small structure foundations
- Deeper subsurface (10-100 m) for large structures, e.g., piled foundations (Cook et al., 2022).

By creating output that can be understood by different disciplines (e.g., geology, geotechnical engineering, policy), incorporation of geological data and expertise in the decision-making process related to offshore wind is made easier and more intuitive. Examples of the derived maps, generated using the constraint outputs from the Matrix in Section 2.2.5 and 2.2.6, are provided to support initial desktop studies and allow end-users, such as governmental and industry stakeholders, scientists and marine spatial planners. These map examples enable screening which geological data and existing interpretations are available, and where relevant data and interpretations are missing.

1.3. Wind Turbine Foundations and Cables

1.3.1. Fixed foundations

Monopiles currently support ~80% of offshore wind turbines being installed, largely due to their ease of manufacture and compatibility with North and Baltic Sea geology, despite requiring more steel (Figure 1-3). They are cost-effective in water depths up to ~60 m, with new designs potentially extending this range. Jackets, accounting for ~15% of foundations, become more competitive from around 40 m depth. They are lighter for large turbines and better suited to varied seabed conditions. Gravity Base Structures (GBS) are rarely used and are typically limited to shallow, nearshore environments. Suction caisson foundations are gaining traction, especially beneath jackets. While limited to Moderate sands or clays, they offer faster and potentially cheaper installation where conditions are suitable (BVG Associates, 2025).

1.3.2. Floating foundations

Floating wind turbines are an emerging technology that offer an alternative to the fixed foundations in deeper water depths (BVG Associates, 2023). As technology progress, the design of floating turbines is evolving rapidly. Unlike fixed foundations, floating systems are more sensitive to conditions within the upper 10 m the seabed (Figure 1-3). As the anchor design of floating wind turbines are rapidly evolving technology, they have not been incorporated into the Geo-Assessment Matrix, however they are being addressed by assessing the water depth and cost implications. These maps will be available on the EGDI platform ahead of the final phase of the current GSEU programme (scheduled for completion in 2027). Notably, there are some existing crossovers between anchor design and fixed foundations. For example, anchor piles share similar geological constraints to piles in general, although the depth of interest is shallower in comparison to monopiles.

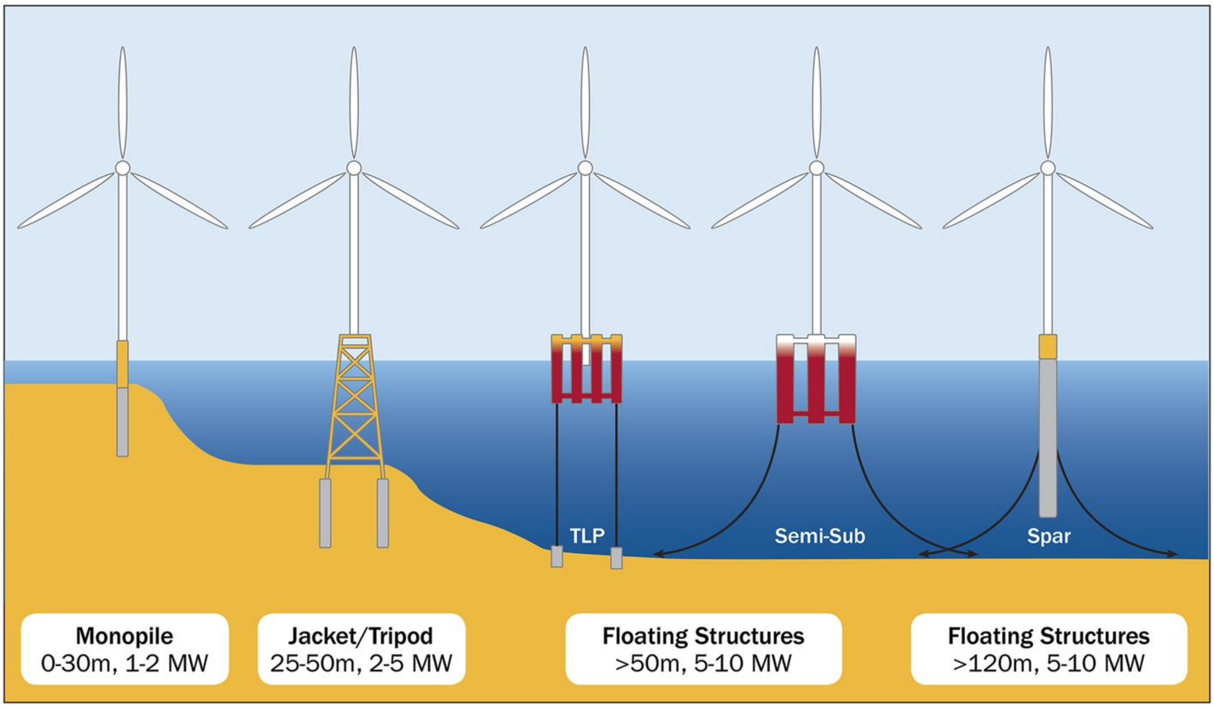

Figure 1-3. Basic wind turbine foundation types, including fixed and floating foundations. Monopile and tripod/jacket foundations are proven technologies. Floating structures have been using three main types of foundations, which are adapted from the oil and gas industry: the Tension Leg Platform (TLP), semi-submersible (Semi-sub), and Spar Buoy (Spar). Figure from © 2014 Bailey et al. (reproduced under the CC BY 4.0 licence).

2. Geo-Assessment Matrix: Methods of Development

This section outlines the step-by-step methodology used to develop the Geo-Assessment Matrix. The process was designed to ensure a robust, transparent and repeatable framework for assessing geological constraints relevant to offshore wind development.

2.1. Geological Constraints per Country

Participating countries were asked to provide the primary geological constraints affecting offshore wind development and associated infrastructure. The results, summarised in **Table 2-1** highlight two dominant characteristics: previously glaciated terrains (e.g., in Poland, Denmark, UK, Finland, Norway, Ireland) and deep-water conditions (e.g., Malta, Croatia, Spain, Norway, Greece, Ireland). Although this was a small-scale study, the findings provide a valuable foundation for identifying key geological features that are now incorporated into the Matrix.

Table 2-1 . Results of self-reported key constraints of participating countries in the GSEU Group

	Cables		Fixed turbines												Floating wind farm experience	
	Constraint		Geohazards			Geological constraints										
	Peat/organic rich	Scour	Shallow gas (thermogenic/OM)	Volcanism	Active faulting	Glacial (boulders/TV/sediments	Packed ice on the seabed	Carbonate domain	Deep water (>200 m)	Shallow water (15-20 m)	Shallow bedrock	Mobile seabed	Geomorphology of coastline	Unknown – lack of data	Experience	Planning
Malta								x	x						N	Y
Croatia									x				x		N	
Spain (inc. Canary Islands)	x			x					x						N	Y
Poland			x			x									N	
Denmark	x	x				x									N	
Italy															N	
Finland						x	x								N	
Norway						x			x						N	
Slovenia	x										x				N	
UK						x					x				N	Y
Greece					x				x	x					N	Y
Ireland						x			x			x			N	
Iceland				x										x	N	?
Netherlands	x	x	x			x				x		x	x		N	N

2.2. Application and Structure of Geo-Assessment Matrix

The Geo-Assessment Matrix is a pan-European data inventory of key parameters, relevant to offshore wind farm siting for countries across the EEA, Southeastern Europe and the UK. The aim of the Geo-Assessment Matrix is to bridge the gap between geology and engineering. It lists geological features, assessing their geological impact and associated engineering impact resulting in an ultimate qualitative ‘geological constraint score’, which can be more readily understood by non-specialist decision makers than traditionally used classes of geological attributes. Based on this geological constraint score, examples of several new thematic derivative maps are presented.

Development of the Geo-Assessment Matrix is the result of a four-step process from collation of geological features to the reattribution to a final relative geological constraint term (Higher, Moderate and Lower constraint). Each step builds upon the previous one, guiding the transformation of diverse geological data into a harmonised, pan-European assessment tool. The methodology reflects collaborative input from participating countries and integrates expert knowledge to support informed decision-making in offshore wind planning.

Steps 1 to 4 (Figure 2-1) are presented from sections 2.2.1 in this report, explaining the rationale behind each step. To showcase how the Geo-Assessment Matrix can be used, we employ examples of open-source datasets to create pan-European maps that show the spatial distribution of typical constraints prior to mitigation techniques, in the form of multivariate Hex-maps. Hex maps offer several benefits to the end-user, allowing for visual clarity that enhances the readability of complex multivariate datasets and can highlight spatial patterns and relationships in the data. The reattribution of these existing datasets and production of hex-maps (Steps 5 and 6 as presented in Sections 2.2.5 and 2.2.6) are additional products to the Matrix. These were created from existing harmonised and open-source datasets including the European Marine Observation and Data network (EMODnet Geology), Norway’s offshore mapping programme (MAREANO) and the Irish Shelf Seabed Geomorphology Map (ISSGM).

The six-step methodology shows how geology can be visualised in terms of engineering implications is outlined briefly below, fully discussed from 2.2.1:

- **Step 1**: Data inventory of geological features
- **Step 2**: Production of Geology matrix
- **Step 3**: Production of associated Engineering matrix
- **Step 4**: Reattribution between geology and engineering constraints to formulate a relative ‘geological constraint assessment’ grading (i.e., Higher, Moderate or Lower constraint)
- **Step 5**: Translation and reattribution of existing datasets
- **Step 6**: Creation of regional screening hex-maps.

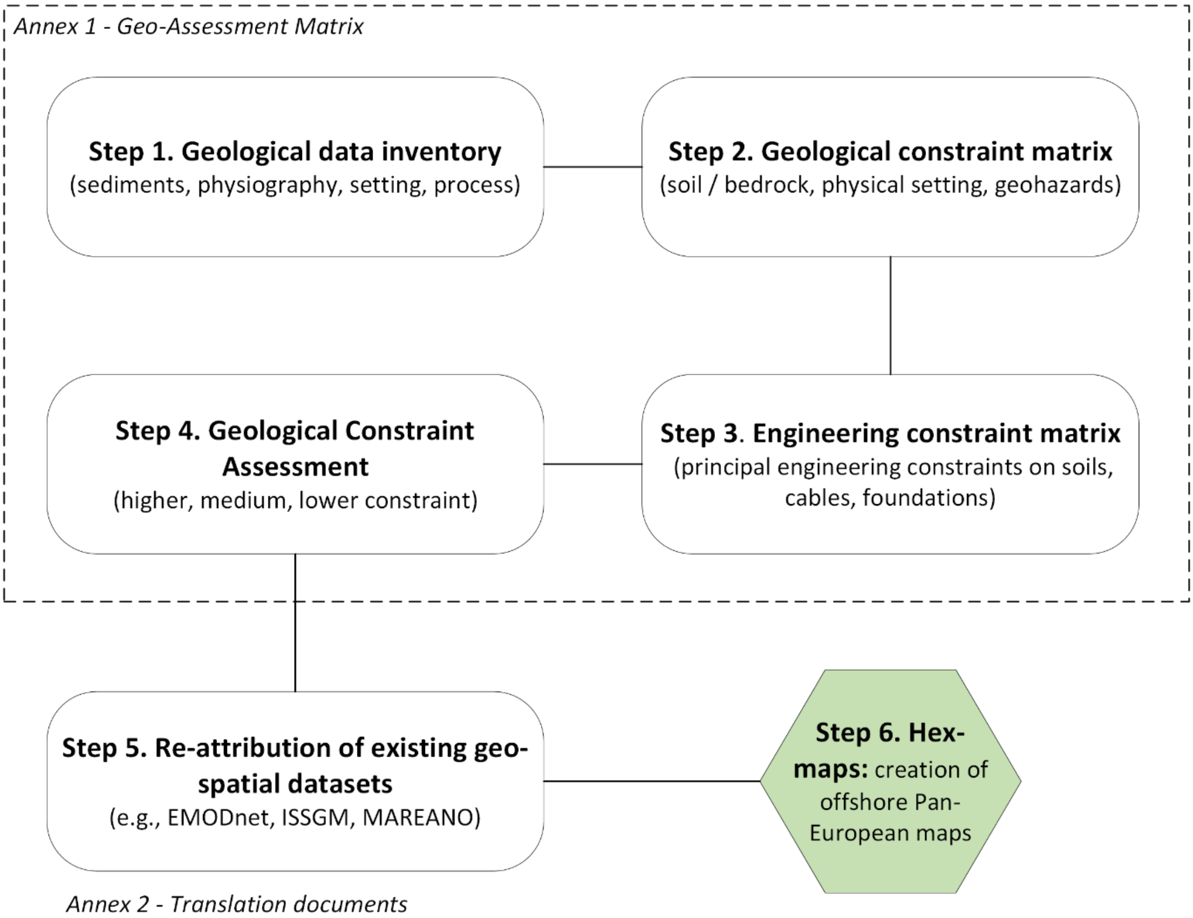

Figure 2-1. Overview of Geo-Assessment Matrix structure from Step 1 to Step 6, from the Geological data inventory to the Geological and Engineering matrices and re-attribution to create the final map-based outputs.

2.2.1. Step 1: Development of Geological feature Inventory

The first step involved creating an inventory comprising 86 geological features, identified and selected based on common geological constraints encountered in OWF development. A key strength of the inventory is the use of harmonised geological terminology, which primarily follows the two-part seabed geomorphology classification schemes of Dove et al. (2020) and Nanson et al. (2023), jointly developed by Geoscience Australia, British Geological Survey, Geological Survey of Norway, Geological Survey of Ireland and researchers from University College Cork and Latrobe University. This two-part classification provides a consistent morphological and geomorphological framework, applicable across a wide range of settings. These features rely on bathymetry data from which geomorphological units can be identified, supported by knowledge of the geological setting and/or processes (Nanson et al. 2023, and references therein).

We utilise the following parent classifications, grouping the 86 geological features, as:

1) **Settings** classified as: *Glacial, Marine, Fluvial, Biogenic, Coastal (including lacustrine), Solid Earth*

2) **Processes** classified as: *Mass movement, Karst and Fluid Flow.*

3) **Physiography** *(e.g., Shelf break, mound, terrace etc)*

We have included additional classification parameters (below), which are not included within Dove et al. (2020) and Nanson et al. (2023) as these have significant implications with regards to foundation-constraints. These additional parameters include:

4) **Sediments** *(e.g., peat, glauconite)*

5) **Post-depositional processes** *(e.g., concretions, shale/salt diapirs).*

Note that non-marine settings in Group 1 (e.g., fluvial, glacial) are included in the inventory because the current definition of marine settings is based solely on the landward extent of the modern coastline. However, many areas that are now submerged were once terrestrial. Since the Last Glacial Maximum (LGM) and relative lower sea level, many areas of present-day shallow shelf environments have transitioned from glacial landscapes to estuarine, coastal plain, and finally shallow marine settings. These past environments are often preserved at or just below the seabed as deposits and or geomorphological forms.

2.2.2. Step 2: Development of the Geological Constraint Matrix

In Step 2, a geological constraint matrix was developed, drawing directly from the 86 geological features, identified in Step 1. A matrix-style approach was adopted to systematically organise and analyse the data, ensuring that all relevant geological considerations were evaluated. This structure enables clear identification and comparison of constraints across different settings. Through this process, the following constraint categories were established (in bold), with the following sub-groups identified (*in italics),* also illustrated in Table 2-2:

(1) **Soil / bedrock properties** (*vertical/lateral variability, rafts/boulders, coarse or soft soil units, over consolidation / dense sands, bedrock at surface)*

(2) **Physical setting** (*uneven ground, steep margins, active sedimentary systems – including mobile sediments, deep or shallow water*)

(3) **Geohazards** *(faults, submarine slope failure, volcanic activity, fluid flow, potential/active, organic soils).*

(4) **Unknown constraints –** this refers to some features, such as polygonal faults, that are in the process of undergoing research at the time of writing this report.

Individual geological features can be associated with multiple constraints. A few examples are outlined here (see Appendix I for more details). For example:

- "**Terraces**" are identified as a physiographic constraint that may comprise uneven ground and can be found in both shallow and deep water;
- A "**glaciotectonic raft**" (or erratic) is identified as a glacially derived constraint that may induce vertical/lateral soil variability, and depending on the situation (e.g., if found at the seabed) may present uneven ground and/or have steep sides (>5 degree angle);

- A “**marine bar form**” is identified as a marine constraint that may pose uneven ground or mobile sediments.

Table 2-2. Geological constraints matrix structure in Step 2. Colours align with those in the Matrix for ease of cross-reference (Appendix **I**, Dakin, 2025).

Category	Geological constraint matrix
Soil / bedrock properties	Vertical/ lateral variability (heterogeneous soils)
	Rafts or boulders
	Coarse soil units (including gravel)
	Soft soil units - low shear strength
	Overconsolidation (clays / extremely dense sands)
	Strong bedrock at/near seabed
Physical setting (physiography)	Uneven ground (relief)
	Steep slopes/margins (>5-degree angle)
	Active sedimentary system (includes mobile sediments)
	Shallow water (<15-20 m)
	Deep water (<200 m)
Geohazards	Potential fault reactivation/seismic activity
	Potential submarine slope failure
	Potential volcanic activity
	Potential conduit for fluids
	Active fluid flow
	Organic soils/gassy sediments
Unknown	Unknown

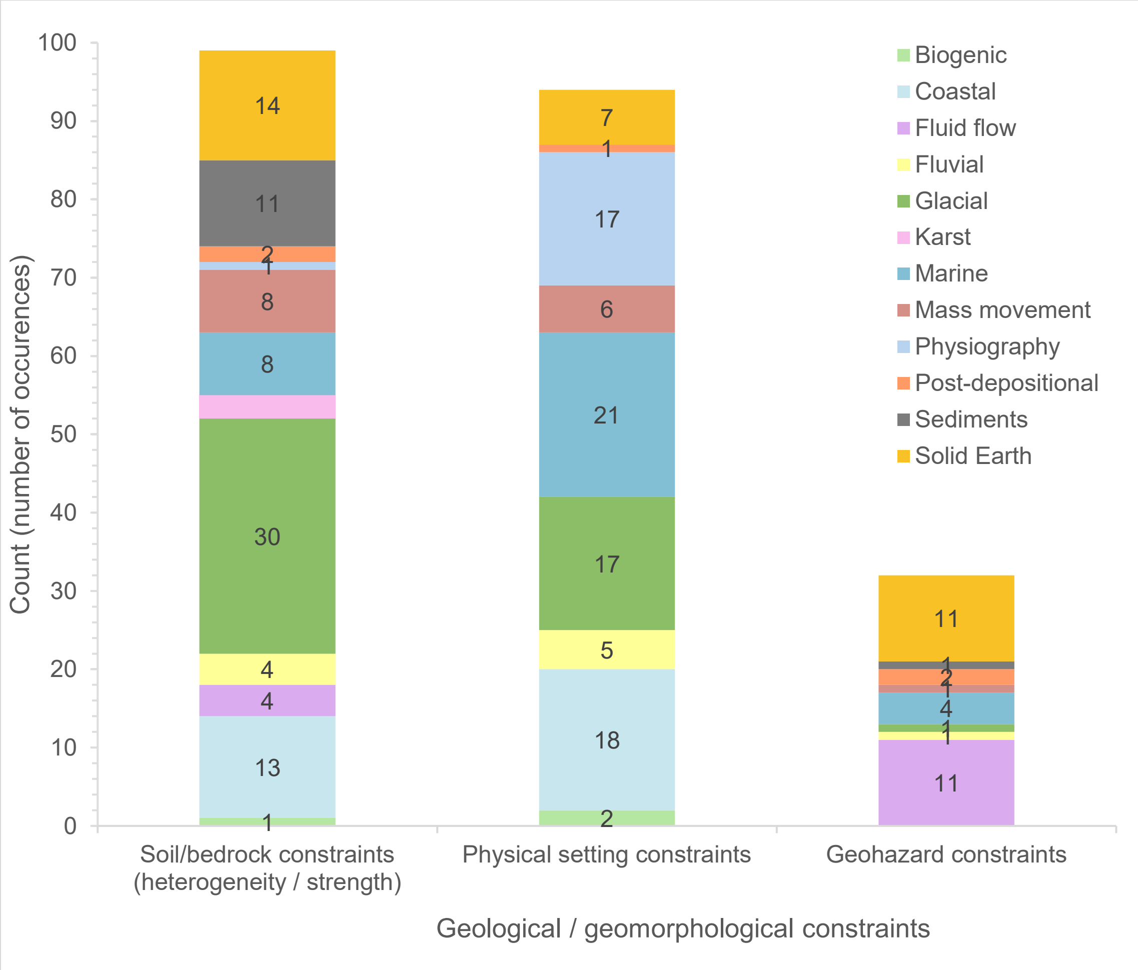

Figure 2-2. Analysis of the number of constraints per setting

Figure 2-2 shows the number of constraints identified per category (e.g., soil/bedrock, physical setting or geohazards). Overall, the physical setting of an offshore environment and soil/bedrock heterogeneity contains the greatest number of constraints (94 and 99, respectively). Other trends, including the number of constraints between different environmental settings, are outlined:

- **Glacial settings** are associated with the highest number of potential soil constraints, typically relating to the number of different geomorphological features and processes involved in these sedimentary environments, such as proglacial lakes, eskers, moraines, proglacial channels, and tunnel valleys.
- **Marine settings** (e.g., geological features that occur below the Lowest Astronomical Tide) are associated with the greatest number of potential constraints relating to the physical setting of an offshore environment. This is typically due to water depth (either too shallow or too deep for fixed foundations), active sedimentary systems (canyons/channels/valleys) and the presence of mobile sediments on the seabed.

- **Solid Earth systems** and **fluid flow** settings are associated with the greatest number of potential geohazards, due to the presence of volcanos, faults and active fluid flow (including presence of pockmarks).

2.2.3. Step 3: Development of the Engineering Constraint Matrix

Building of the geological constraints identified in Step 2, Step 3 focuses on the associated engineering constraints. These are also organised into a matrix structured by soil properties (from an engineering perspective) and foundation type – piles, suction caisson and GBS (Table 2-3 and Appendix I). While some engineering properties are common across all foundation types, others are specific to individual designs. Note the statement "requires individual WTG micro-siting investigation" applies to all geological features to ensure the end-user is aware of the limitations of the products associated with this work.

This step categorises the constraints into distinct groups, enabling a clearer understanding of how geological conditions influence engineering feasibility and design requirements. The following Engineering Constraint groups are identified:

- **Soil properties** from an engineering perspective (*e.g., low thermal conductivity, collapsable or compressible/contractive soils, soils that change character upon crushing, or sediments that may be an important resource*)
- **Cable-related constraints** (*e.g., trenching technique selection, free span (unsupported for >3 m), cable deviation or abrasion of cables*)
- **Specific constraints for fixed foundations**:
  - Piles (e.g., *increased lateral load or scour*)
  - Suction caisson and piles (*e.g., voids, punch through or pile run)*
  - Gravity-based structures (GBS) *e.g., uneven load distribution*
- **Constraints that impact all foundation types** (GBS, suction caisson and piles), *e.g., refusal, damage to tool, increased or reduced overburden, etc.*

Table 2-3. Principal engineering constraint matrix structure. Colours align with those in the Matrix for ease of cross-reference (Appendix I, Dakin, 2025).

Soil properties		Low thermal conductivity / low water content, overheating
		Compressible / contractive soils
		Collapsable soils
		Soil changes character upon crushing
		Potential important resource
Cable-related constraints		Cable/pipeline abrasion or bending
		Free span development
		Cable plough deviation
		Trenching technique selection
Specific constraints for fixed foundations	**Gravity based structures**	Uneven load distribution / differential settlement
	Gravity based structures; **Suction caisson foundations**	Seabed preparation (e.g., flattening)
	Gravity based structures; **Suction caisson foundations**	Reduced skirt burial depth
	Suction caisson foundations; **Pile foundations**	Voids/ punch through / pile run
	Pile foundations	Reduced shaft friction - soft sediments
	Pile foundations	Scour - removal of lateral support
	Pile foundations	Increased lateral load
Constraints that impact all fixed foundations		Lateral/vertical variability in geotechnical values
		Reduced overburden (vertical)
		Increased overburden (vertical)
		May not support hole while drilling
		Poor drivability / refusal
		Blowout
		Damage to tool / foundation during installation
		Unknown
		Geological feature potentially unsuitable
		Requires individual WTG siting investigation

Although the reader is referred to the original matrix, Appendix I, a few examples of translating geology to engineering constraints (*in italics)* are outlined below:

- "**Peat**" is identified as a lithological constraint that can have vertical/lateral variability of organic soils, *which has low thermal conductivity and is a compressible soil that may require cable plough deviation and requires site-specific ground investigation (e.g., Cable Risk Assessments [CBRA] and/or individual WTG planning).*
- "**Terraced settings**" are identified as a physiographic constraint that may comprise uneven ground and can be found in both shallow and deep water, *which may require cable plough deviation and requires site-specific ground investigation (e.g., CBRA and/or WTG planning).*

- A "**glaciotectonic raft**" (or erratic) is identified as a glacial constraint that may induce vertical/lateral soil variability, and depending on the situation (e.g., if found at the seabed) may present uneven ground and/or have steep sides (>5-degree angle). *This may result in variable geotechnical properties, or if boulders are present, these may have poor drivability or lead to refusal resulting in tip damage and the site will require a site-specific ground investigation (e.g., CBRA and/or WTG planning).*
- A "**marine bar form**" is identified as a marine constraint that may pose uneven ground or mobile sediments, *which may result in scour around the seabed infrastructure and requires site-specific ground investigation (e.g., CBRA and/or WTG planning).*

2.2.4. Step 4: Geological Constraint Assessment by Foundation Type – Qualitative Assessment

This step of the Geo-Assessment Matrix involves assigning a relative geological constraint rating specific to each foundation type (piles, suction caisson, GBS and cables). Each of these have different installation and design requirements, depending on the geology. As a result, separate constraint assessments are required for each foundation type, leading to the development of four distinct map outputs. The examples provided herein focus' solely on piled foundations to demonstrate the methodology and potential of this approach. However, expanding this work to cover all foundation types at a comparable level of detail requires additional resources and support. The constraints presented as part of the Geo-Assessment Matrix and the map-based outputs are qualitative/indicative and will vary on site-specific conditions.

To ensure consistency and comparability across the various geological features and map-based products, a systematic scoring framework was developed (**Table 2-4**). This framework defines a qualitative geological constraint score, providing a structured basis for evaluating the suitability of different seabed conditions: 'Higher', 'Moderate' and 'Lower' constraints. As this is a qualitative assessment, they are comparative forms, permitting categories that reflect the relative difference, not the absolute.

- **Higher constraint:** Geological features may *present significant challenges to engineering solutions.*
    - These are typically (but not limited to) geohazards, such as organic soils, pockmarks, active sedimentary systems, slope instability and soft sediments. There are instances where, for example, shallow water depth is not considered a high constraint for cable emplacement, however, is a high constraint for suction caisson and GBS foundations.
- **Moderate constraint**: Geological features *may be suitable for foundations, however, likely need additional engineering design/solutions mitigation measures*.
    - These are typically variable sedimentary features, such as heterogeneous sediments, mobile sediments, weak bedrock and gravel.
- **Lower constraint**: Geological features are *likely suitable for foundations*.

- These are typically more predictable sediments, such as homogeneous or layered sediments or strong bedrock. Note that some features may still require mitigation measures.

2.2.5. Step 5: Application and Demonstration of the Geo-Assessment Matrix using Basin-Scale Case Studies

Steps 5 and 6 extend the Geo-Assessment matrix by demonstrating its practical application through a use-case involving open-access datasets (EMODnet, MAREANO and ISSGM). These steps showcase how the Matrix can be used to generate pan-European screening products to support OWF siting highlighting the flexibility and useability of the data inventory. Through demonstrating the applicability of the Matrix, this ensures further accessibility and impact of the geological baseline data, which are critical for informed decision making, and the successful implementation of OWF projects.

To enable data reattribution, harmonisation is required to align the terminology used in open-source datasets with that of the Geo-Assessment Matrix. **Table 2-4** illustrates how GIS layers are reattributed according to the geological constraint assessment framework. Map-based case studies of this data re-attribution are provided using the regional EMODnet Geomorphology layer (**Figure 2-3**) and the Irish dataset (ISSGM) (**Figure 2-4**). This translation process involves simplifying and standardising terms for the purposes of GSEU. For example, in the EMODnet Geomorphology dataset, there are over 120 different geological terms (**Figure 2-3**A), which are reduced to only three terms “Higher, Moderate and Lower constraint’ **Figure 2-3**B). In the ISSGM dataset, over 20 different geological terms (**Figure 2-4**A) are reduced to either Higher or Lower constraints (**Figure 2-4**B).

Examples of these include:

- ‘bank’ and ‘bank crest’ become ‘sediment bank’, with *relief* becoming the common constraint and becomes ‘moderate constraint’ for piled foundations;
- ‘bench’, ‘contourite deposit’ and ‘contourite drift’ become ‘marine barform’, with *active sedimentary system* becoming the common constraint and becomes ‘higher constraint’ for piled foundations.

Table 2-4. Example of EMODnet Geomorphology layer to GSEU translation and Geological Constraint Assessment providing an overview of the translation process

Original data	GSEU re-attribution	*Geological constraint*			*Final unmitigated assessment (once engineering factors taken into consideration)*			
EMODnet Geomorphology	**GSEU translation**	**Setting**	**Type of constraint**	**Hazard translation / assumptions**	**Suction Caisson foundation**	**Gravity based foundation**	**Piled foundation**	**Export cables**
area with pockmarks	Pockmark (field)	Fluid flow	Geohazard, relief	Active fluid flow	Moderate constraint	Moderate constraint	Moderate constraint	Moderate constraint
area with slide deposits	Depositional zone	Mass movement	Lithology, relief	Heterogeneous sediments	Higher constraint	Higher constraint	Moderate constraint	Moderate constraint
bank	Sediment bank	Marine	Relief	>5-degree slope	Higher constraint	Higher constraint	Moderate constraint	Higher constraint
bank crest	Sediment bank	Marine	Relief	>5-degree slope	Higher constraint	Higher constraint	Moderate constraint	Higher constraint
beach ridge	Beach	Coastal	Lithology, relief	Shallow water depth (<15-20 m)	Higher constraint	Higher constraint	Moderate constraint	Moderate constraint
beach rock	Bedrock outcrop/subcrop; sedimentary; clastic	Solid Earth	Lithology	Strong bedrock	Higher constraint	Low constraint	Higher constraint	Higher constraint
bedform	Sediment waves/dunes	Marine	Lithology	Active sedimentary system	Moderate constraint	Higher constraint	Moderate constraint	Moderate constraint
bench	Marine barform	Marine	Lithology, relief	Active sedimentary system	Higher constraint	Higher constraint	Higher constraint	Higher constraint
canyon	Submarine canyon	Marine	Lithology, relief	Active sedimentary system	Higher constraint	Higher constraint	Higher constraint	Higher constraint
channel	Submarine channel	Marine	Lithology, relief	Active sedimentary system	Higher constraint	Higher constraint	Higher constraint	Higher constraint
collapsed blocks	Erratic blocks and rafts (non-glacial origin)	Mass movement	Lithology, relief	Rafts or boulders	Higher constraint	Higher constraint	Higher constraint	Higher constraint
contourite deposit	Marine barform	Marine	Lithology, relief	Active sedimentary system	Higher constraint	Higher constraint	Higher constraint	Higher constraint
contourite drift	Marine barform	Marine	Lithology, relief	Active sedimentary system	Higher constraint	Higher constraint	Higher constraint	Higher constraint
coral mound	Reefs (ancient, buried and present day)	Biogenic	Lithology, relief	Active sedimentary system / hardground	Higher constraint	Higher constraint	Higher constraint	Moderate constraint
current channel	Submarine channel	Marine	Lithology, relief	Active sedimentary system	Higher constraint	Higher constraint	Higher constraint	Higher constraint
debris-avalanche deposit	Depositional zone	Mass movement	Lithology, relief	Heterogeneous sediments	Higher constraint	Higher constraint	Moderate constraint	Moderate constraint

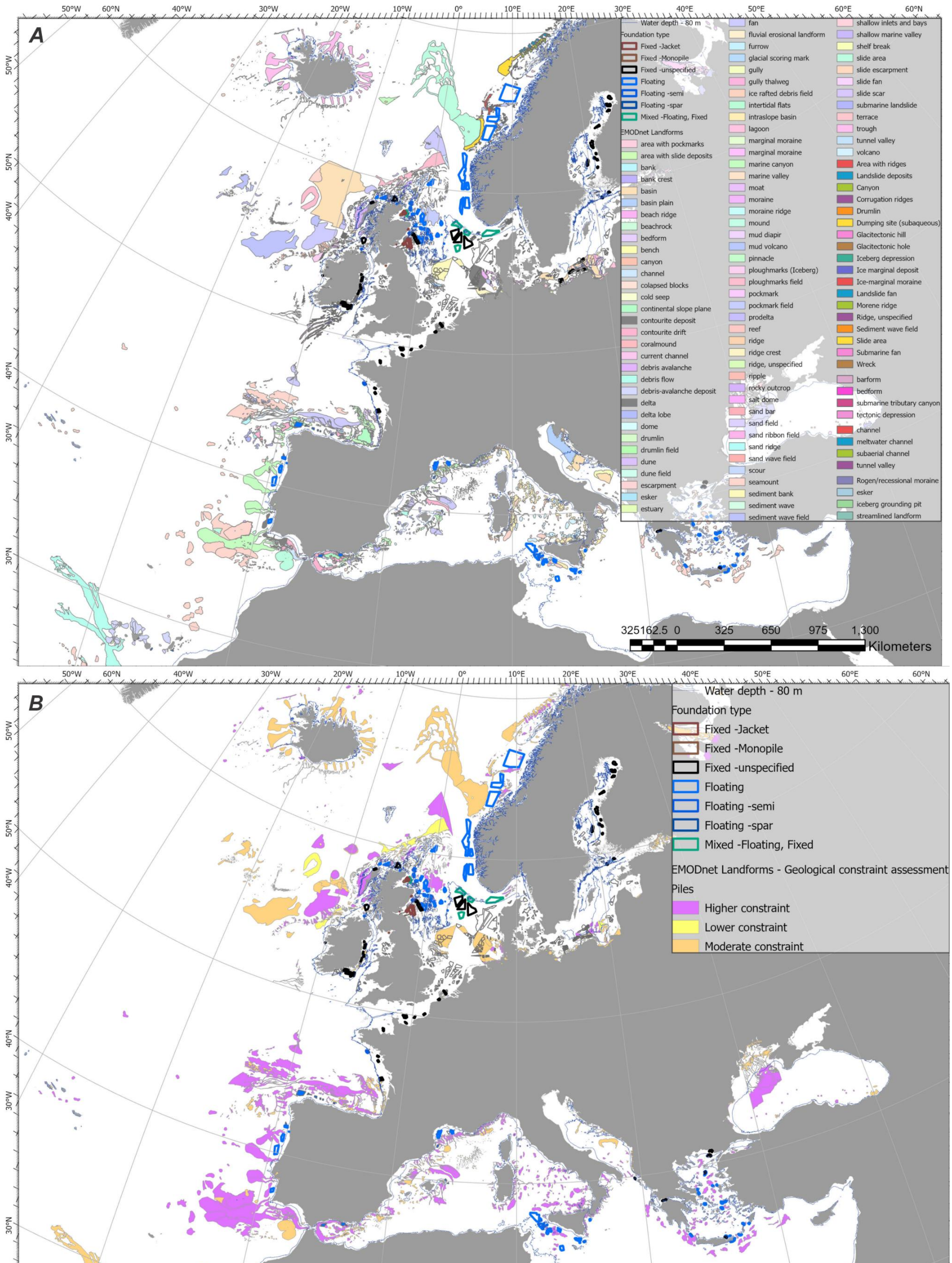

Figure 2-3. (A) Pan-European geomorphology dataset (EMODnet, Ireland - ISSGM 2023 and MAREANO) with ~120 attributes. (B) Translation of geological constraints from the Geo-Assessment into simplified terminology. Example for pile foundations only with -80 m water depth contour extracted from EMODnet Bathymetry (© European Union 1995-2005). Projection - European Terrestrial Reference System 1989 / Lambert Azimuthal Equal Area. Only opensource wind farm polygons are shown. BGS © UKRI 2025.

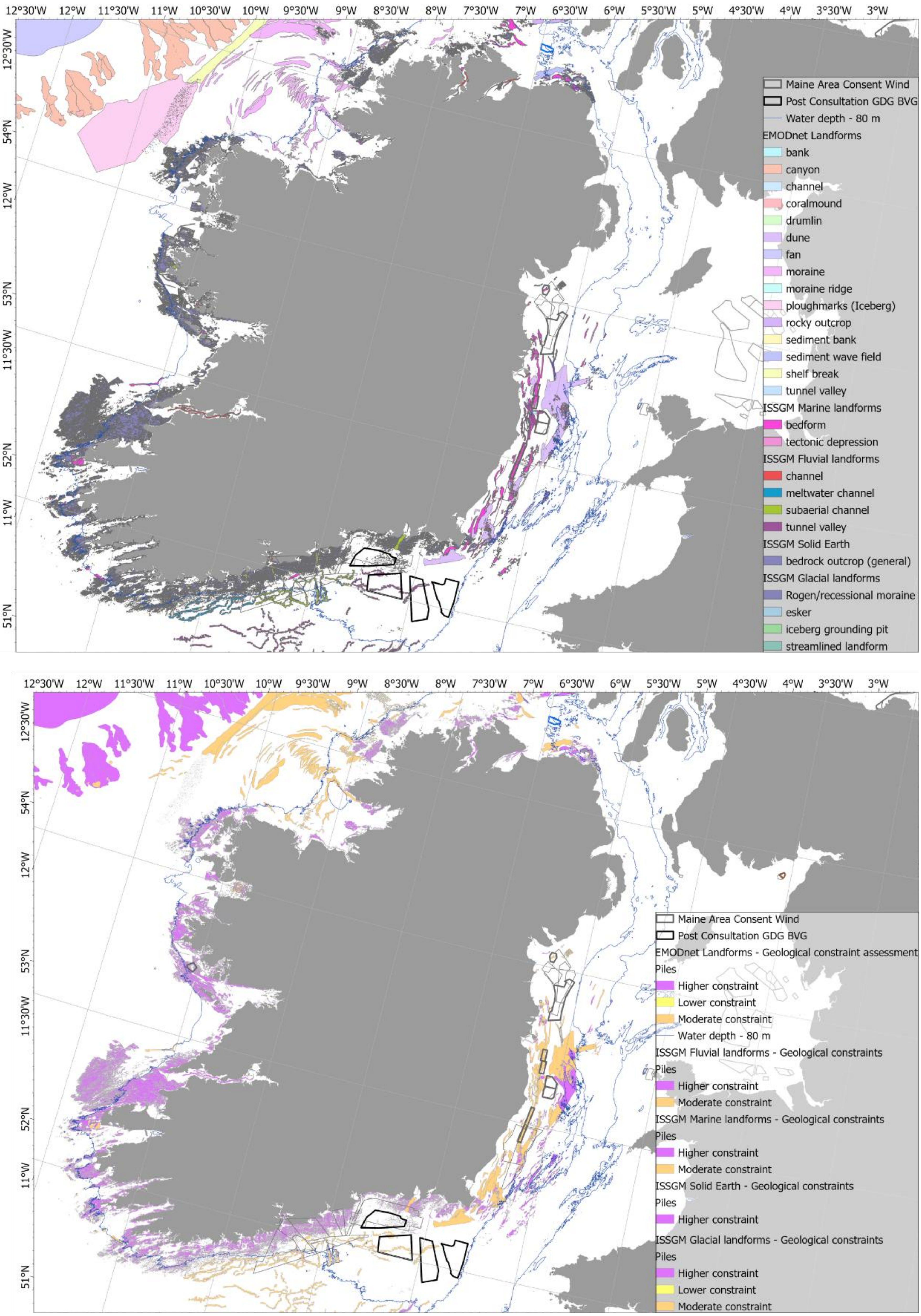

Figure 2-4. Case-study offshore Ireland (A) EMODnet and ISSGM 2023 data. (B) Translation of geological constraints from the Geo-Assessment into simplified terminology to support cross-disciplinary understanding. Example for pile foundations only with 80 m water depth contour extracted from EMODnet Bathymetry (© European Union 1995-2005). Projection - European Terrestrial Reference System 1989 / Lambert Azimuthal Equal Area. BGS © UKRI 2025.

2.2.6. Step 6: Creation of offshore pan-European Hex maps: a useful screening tool

The final step of creating pan-European maps is the process of turning geological polygons into hex maps. Hex-style maps are a powerful and versatile approach of spatial data visualisation and analysis, making it easier for the end-user to understand practical implications of complex geological challenges. Hexagons are preferred over a rectangular grid for spatial analysis as their shape minimises edge effects and they represent curves in patterns more naturally, highlighting spatial patterns and relationships in the data (Figure 2-5). Hexagons also allow for visual and aesthetic clarity that enhances the readability of complex multivariate datasets (e.g., Birch et al. 2007).

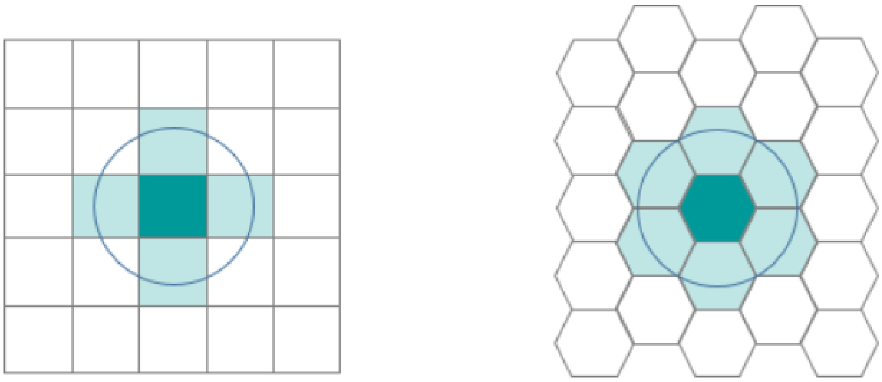

Figure 2-5. Comparison of square and hexagonal grid systems illustrating spatial coverage and intersection with a circular feature (Figure from Thompson et al. 2024).

Hexagons are commonly used by ArcPro, Business Analyst Pro and Web App users utilising 'Uber H3 hexagons', a widely adopted global grid system, abbreviated to *H3 hexagons* (Thompson et al. 2024). There are six H3 hexagon resolutions, starting at resolution 2 (~86,800 km^2 average hexagon area) through resolution 7 (36.1 km^2 average hexagon area), Table 2-5. For the GSEU project, 'Resolution 6' is suggested for regional screening products as this is well-suited with the size of OWF leases.

Examples of these hex-based maps are provided around the Baltic Sea (Figure 2-6) and offshore Scotland (Figure 2-7) to illustrate the approach. However, generating the full suite of outputs for all regions and foundation types is beyond the scope of this phase of GSEU and requires additional time and development effort. A suite of recommendations are provided in Section 3.1 to further develop these hex-based screening products for optimised offshore wind screening. We suggest the creation of Common Risk Segment (CRS) and Combined Common Risk Segment (CCRS) mapping methods.

Table 2-5. Hexagon area differences between ESRI resolution sizes (2 to 7). Resolution 6 suggested for OWF screening purposes.

Resolution	Average hexagon area		Average radius (apothem)	
2	86,801.8 km^2	33,514.4 miles^2	158.1 km	98.2 miles
3	12,393.4 km^2	4,785.1 miles^2	59.7 km	37.1 miles
4	1,770.3 km^2	683.5 miles^2	22.6	14 miles
5	252.9 km^2	97.6 miles^2	8.5 km	5.3 miles
6	36.1 km^2	13.9 miles^2	3.2 km	2 miles
7	5.2 km^2	2.0 miles^2	1.2 km	0.8 miles

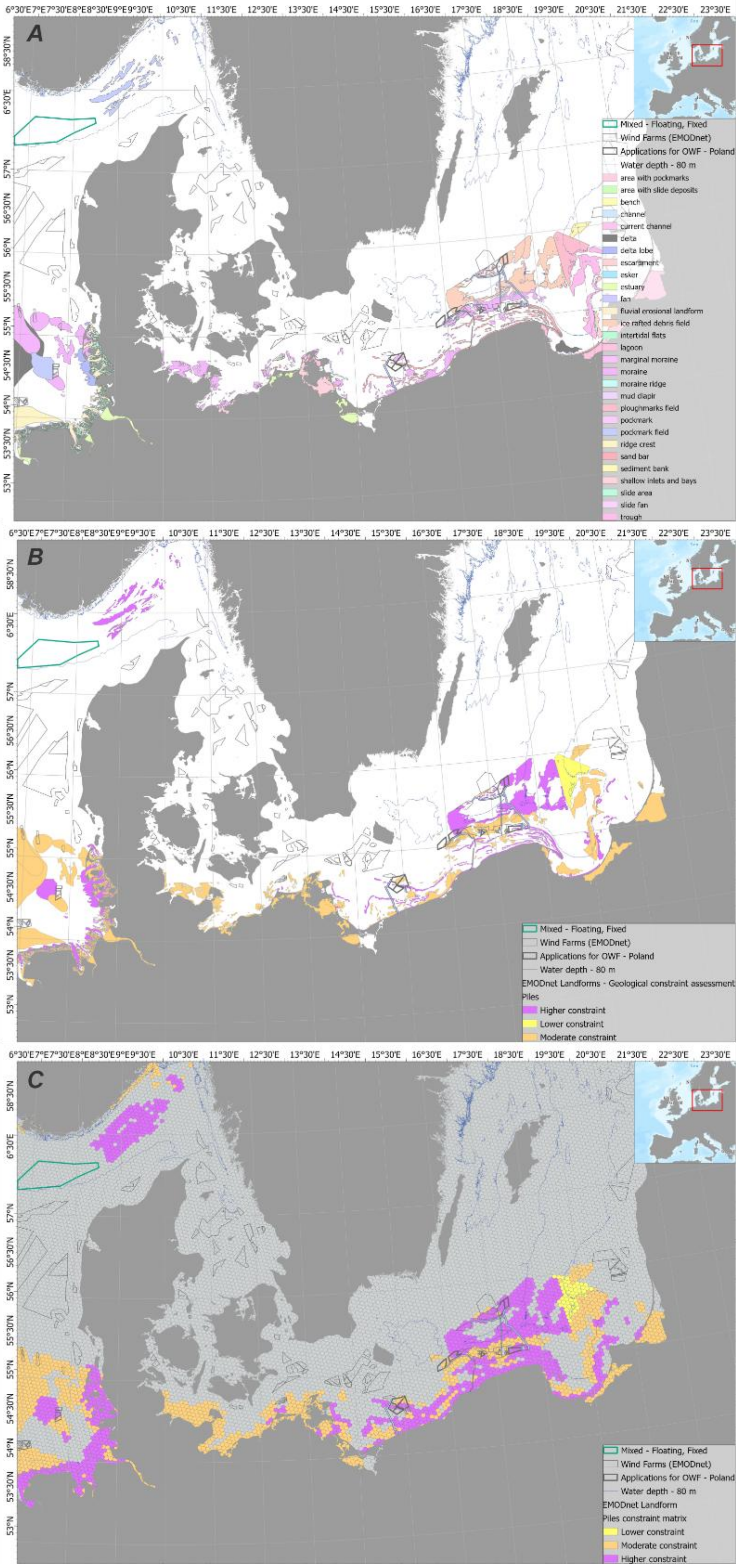

Figure 2-6. Baltic Sea case study (A) Map showing EMODnet Geomorphology attributes in the Southern Baltic Sea (© European Union 1995-2005). (B) Map showing GSEU translation of the EMODnet Geomorphology layer. Example for pile foundations only with 80 m water depth contour extracted from EMODnet Bathymetry (© European Union 1995-2005). (C) Example of hex-attribution process showing simplification of geological data for screening maps. Projection - European Terrestrial Reference System 1989 / Lambert Azimuthal Equal Area. Wind farm polygons from EMODnet Human Activities and SIPAM. BGS © UKRI 2025.

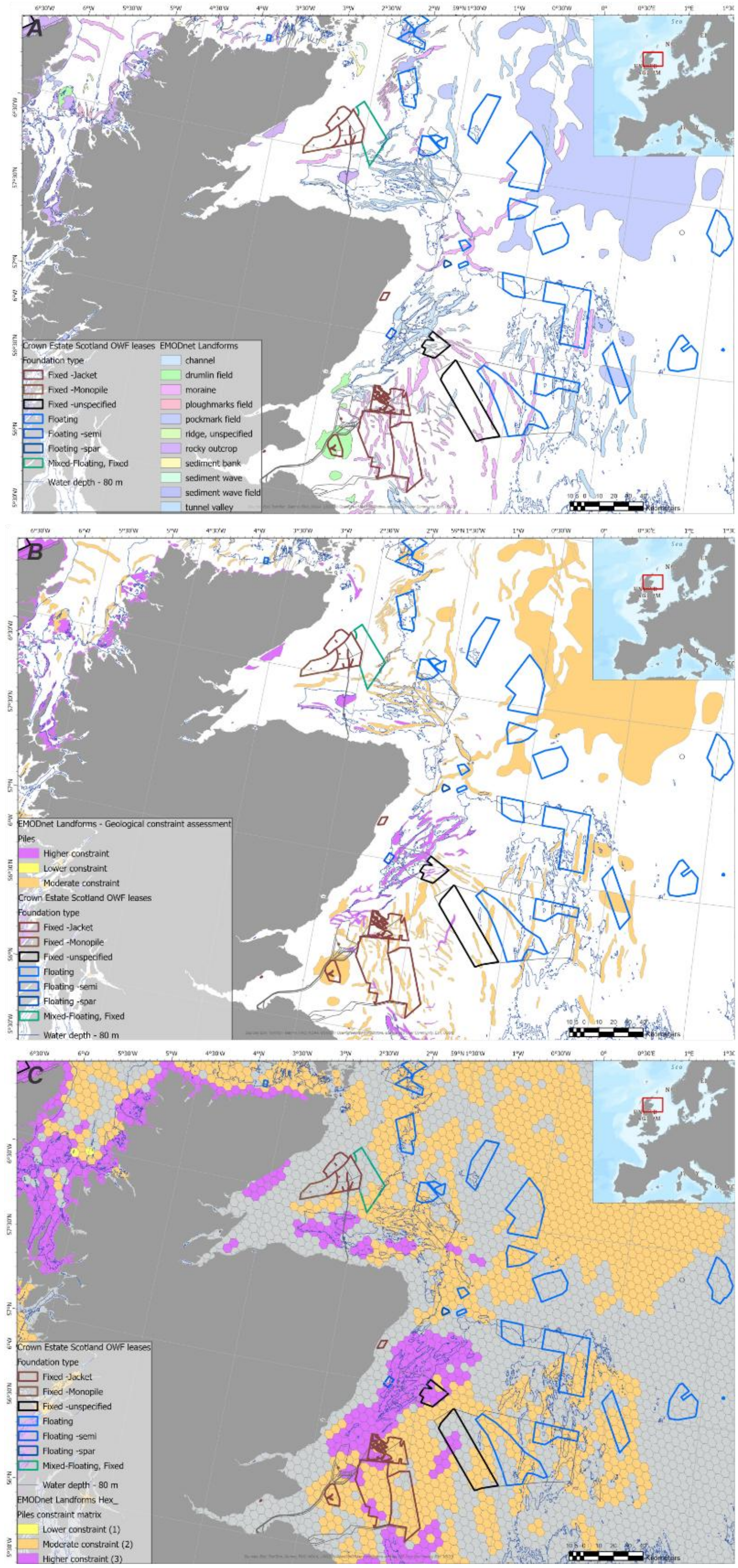

Figure 2-7. Central North Sea Case Study (A) Map showing EMODnet Geomorphology attributes across the east coast of Scotland (n=11) (B) Map showing GSEU translation of the EMODnet Geomorphology layer. Example for pile foundations only with 80 m water depth contour extracted from EMODnet Bathymetry (© European Union 1995-2005). (C) Example of Hex3 (Copyright 1995-2025 Esri) attribution process showing simplification of geological data for screening maps -. Projection - European Terrestrial Reference System 1989 / Lambert Azimuthal Equal Area. Wind farm polygons from The Crown Estate Scotland. BGS © UKRI 2025.

3. Geo-Assessment Matrix: Conclusion and Future Outlook

As governments across the UK, Europe and neighbouring nations accelerate their offshore wind ambitions, the number of OWF licenses continues to grow rapidly. This expansion underscores the critical need to integrate geological knowledge with geotechnical and engineering principles to reduce risk, anticipate unforeseen ground conditions and optimise the design and placement of Wind Turbine Generators. The GSEU has made significant progress in fostering collaboration between Geological Survey Organisations. Through the development of the Geo-Assessment Matrix, it was presented how geological conditions can influence engineering decisions. It also promotes the use of standardised geological nomenclature across disciplines and provides a framework for translating geological constraints into engineering-relevant, user-friendly map products. The Geo-Assessment Matrix is designed to be adaptable, supporting future applications such as floating OWF structures and evolving policy or technological contexts. This phase of the Geo-Assessment Matrix and the reattribution of existing datasets forms a robust foundation for the creation of pan-European, map-based screening tools. The continued development of the Geo-Assessment Matrix explorer will provide a user-friendly interface and will be available ahead of the final phase of the current GSEU programme, scheduled for completion in 2027.

3.1. Future Recommendations

Future work should focus on expanding the data landscape and refining the integration of more geological datasets. Several open-source datasets, such as those listed in **Table 3-1**, offer valuable inputs for future project phases. These dataset layers, such as seabed lithology, Quaternary (bedrock) lithology (and depth to bedrock) can be combined to create a Combined Common Risk Segment (CCRS) map. A CCRS map is generated by combining multiple constraint layers (e.g., derived from geomorphology, Quaternary lithology, seabed sediments, and submerged landscape data layers) into a composite constraint map. This approach enables a clear visualisation of the lateral and vertical distribution of geological constraints across broad areas. This methodology could support strategic site selection during regional screening exercises.

Table 3-1. Strategically relevant GIS datasets that can be leveraged in future phases of development to enhance re-attribution workflows and inform regional screening outputs.

Source dataset	Source dataset GIS layer name	Constraint type (GSEU)	Polygon/lines/Point	Presented in D5.4
EMODnet	Geomorphology	Geological features	Polygon	Y
MAREANO	Landforms	Geological features	Polygon	Y
ISSGM	Fluid flow	Geohazards	Polygon	Y
ISSGM	Fluvial landforms	Geological features	Polygon	Y
ISSGM	Glacial landforms	Geological features	Polygon	Y
ISSGM	Marine landforms	Geological features	Polygon	Y
EMODnet	Quaternary lithology1	Sediments (pre-Holocene)	Polygon	N
EMODnet	Pre-Quaternary lithology1	Bedrock	Polygon	N
EMODnet	Seabed sediments	Sediments	Polygon	N

Source dataset	Source dataset GIS layer name	Constraint type (GSEU)	Polygon/lines/Point	Presented in D5.4
EMODnet	Submerged landscapes	Geological features	Polygon	N
EMODnet	Volcanic emissions/centres	Geohazards	Polygons, lines and points	N
MAREANO	Seabed sediments	Sediments	Polygon	N
MAREANO	Landforms	Geological features	Polyline	N
ISSGM	Fluid flow	Geohazards	Polygon	N
ISSGM	Fluvial landforms	Geological features	Polygon	N
ISSGM	Solid Earth	Bedrock	Polygon	N
ISSGM	Substrates	Sediments/bedrock	Polygon	N
ISSGM	Various fields	Sediment waves/Iceberg	Polygon	N
ISSGM	Glacial linework	Geological features	Polyline	N
ISSGM	Marine landforms	Geological features	Polygon	N
ISSGM	Marine linework	Geological features	Polyline	N

Some data availability remains a limiting factor, particularly for key layers such as Holocene sediment thickness and mobile sediment distribution in offshore regions. To address these gaps and enhance regional screening capabilities, the following actions are recommended:

- **Identification and harmonisation of additional datasets**: Evaluate underutilised or emerging datasets from national surveys, academic research and European data portals (e.g., EMODnet Geology, OneGeology, Copernicus, MAREANO, INSS-INFOMAR) and harmonise these datasets with the Geo-Assessment Matrix for consistency and usability;
- **Enhancement of the Geo-Assessment Matrix**: Expand the Matrix to include new geological features and engineering constraints as more data becomes available. This will improve its applicability to a wider range of seabed conditions and OWF technologies;
- **Creation of constraint and CCRS maps**: Using the Geo-Assessment Matrix, continue to create constraint maps as shown in the case studies within this report, and using these data layers create a final Combined Common Risk Segment map;
- **Collaboration and knowledge exchange**: Continue fostering open communication between GSOs, engineers and policymakers to ensure that geological insights are effectively translated into practical guidance for OWF development.

By building on the foundation established in this phase of GSEU, future work can significantly enhance the ability to screen, assess and optimise OWF site across Europe, supporting a more resilient and informed transition to renewable energy systems.

4. Appendix I – Geo-Assessment Matrix

Downloadable from here: https://doi.org/10.5285/a7622a1d-2638-4ec6-a77e-7de2e7fe28b1

5. Appendix II – Glossary

TERM	DEFINITION	REFERENCE(S)
Anchor	Device to prevent or restrict vessel/structure movement.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Anisotropic stiffness	Variability in soil stiffness both laterally and vertically. Prone to differential settlement	Giles, D.P., Griffiths, J.S., Evans, D.J.A. and Murton, J.B., 2017. Chapter 3 Geomorphological framework: glacial and periglacial sediments, structures and landforms. Geological Society, London, Engineering Geology Special Publications, 28(1), pp.59-368.
Anisotropic permeability	Variability in permeability both laterally and vertically	Giles, D.P., Griffiths, J.S., Evans, D.J.A. and Murton, J.B., 2017. Chapter 3 Geomorphological framework: glacial and periglacial sediments, structures and landforms. Geological Society, London, Engineering Geology Special Publications, 28(1), pp.59-368.
Anisotropic strength	Variability in soil strength and behaviour both laterally and vertically	Giles, D.P., Griffiths, J.S., Evans, D.J.A. and Murton, J.B., 2017. Chapter 3 Geomorphological framework: glacial and periglacial sediments, structures and landforms. Geological Society, London, Engineering Geology Special Publications, 28(1), pp.59-368.
Bearing capacity	Capacity of soil to support the loads that are applied by the foundation.	Barnes, G. (2017). Soil mechanics. Bloomsbury Publishing.
Cables	See Export cables	https://www.windandwaterworks.nl/cases/export-and-inter-array-cable-installation#:~:text=Cabling%20is%20a%20critical%20component,substation%20to%20the%20onshore%20network.
Cable Burial Risk Assessment (CBRA)	Cable burial has long been regarded as the optimal protection technique against external hazards (e.g., interaction with vessel anchors). The Cable Burial Risk Assessment (CBRA) Guidance offers a standardised, repeatable and qualitative method to improve risk management of subsea cables for offshore wind farms, improve conservative estimates of residual risk, and ultimately reduce the installation and insurance costs for subsea cables.	The Carbon Trust. (2015). Cable Burial Risk Assessment Methodology - Guidance for the Preparation of Cable Burial Depth of Lowering Specification. CTC835, February 2015. https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/cable-burial-risk-assessment-cbra-guidance-and-application-guide
Compressible soils	Highly compressible horizons potentially present in the subsurface	Giles, D.P., Griffiths, J.S., Evans, D.J.A. and Murton, J.B., 2017. Chapter 3 Geomorphological framework: glacial and periglacial sediments, structures and landforms. Geological Society, London, Engineering Geology Special Publications, 28(1), pp.59-368.
Constraint	See Engineering constraint and Geological constraint and Geomorphological constraint	
Driven pile	Pre-made piles installed into the ground by percussion, pressing or vibration.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.

Engineering constraint	Static feature that can be addressed by routine engineering processes	Dimmock, P.S., Riera, R., Tam, T.A. and Boylan, N., 2023, January. Geohazard or Geo-engineering constraint?. In Offshore Site Investigation Geotechnics 9th International Conference Proceeding (Vol. 2067, No. 2071, pp. 2067-2071). Society for Underwater Technology.
Export cables	Export cables transport electricity from the offshore substation to the onshore network (see Landfall glossary entry).	https://www.windandwaterworks.nl/cases/export-and-inter-array-cable-installation#:~:text=Cabling%20is%20a%20critical%20component,substation%20to%20the%20onshore%20network.
Foundation types	Includes fixed turbines (gravity-based structures, suction caisson, pile design)	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Freespan, free-span, or free span	The scenario whereby a section of installed cable or pipeline becomes exposed and is unsupported along its length on the seabed for a distance, typically greater than 3m. This can result in exposure to vessel equipment (e.g., anchor or trawling gear interactions) and/or can lead to exposure to vortex-induced vibrations (VIV - see below for glossary definition).	Offshore Engineer article (https://www.oedigital.com/news/459021-free-span-analysis)
Geohazard	A geohazard is a geological state, feature or process that presents a risk to development. Term is restricted to dynamic processes that may impact the development	Dimmock, P.S., Riera, R., Tam, T.A. and Boylan, N., 2023, January. Geohazard or Geo-engineering constraint?. In Offshore Site Investigation Geotechnics 9th International Conference Proceeding (Vol. 2067, No. 2071, pp. 2067-2071). Society for Underwater Technology.
Geological constraint	A geological feature that does not have a topographic expression at seabed or is buried in the subsurface and may impact development	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M.F.J., Guinan, J., Post, A., Webb, J. and S. Nichol. 2022. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary - Version 1.0. Published 14th April 2023. DOI: 10.5281/zenodo.7804019
Geological feature	A broad term encompassing seabed or subsurface physical features present within area of interest	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M.F.J., Guinan, J., Post, A., Webb, J. and S. Nichol. 2022. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary - Version 1.0. Published 14th April 2023. DOI: 10.5281/zenodo.7804019
Geomorphological constraint	A morphological feature with process of formation interpreted and has a topographic expression at the seabed that may impact development	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M.F.J., Guinan, J., Post, A., Webb, J. and S. Nichol. 2022. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary - Version 1.0. Published 14th April 2023. DOI: 10.5281/zenodo.7804019
Geomorphology	Morphological feature on the seabed with a topographic expression that is classified in terms of process and setting	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M.F.J., Guinan, J., Post, A., Webb, J. and S. Nichol. 2022. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary - Version 1.0. Published 14th April 2023. DOI: 10.5281/zenodo.7804019
Gravity base structure (GBS)	A concrete or ballasted steel structure, supported by a shallow foundation, that may or may not have skirts.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.

Inter-array cables	Cables within a specific development area (as opposed to export cables), typically between wind turbines or other renewable energy generating units and hub platforms.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Jacket	A Jacket structure is a welded tubular space frame consisting of vertical or battered legs, supported by a lateral bracing system.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Landfall	The term landfall refers to the point at which the export cables (see glossary entry above) carrying power from an offshore wind farm reach the shore. This is where the offshore and onshore infrastructure is connected – an important step in bringing renewable wind energy into the power grid.	Orsted webpage (https://us.orsted.com/renewable-energy-solutions/offshore-wind/offshore-wind-farm-construction/bringing-wind-power-ashore)
Lateral loading	Stress applied to the structure in a horizonal plane.	Anastassopoulos, C., Charles, J.A. and Gourvenec, S., 2023, January. Effect of CPT profile resolution on minimum required size of monopile for ultimate limit state design. In Offshore Site Investigation Geotechnics 9th International Conference Proceeding (Vol. 393, No. 400, pp. 393-400). Society for Underwater Technology.
Monopile	A single cylindrical steel pile (see pile for definition).	Barnes, G. (2017). Soil mechanics. Bloomsbury Publishing.
Overconsolidation	If the present-day (effective overburden) pressure being exerted on the soil unit is not high enough to account for the strength of that unit, then it is said to be overconsolidated. This can typically happen when (1) soil has been removed (eroded) from over the unit, meaning it has experienced more loading and therefore Possibly unsuitable stresses in the past, (2) the unit has experienced significant loading from ice sheets in the past, or (3) the soil unit has experienced desiccation in the past.	Barnes, G. (2017). Soil mechanics. Bloomsbury Publishing.
Periglacial process	Periglacial processes refer to the forms and processes that occur in a cold climate environment, characterised by the freezing and thawing of water	Shiklomanov, N.I. and Nelson, F.E., 2013. Thermokarst and civil infrastructure. In Treatise on geomorphology (pp. 354-373).
Pile	A long, slender structural member (typically a hollow steel cylinder) used to transmit loads applied at its top to the ground at Likely suitable levels.	Barnes, G. (2017). Soil mechanics. Bloomsbury Publishing.
Pile refusal	Where a pile cannot be completely driven to its target depth without further intervention, typically associated with reaching the maximum energy transfer for a given hammer system. Turbine locations are typically chosen to avoid areas where piling is likely to be problematic. For some sites, a vessel will be mobilised with drilling equipment	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.

	to mitigate the risk to the project schedule in cases of pile refusal	https://www.thecrownestate.co.uk/media/2860/guide-to-offshore-wind-farm-2019.pdf
Pile run	During installation, a pile may suddenly and catastrophically go into freefall. This uncontrolled fall can pose a serious risk to the lives of the crew onboard the vessel. This is termed a pile run, and can occur when unexpected voids are encountered or where unexpected very soft soils are encountered beneath dense and/or stiff to very stiff soils.	Ciavaglia, F., Morgan, N. and Casanovas, C., 2023, January. High-level engineering considerations for the concept selection of fixed offshore wind turbine foundations. In Offshore Site Investigation Geotechnics 9th International Conference Proceeding (Vol. 2080, No. 2087, pp. 2080-2087). Society for Underwater Technology.
Piled jacket	Fixed typically steel framed structure with pile foundations.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Process	The term “Process” grouped geomorphic units formed by groups of similar processes. Also, see 'Setting'	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M., Guinan, J., Post, A., Webb, J. and Nichol, S., 2023. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary-Version 1.0.
Prone to liquefaction	Prone to liquefaction on disturbance or overloading	Giles, D.P., Griffiths, J.S., Evans, D.J.A. and Murton, J.B., 2017. Chapter 3 Geomorphological framework: glacial and periglacial sediments, structures and landforms. Geological Society, London, Engineering Geology Special Publications, 28(1), pp.59-368.
Punch-through	Rapid, uncontrolled penetration of a jack-up rig's leg and spudcan (see spudcan for definition), which can be used to install some foundations. Often caused when unexpected voids are encountered or where unexpected very soft soils are encountered beneath dense and/or stiff to very stiff soils.	DeGroot, D.J., Westgate, Z.J. and Yetginer-Tjelta, T.I., 2023, January. Geological and geotechnical challenges of the East Coast United States for offshore energy transition. In Offshore Site Investigation Geotechnics 9th International Conference Proceeding (Vol. 82, No. 111, pp. 82-111). Society for Underwater Technology.
Rock dumping / rock placement	Installation of rock or gravel in the form of protective structures, typically around foundations or over cables, etc.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Rockhead	The surface of the bedrock beneath the soil cover.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Setting	The term “Setting” groups geomorphic units that are generally formed in specific depositional environments	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M., Guinan, J., Post, A., Webb, J. and Nichol, S., 2023. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary-Version 1.0.

Shaft friction	Refers to the axial pile capacity component associated with the interface friction between the pile walls and the surrounding material.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Skirt or skirt embedment	Skirts are vertical plates below gravity base or mudmat structures, that penetrate into the seabed. Embedment is the penetration depth below seabed.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Solid Earth	The “Solid Earth” system, although not a “Setting” per se, is defined this way as it includes several different processes and can often be considered the general background for other Settings and Processes. See 'Setting' and 'Process'	Nanson, R., Arosio, R., Gafeira, J., McNeil, M., Dove, D., Bjarnadóttir, L., Dolan, M., Guinan, J., Post, A., Webb, J. and Nichol, S., 2023. A two-part seabed geomorphology classification scheme. Part 2: Geomorphology classification framework and glossary-Version 1.0.
Spudcan	Inverted cones mounted at the base of a jack-up leg, which provide stability to lateral forces on the jack-up rig when installed on the seabed.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Suction caisson/suction pile/suction bucket/suction can	A cylindrical caisson foundation that is installed using a combination of self weight and suction. A pile/deep skirted foundation that is installed using suction pumps for assistance. The suction caisson technology functions very well in a seabed with soft clays or other low strength sediments. The presence of soil layers which have different properties (strength, stiffness, permeability etc.) and exhibit different behaviour under stress can have a large impact on the installation of suction buckets.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee. Remmers, J., Reale, C., Pisanò, F., Raymackers, S., & Gavin, K. (2019). Geotechnical installation design of suction buckets in non-cohesive soils: A reliability-based approach. Ocean Engineering, 188, 106242.
Tethered foundations	Floating structures that are held in place by anchors or piles. Structures that are held in place by anchors.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Thermal conductivity	The property of a material to conduct heat, typically measured in watts per metre kelvin. Typically, is computed from the linear portion of the plot of temperature vs. the natural log (ln) of time.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.

Trenching (cables & pipelines)	In order to protect cables and pipelines from risk of interactions with vessels anchors and fishing gear, the asset is often buried in the shallow subsurface (typically ≤2 m below seabed). This is often done through placing the asset in a linear trench that has been excavated by specialist equipment, which can include seabed ploughs, jetting equipment, and chain cutting tools. For an example, see this short video: https://www.youtube.com/watch?v=d9tRmJLOCdg	Powell, T.A., White, D.J., Alvarez-Borges, F. and Fearn, M., 2023, January. In-situ testing in trench backfill: Evidence of evolving backfill density. In Offshore Site Investigation Geotechnics 9th International Conference Proceeding (Vol. 476, No. 483, pp. 476-483). Society for Underwater Technology.
Tripod	A structure supported by three separate foundations.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Unconfined or uniaxial compressive stress (UCS) test	Laboratory test for determining the maximum axial compressive stress of a soil or rock specimen at zero confining stress	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Undrained shear strength	In the context of soil mechanics, resistance to shear failure of the soil without dissipation of the pore water pressure generated by the applied shear stresses.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Unexploded Ordnance (UXO)	Explosive objects that did not explode when they were employed and still pose a risk of detonation.	Cook, M., Barwise, A., Carey, N., Carrington, T., Dix, J., Giuliani, G., Hobbs, R., James, L., Wood, A. M., Lawrence, M., Jones, D. L., Morgan, N., Orren, R., Osborne, J., Andrade, M. P., Rushton, D., Searle, A., Smith, A., Wilson, P. (2022). Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments. Society for Underwater Technology - Offshore Site Investigation & Geotechnics Committee.
Variable particle sizes	Variability in particle sizes both laterally and vertically, e.g., clay, silt, sand , gravel, cobbles and boulders all potentially present	Giles, D.P., Griffiths, J.S., Evans, D.J.A. and Murton, J.B., 2017. Chapter 3 Geomorphological framework: glacial and periglacial sediments, structures and landforms. Geological Society, London, Engineering Geology Special Publications, 28(1), pp.59-368.
Vortex-Induced Vibrations (VIV)	Exposed, hanging cables and pipelines can, under certain flow conditions, experience sustained periods of vibration due to the transfer of energy from the fluid to the structure. These vibrations (VIV) may promote fatigue and significantly degrade the service life and performance of the asset.	Kim, W. J., & Perkins, N. C. (2002). Two-dimensional vortex-induced vibration of cable suspensions. Journal of Fluids and Structures, 16(2), 229-245.

6. Appendix III – References

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7. Appendix IV – Consortium Partners

Consortium partners WP5 WP5.2 optimised offshore wind farm siting are indicated				
	Partner Name	**Acronym**	**Country**	**Task 5.2**
1	EuroGeoSurveys	EGS	Belgium	
2	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek	TNO	Netherlands	√
3	Sherbimi Gjeologjik Shqiptar	AGS	Albania	
4	Vlaamse Gewest	VLO	Belgium	
5	Bureau de Recherches Géologiques et Minières	BRGM	France	√
6	Ministry for Finance and Employment	MFE	Malta	√
7	Hrvatski Geološki Institut	HGI-CGS	Croatia	√
8	Institut Royal des Sciences Naturelles de Belgique	RBINS-GSB	Belgium	√
9	Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy	PGI-NRI	Poland	√
10	Institut Cartogràfic i Geològic de Catalunya	ICGC	Spain	√
11	Česká Geologická Služba	CGS	Czechia	
12	Department of Environment, Climate and Communications - Geological Survey Ireland	GSI	Ireland	√
13	Instituto Geológico y Minero de España-CSIC	IGME-CSIC	Spain	√
14	Bundesanstalt für Geowissenschaften und Rohstoffe	BGR	Germany	
15	Geološki zavod Slovenije	GeoZS	Slovenia	√
16	Federalni Zavod za Geologiju Sarajevo	FZZG	Bosnia and Herzegovina	
17	Istituto Superiore per la Protezione e la Ricerca Ambientale	ISPRA	Italy	√
18	Regione Umbria	-	Italy	
19	State Research and Development Enterprise State Information Geological Fund of Ukraine	GIU	Ukraine	
20	Institute of Geological Sciences National Academy of Sciences of Ukraine	IGS	Ukraine	
21	M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of NAS of Ukraine	IGMOF	Ukraine	
22	Ukrainian Association of Geologists	UAG	Ukraine	
23	Geologian Tutkimuskeskus	GTK	Finland	√
24	Geological Survey of Serbia	GZS	Serbia	
25	Ministry of Agriculture, Rural Development and Environment of Cyprus	GSD	Cyprus	√
26	Norges Geologiske Undersøkelse	NGU	Norway	√

27	Latvijas Vides, ģeoloģijas un meteoroloģijas centrs SIA	LVGMC	Latvia	
28	Sveriges Geologiska Undersökning	SGU	Sweden	√
29	Geological Survey of Denmark and Greenland	GEUS	Denmark	√
30	Institutul Geologic al României	IGR	Romania	√
31	Szabályozott Tevékenységek Felügyeleti Hatósága	SZTFH	Hungary	
32	Eidgenössisches Departement für Verteidigung, Bevölkerungsschutz und Sport	VBS (DDPS)	Switzerland	
33	Elliniki Archi Geologikon kai Metalleftikon Erevnon	HSGME	Greece	√
34	Laboratório Nacional de Energia e Geología I.P.	LNEG	Portugal	√
35	Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos	LGT	Lithuania	
36	Geologische Bundesanstalt	GBA	Austria	
37	Service Géologique de Luxembourg	SGL	Luxembourg	
38	Eesti Geoloogiateenistus	EGT	Estonia	
39	Štátny Geologický ústav Dionýza Štúra	SGUDS	Slovakia	
40	Íslenskar Orkurannsóknir	ISOR	Iceland	√
41	Instituto Português do Mar e da Atmosfera	IPMA	Portugal	√
42	Jarðfeingi	Jardfeingi	Faroe Islands	√
43	Regierungspräsidium Freiburg	LGRB	Germany	
44	Geologischer Dienst Nordrhein-Westfalen	GD NRW	Germany	
45	Landesamt für Geologie und Bergwesen Sachsen-Anhalt	LfU	Germany	
46	Vlaamse Milieumaatschappij	VMM	Belgium	
47	Norwegian Petroleum Directorate	NPD	Norway	
48	United Kingdom Research and Innovation - British Geological Survey	UKRI-BGS	UK	√