Version June 2020

Sustainable Energy Authority of Ireland

National Energy Research, Development & Demonstration Funding Programme

FINAL REPORT TEMPLATE

SECTION 1: PROJECT DETAILS – FOR PUBLICATION

Project Title	Developing Site Investigation Methodologies and Constraint Mapping Products for Offshore Renewable Energy (DeSIRE)
Lead Grantee (Organisation)	University College Dublin (UCD)
Lead Grantee (Name)	Dr. Mike Long
Final Report Prepared By	Dr. Mark Coughlan and Dr. Mike Long
Report Submission Date	17 December 2021

	Name	**Organisation**
Project Partner(s)	Dr. Shane Donohue Tony Lombard	University College Dublin APEX Geophysics
Collaborators		

Project Summary (max 500 words)
Please provide an overview of your project, the context, objectives, key results and outcomes. The DeSIRE project was a collaborative research initiative undertaken by the Irish Research Centre for Applied Geosciences (iCRAG) and APEX Geophysics, funded under the SEAI RD&D Funding Programme 2019. The target area for the DeSIRE survey was located in the north Irish Sea, east of Dundalk Bay. Within this area there are a number of proposed offshore wind farm projects at various stages of planning and development. The complex Quaternary history of this area has resulted in a legacy of geotechnically challenging deposits. Therefore in this area, three offshore field-scale case study areas were identified for investigation, including a nearshore area comprising sands and glacial units overlying bedrock, an interface zone consisting of a complex glacial till stratigraphy overlain by varying degrees of Holocene sands and silts and finally an area of soft, fine-grained sediments (clays, silts and sands) overlying a glacial unit. This latter area is also known to have shallow gas hosted in marine sediments.

iCRAG and APEX have identified seismic refraction, underwater multichannel analysis of surface waves (UMASW) and multichannel sparker seismic techniques as tools that can improve data collection practises at sea and reduce the costs of site investigations.

To successfully site foundation structures and mitigate against critical structural failure resulting from such geohazards understanding seabed conditions using robust geophysical and geotechnical data is paramount. Therefore, the overall scientific goal of the DeSIRE survey was to gather high-resolution data at selected sites in the north Irish Sea, which will be used for research into potential geohazards that may constrain infrastructure development and impact on future offshore renewable energy (ORE) deployment.

Within these three areas, a total of 20 individual sites were investigated using seismic refraction/UMASW data acquisition. These sites corresponded with locations where there was good geological control based on previous shallow core and in-situ cone penetration testing (CPT) data. To compliment this dataset, approximately 83.4 km of multichannel sparker data was collected across the 3 areas and 16 site locations.

In this study the UMASW technique was successfully applied across this variety of geological conditions and a range of water depths from 17 to 45 m, obtaining reliable shear wave velocity (V_s) profiles from the seafloor to approximately 30 m below the surface. UMASW proved effective at Clogherhead and Dundalk Bay in characterising sediments at depths below CPT refusal. However, UMASW was less effective at the Western Irish Sea Mudbelt in determining the presence of shallow gas, which was identified using a combination of CPTU (mainly pore water pressure, u_2 values) and seismic sparker profiles. V_s and CPTU profiles in particular show good agreement and can be used to develop classification charts for offshore deposits in complex geological areas. The survey work showed that the 3 methods complimented each other.

The project also demonstrated that the techniques can be successfully employed using locally available craft without the need to expensive non-indigenous survey vessels. It also proved that expertise exists within Ireland to booth undertake and analyses the data resulting from such surveys.

Keywords (min 3 and max 10)	Site investigation, geohazards, geophysics, geotechnics, constraint mapping, marine spatial planning

* All technical reports had been previously submitted to SEAI by August 2021

NB – Both Section 1 and Section 2 of this Final Report will be made publicly available in a Final Technical Report uploaded online to the National Energy Research Database.

In the following Section, please provide a clear overview of your project, including details of the key findings, outcomes and recommendations. The section headings below are provided as a guide, please update or add to these as best suits your project.

By submitting this project report to SEAI, you confirm you are happy for Section 1 and Section 2 of this report to be made publicly available. If you wish to request edits to this section in advance of publication, please contact SEAI at EnergyResearch@seai.ie.

SECTION 2: FINAL TECHNICAL REPORT – FOR PUBLICATION (max 10 pages)

2.1 Executive Summary

The Developing Site Investigation Methodologies and Constraint Mapping Products for Offshore Renewable Energy (DeSIRE) survey was a collaborative research project undertaken by the Irish Research Centre for Applied Geosciences (iCRAG) and APEX Geophysics, funded under the Sustainable Energy Authority of Ireland (SEAI) National Energy Research Development and Demonstration (RD&D) Funding Programme 2019. iCRAG and APEX have identified seismic refraction, multichannel analysis of surface waves (MASW) and multichannel sparker seismic techniques as tools that can improve data collection practises at sea and reduce the costs of site investigations.

Through the DeSIRE project, iCRAG and APEX have developed these techniques in the Irish context producing key data-driven outputs that de-risk offshore renewable energy and provide guidance and support to policy makers, public bodies and developers through constraint mapping and geotechnical assessments. Subsequently, the project results will directly feed into current investigation and development activities for Irish offshore wind farms. The use of these novel technologies on Irish sites will improve both the expertise and capabilities of Irish researchers and consultants alike. Moreover, the development of a protocol to characterise sub-seabed sediment properties incorporating the use of the MASW and sparker seismic techniques will provide easy access to other operators to adopt the same procedure that has been evaluated in this "proof of concept" project.

The north Irish Sea is earmarked for the development of several offshore wind farms. The complex Quaternary history of this area has resulted in a legacy of geotechnically challenging deposits. Therefore in this area, three offshore field-scale case study areas were identified for investigation based on previous work and a desktop study, including;

1. A nearshore area close to **Clogherhead** comprising sands and glacial units overlying bedrock;
2. A potential ground zone wedge (GZW) outside **Dundalk Bay** consisting of a complex glacial till stratigraphy overlain by varying degrees of Holocene sands and silts;
3. An area of soft, fine-grained sediments (clays, silts and sands) overlying a glacial unit. This area, known as the **Western Irish Sea Mud Belt**, is also known to have shallow gas hosted in marine sediments.

Within these three areas, a total of **twenty individual sites** were investigated using seismic refraction/UMASW data acquisition. These sites corresponded with locations where there was good geological control based on previous shallow core and in-situ cone penetration testing (CPT) data. To compliment this dataset, approximately **83.4 km** of multichannel sparker data was collected across the 3 areas and 16 site locations.

Analysis of the data gathered suggests distinct variations in seismic velocity profiles corresponding with discrete units identified from single-channel sparker previously analysed. In the Dundalk Bay area, lower than expected seismic velocities suggest the presence of an intermediate till layer. Multichannel sparker data worked particularly well in the Western Irish Sea Mud Belt area where resolution below a gas layer had proven problematic with single-channel data previously. Details in bedrock depth and morphology were also noted in this area. Seismic velocity data from this area suggests a weathered bedrock potentially.

In this study the UMASW technique was successfully applied across this variety of geological conditions and a range of water depths from 17 to 45 m, obtaining reliable V_s from the seafloor to approximately 30 m below the surface. UMASW proved effective at Clogherhead and Dundalk Bay in characterising sediments at depths below CPT refusal. These included heterogenous glacial sediments. However, UMASW was less effective at the Western Irish Sea Mudbelt in determining the presence of shallow gas, which was identified using a combination of CPTU (mainly u_2 values) and seismic sparker profiles. V_s and CPTU profiles in particular show good agreement and can be used to develop classification charts for offshore deposits in complex geological areas.

The application UMASW did prove to be a cost-effective method of characterising the sub-seabed, providing valuable V_s profiles. When used in combination with other methods such as CPTU and seismic sparker, these profiles provide a robust characterization of the sub-seabed with the 3 methods complimenting each other.

The project also demonstrated that the techniques can be successfully employed using locally available craft without the need to expensive non-indigenous survey vessels. It also proved that expertise exists within Ireland to booth undertake and analyses the data resulting from such surveys.

2.2 Introduction to Project

The target area for the DeSIRE survey was located in the north Irish Sea, east of Dundalk Bay (Figure 1). Within this area there are a number of proposed offshore wind farm projects at various stages of planning and development.

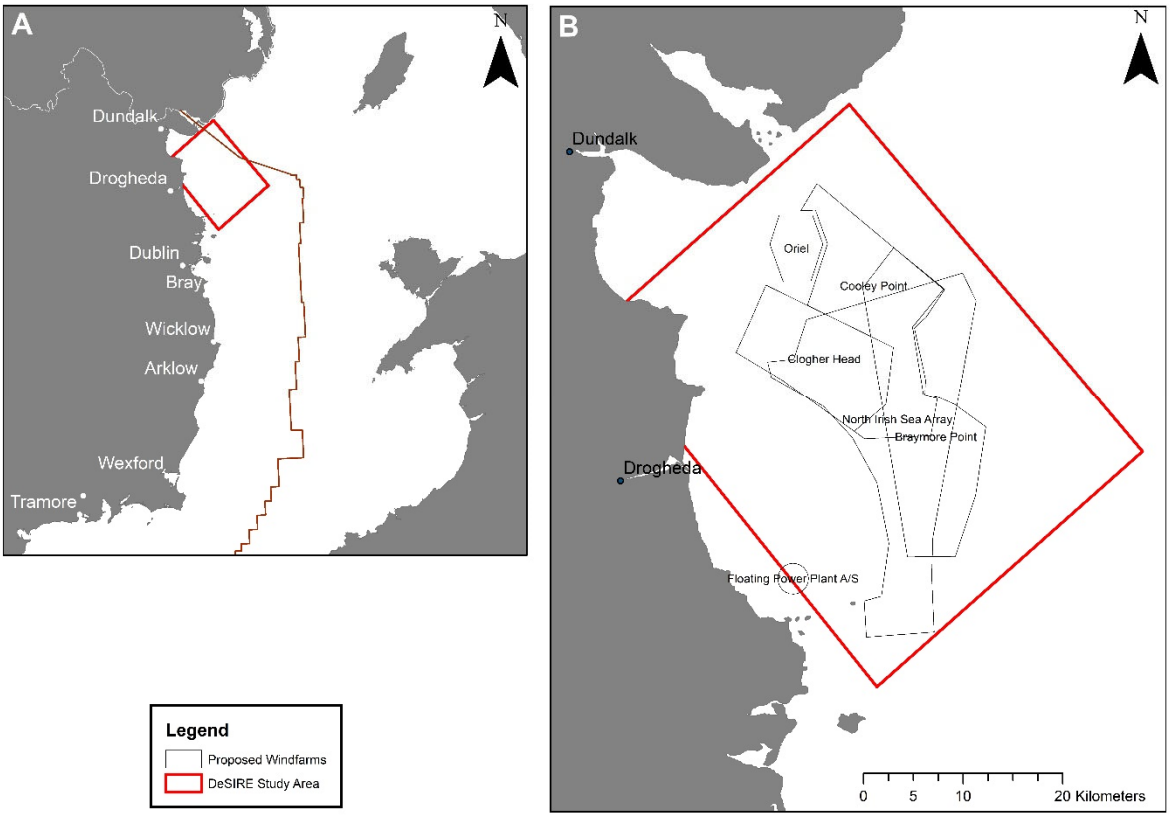

Figure 1 DeSIRE study area in the Irish Sea (A) and highlighted in B with proposed wind farms for the area

These projects will be key to Ireland meeting much of its future energy demand through renewable power generation, hence de-carbonising our economy and helping us to reach our EU climate and energy targets. At present there are no turbines constructed in this area, although significant potential geohazards have been identified by the presence of glacial units near the surface, shallow gas and soft, under-consolidated sediments (Coughlan *et al.*, 2019; Coughlan, Long and Doherty, 2020). Such

sediments and features can severely constrain where turbines can be sited and offer significant engineering challenges.

To successfully site foundation structures and mitigate against critical structural failure resulting from such geohazards (i.e. shallow gas, under-consolidated sediments and glacial units) understanding seabed conditions using robust geophysical and geotechnical data is paramount. Therefore, the overall scientific goal of the DeSIRE survey was to gather high-resolution data at selected sites in the north Irish Sea, which will be used for research into potential geohazards that may constrain infrastructure development and impact on future offshore renewable energy (ORE) deployment.

2.3 Project Objectives

The DeSIRE project had the following aims:

1. Providing greater clarity on the sub-seabed structure through the acquisition of novel, high-resolution seismic data;
2. Garnering a greater insight into the engineering properties of geological layers in the Irish Sea which can be used in key front-end engineering (FEED) design for foundations and cable routes.

To achieve these aims, the key objectives of the DeSIRE survey are:

I. To gather critical geophysical and geotechnical data in the Irish Sea that can be validated and integrated with previously gathered in-situ data to develop a robust geotechno-stratiography;
II. To successfully deploy and improve seismic investigation techniques in an Irish offshore context, including UMASW and multichannel sparker;
III. To develop robust best practice methodologies for these techniques to help improve and standardise future deployment of the equipment;
IV. To build up a unique Geographical Information System (GIS) based geotechnical database and constraint map, with associated risk register, of offshore sediments in the Irish Sea that can be used in future engineering and environmental studies.

These objectives were be achieved at several sites in the north Irish Sea that are potential areas of identified windfarm development. The data from this project feeds into the ongoing offshore wind work at the Irish Centre for Research in Applied Geoscience (iCRAG), which is led by Dr. Mark Coughlan and Dr. Mike Long.

2.4 Summary of Key Findings/Outcomes

The main objective of this study was to further develop and test the application of a novel multichannel analysis surface waves (MASW) method in determining the properties of Irish offshore sediments, and integrate this data with other state-of-the-art site investigation techniques, namely cone penetration testing (CPTu) and multichannel sparker (MCS) data, to better constrain challenging geological conditions for the development of offshore renewable energy infrastructure. To our knowledge, this was the first time such an integration has been attempted in Irish conditions. To this end we conclude the following:

1. The integration of MASW, CPTu and MCS was successfully applied in 4 significantly different geological environments in the north Irish Sea.
2. This method has been shown to be capable of both defining the stratigraphy and layering in an area, and also obtaining geotechnical design parameters without need for intrusive investigation.
3. The deployment and acquisition of MASW proved successful in water depths up to 45 m and applicable in all conditions building on previous work by UCD and APEX (e.g. McGrath *et al.* 2016).
4. These techniques can be employed using relative small vessels, which are readily available in Ireland, without the need for specialised vessels.
5. In addition, these techniques and methods have been developed here using indigenous Irish expertise both in academia (UCD) and industry (Apex), providing significant experience to staff at Irish SME to enable them to grow their business in an area crucial to Ireland's future energy needs.
6. The main constraints posed by ground conditions in the DeSIRE study area:
    a. Soft sediments
    b. Shallow gas
    c. Heterogeneous glacial units which may be over-consolidated

7. Multi-channel sparker may be best suited to deeper environments and proved highly suitable in determining bedrock below the acoustic blanking effect of shallow gas.
8. Robust and reliable data results were garnered to 30 mbsf, suggesting these methods are generally applicable to other Irish offshore conditions.
9. Results were in good agreement with CPTu data where available, and in areas where CPTu could not penetrate to depth, V_s from MASW offers a robust inference on material present.
10. Glacial deposits in the north Irish Sea, including till, exhibits a high degree of vertical and lateral variability which isn't well captured often in single channel sparker data. MASW offers a reliable method with which to map this variability.
11. The use of V_p derived from multichannel sparker is also useful in determining and mapping this variability.

2.5 Project Impact

Central to the deployment of critical offshore energy infrastructure, and accelerating the development of renewable energy systems, is a firm understanding of seabed conditions and their geotechnical parameters. At present, there is a paucity of such information in Ireland and a growing need for reliable, cost-effective techniques that can deliver robust geological and seabed conditions surveys to overcome engineering challenges and prepare for impact assessments. By undertaking a multi-technique geophysical approach to site investigation and integrating the subsequent data into robust ground modelling and site characterisation, the DeSIRE project has proven this approach as a viable concept, which offers the opportunity to significantly reduce costs.

In this way, the expertise, processes and data generated by the DeSIRE has helped address a number of key needs in the Irish Energy Sector, specifically the offshore renewable energy sector. Primarily, the collaboration and transfer of knowledge between industry and academia has grown Ireland's national capacity to undertake independent offshore survey work and provide high-quality data for use in international class R&D. In particular this refers to the development of MASW as a viable site investigation technique as part of offshore wind development. This technology is applied widely in the onshore development of ORE infrastructure such as turbine foundations, but it's use in offshore settings is still under-developed. This project has shown MASW capable of obtaining reliable data for use in the design process, as well as providing a working methodology assessment of data acquisition procedures, data processing, the type of seismic source used and the optimum spacing of the receivers required to produce good quality data over the required depth intervals.

The proof of this concept allows it to support solutions that enable technical and other barriers to energy market uptake to be overcome, specifically understanding challenging ground conditions offshore in order to make more informed and data-driven decisions around suitable site selection and foundation design. The use of the data as part of integrated constraint mapping, as undertaking as part of the DeSIRE project, highlights areas of the Irish seafloor which may prove costly in terms of development due to challenging characteristics. The high-level outcome of this work provides guidance and support to policy makers and developers through results and outcomes in relation to site selection and seabed zonation.

2.6 Recommendations

The results of the DeSIRE project, along with previous work by the project partners, would suggest that MASW is a viable technique that can be deployed as part of future offshore site investigations for offshore renewable energy development in Irish offshore conditions. The fact that the technique can be deployed from relatively small vessels without the need for large, specialised ones helps reduce costs and increases flexibility. Both of which are key considerations for any planned offshore campaign. There is significant scope for Irish supply chain, in particular specialist consultants and contractors, such as Apex, to be world-leaders in the utilisation of this technology and, therefore, significant opportunities to support offshore infrastructure development projects world-wide.

For the research community, the ability to undertake such independent offshore surveys using relatively low-cost vessels and indigenous equipment offers opportunities to deliver meaningful research into Irish seabed conditions.

The value of multichannel sparker seismic data was highlighted as part of the DeSIRE project, particularly in areas where identifying bedrock depths proved challenging. In this project, seismic source equipment was supplemented by state-of-the-art seismic receivers (i.e. multichannel streamer). Given the high-quality and value of the data collected it is recommended that a cost-benefit analysis be undertaken by the INFOMAR programme as to whether the procurement of multichannel equipment and provision of multichannel data will provide sufficient "value add" to justify the investment. It is the view of the project partners that it would when compared to existing shallow seismic datasets on offer.

2.7 Conclusions and Next Steps

The main conclusions have been outlined in Section 2.4. The techniques and technologies have been proven to be suitable and valuable in gathering data in challenging offshore ground conditions. The data derived from the geophysical techniques showed good correlation with in-situ data from CPTu. However, missing from this study is the empirical correlation between the MASW data in particular and lab-based geotechnical testing of samples from the same locations to provide control. Therefore, an important next step would be to undertake a similar study, but to incorporate borehole and lab-testing information. This is particularly relevant to the heterogeneous glacial deposits found offshore Ireland, that are likely to be encountered in the majority of offshore wind farms to be developed in Irish waters.