LLŶR FLOATING OFFSHORE WIND PROJECT

Llŷr 1 Floating Offshore Wind Farm

Environmental Statement

Volume 6: Appendix 19C – Electromagnetic Field (EMF) Assessment

August 2024

Prepared by: Llŷr Floating Wind Ltd

Document Status

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Glossary of project terms

Term	Definition
The Applicant	The developer of the Project, Llŷr Floating Wind Limited.
Array	All wind turbine generators, inter array cables, mooring lines, floating sub-structures and supporting subsea infrastructure within the Array Area, as defined, when considered collectively, excluding the offshore export cable(s).
Array Area	The area within which the wind turbine generators, inter array cables, mooring lines, floating sub-structures and supporting subsea infrastructure will be located.
Floventis Energy	A joint venture company between Cierco Ltd and SBM Offshore Ltd of which Llŷr Floating Wind Limited is a wholly owned subsidiary.
Landfall	The location where the offshore export cable(s) from the Array Area, as defined, are brought onshore and connected to the onshore export cables (as defined) via the transition joint bays.
Llŷr 1	The proposed Project, for which the Applicant is applying for Section 36 and Marine Licence consents. Including all offshore and onshore infrastructure and activities, and all project phases.
Marine Licence	A licence required under the Marine and Coastal Access Act 2009 for marine works which is administered by Natural Resources Wales (NRW) Marine Licensing Team on behalf of the Welsh Ministers.
Offshore Development Area	The footprint of the offshore infrastructure and associated temporary works, comprised of the Array Area and the Offshore Export Cable Corridor, as defined, that forms the offshore boundary for the S36 Consent and Marine Licence application.
Offshore Export Cable	The cable(s) that transmit electricity produced by the WTGs to landfall.
Offshore Export Cable Corridor (OfECC)	The area within which the offshore export cable circuit(s) will be located, from the Array Area to the Landfall.
Onshore Development Area	The footprint of the onshore infrastructure and associated temporary works, comprised of the Onshore Export Cable Corridor and the Onshore Substation, as defined, and including new access routes and visibility splays, that forms the onshore boundary for the planning application.
Onshore Export Cable(s)	The cable(s) that transmit electricity from the landfall to the onshore substation.
Onshore Export Cable Corridor (OnECC)	The area within which the onshore export cable circuit(s) will be located.
proposed Project	All aspects of the Llŷr 1 development (i.e. the onshore and offshore components).
Onshore Substation	Located within the Onshore Development Area, converts high voltage generated electricity into low voltage electricity that can be used for the grid and domestic consumption.
Section 36 consent	Consent to construct and operate an offshore generating station, under Section 36 (S.36) of the Electricity Act 1989. This includes deemed planning permission for onshore works.

LLŶR FLOATING OFFSHORE WIND PROJECT

Issued: 26/06/2024

EMF Assessment Report

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ABBREVIATIONS AND ACRONYMS

The abbreviations and acronyms used in this report are defined in Table 1.

Table 1 – Abbreviations and Acronyms

Abbreviation / Acronym	Definition
A	Ampere
AC	Alternating Current
AEP	Annual Energy Production
CAPEX	Capital Expenditure
cm	Centimetre
COD	Commercial Operation Date
DC	Direct Current
EIA	Environmental Impact Assessment
EMF	Electromagnetic Field
GB	Great Britain
GBP	British Pound Sterling
GW	Gigawatt
GWh	Gigawatt-Hour
HV	High Voltage
kA	Kiloampere
km	Kilometre
K-m/W	Kelvin-metre per watt
kV	Kilovolt
LAT	Lowest Astronomical Tide
LV	Low Voltage
m	Metre
mA	Milliampere
mH	Millihenry
mF	Millifarad
mT	Milliteslas
MTTR	Mean Time To Recovery
MW	Megawatt
MWh	Megawatt-Hour
NB	Nota Bene
NGESO	National Grid Electricity System Operator
nT	Nanotesla
nV	Nanovolt
OPEX	Operational expenditure
pT	Picotesla
SLD	Single Line Diagram
T	Tesla
TEC	Transmission Entry Capacity
WTG	Wind Turbine Generator
µT	Microtesla

1. Introduction

The use of subsea cables in offshore wind farms may pose a number of risks to marine flora and fauna [1,2], some of which are displayed in Figure 1. The purpose of this document is to analyse and explore Electromagnetic Field (EMF) emissions from the array cables and offshore export cables for the Llŷr 1 offshore windfarm project (the proposed Project). Thermal Radiation from subsea cables will also be discussed.

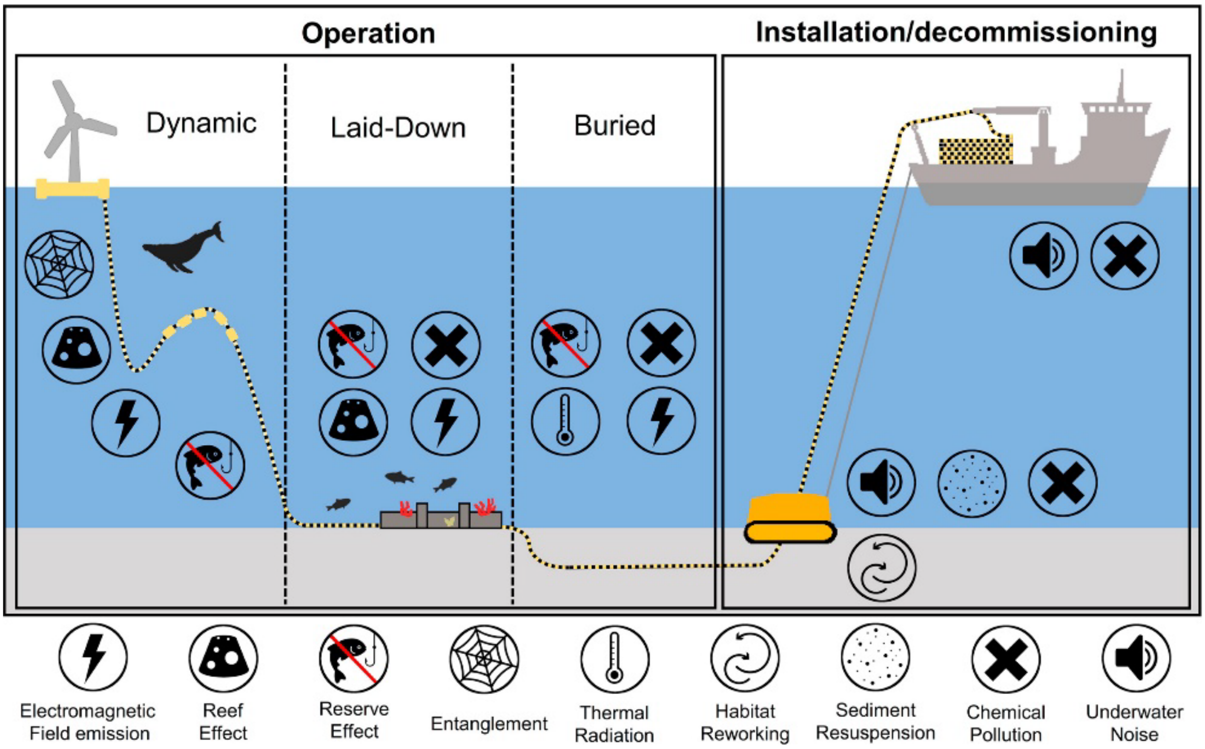

Figure 1 – Effects of Subsea Cabling and the Potential Effects on Local Fauna [1]

2. Project Description

Floventis is developing the proposed Project, located in the Celtic Sea, approximately 35km southwest off the Pembrokeshire coast as shown in Figure 2. Please see Section 3 for a list of the base case assumptions.

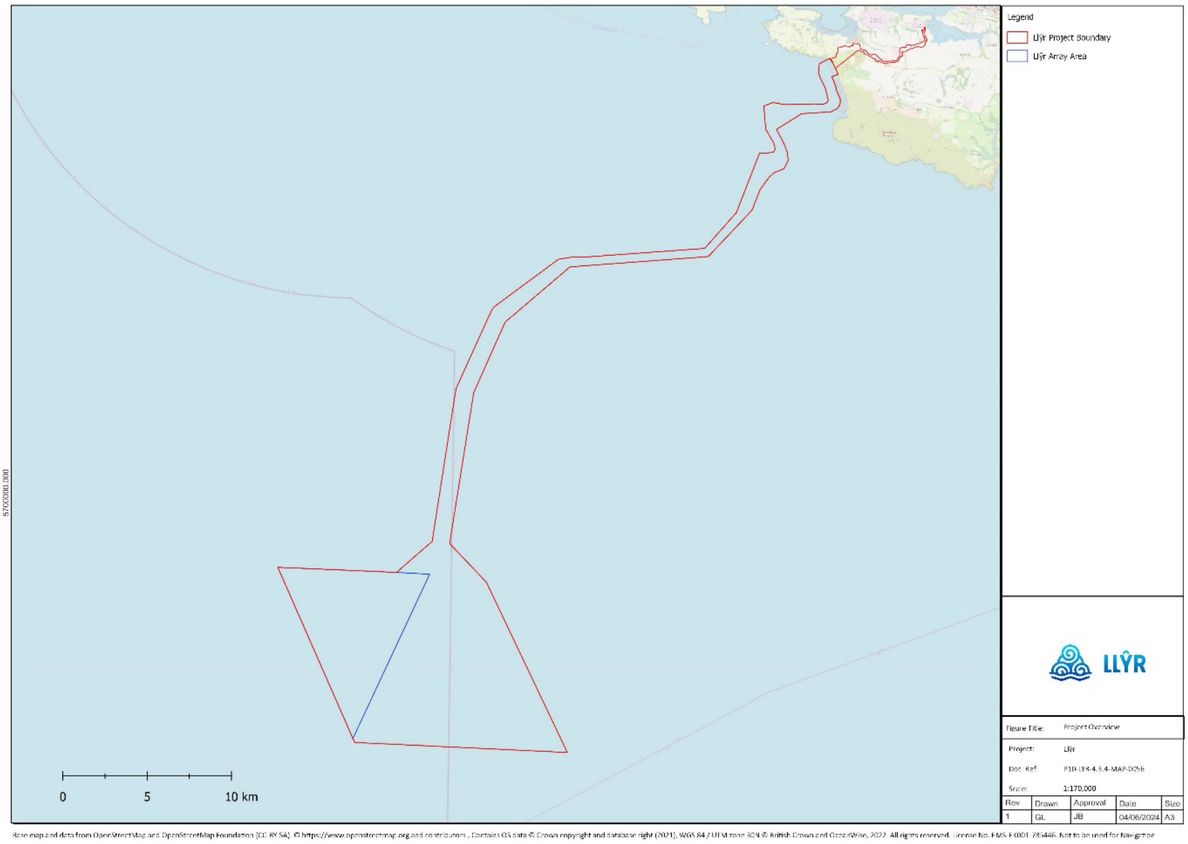

Figure 2 – Proposed Project Area for Llŷr

3. Assumptions

- TEC entry capacity for Llŷr 1 is assumed to be 99.9MW in order to avoid OFTO risk;
- The base case layout for Llŷr 1 is based on 10 x 14 - 19MW turbines;
- The wind farm control system will curtail generation when export at the point of connection reaches 99.9MW;
- Preliminary target cable burial depth is 1.2m. For this report burial depths of 0.5m and 1.25m were shown for comparison purposes, but the effects at 1.2m burial depth can be considered as similar to that of 1.25m burial (Assessment tool calculates from centre of cable);
- Floating array cables are configured in a lazy S arrangement as a base case;
- Resistance and electrical parameters of the cables are taken from manufacturers' data sheets;
- The cores within the subsea cables are arranged in a helix formation such that a full rotation of the cores occurs every 2m of cable length;
- Cable screens and armouring will be connected to earth;
- Any missing subsea cable electrical specification data is calculated based on the cable geometry;
- While 66kV and 132kV voltages have been considered, this report is based on 66 kV as a base case for array cabling and export cable. A 132kV export cable option has also been considered;
- Dynamic cables will be 66kV and would require a subsea 132/66kV transformer if static export cabling is 132kV;
- The project's minimum operational lifetime is 30 years;
- The thermal resistivity of the seabed is assumed to be 0.7 K·m/W;
- The magnetic field density on the seabed due to the Earth is assumed to be ~50µT;
- The peak tidal current speed of water is assumed to be 1.03 m/s [10]; and

- Any parameters not provided have been assumed to be a reasonable/industry standard value.

3.1. Cable Infrastructure

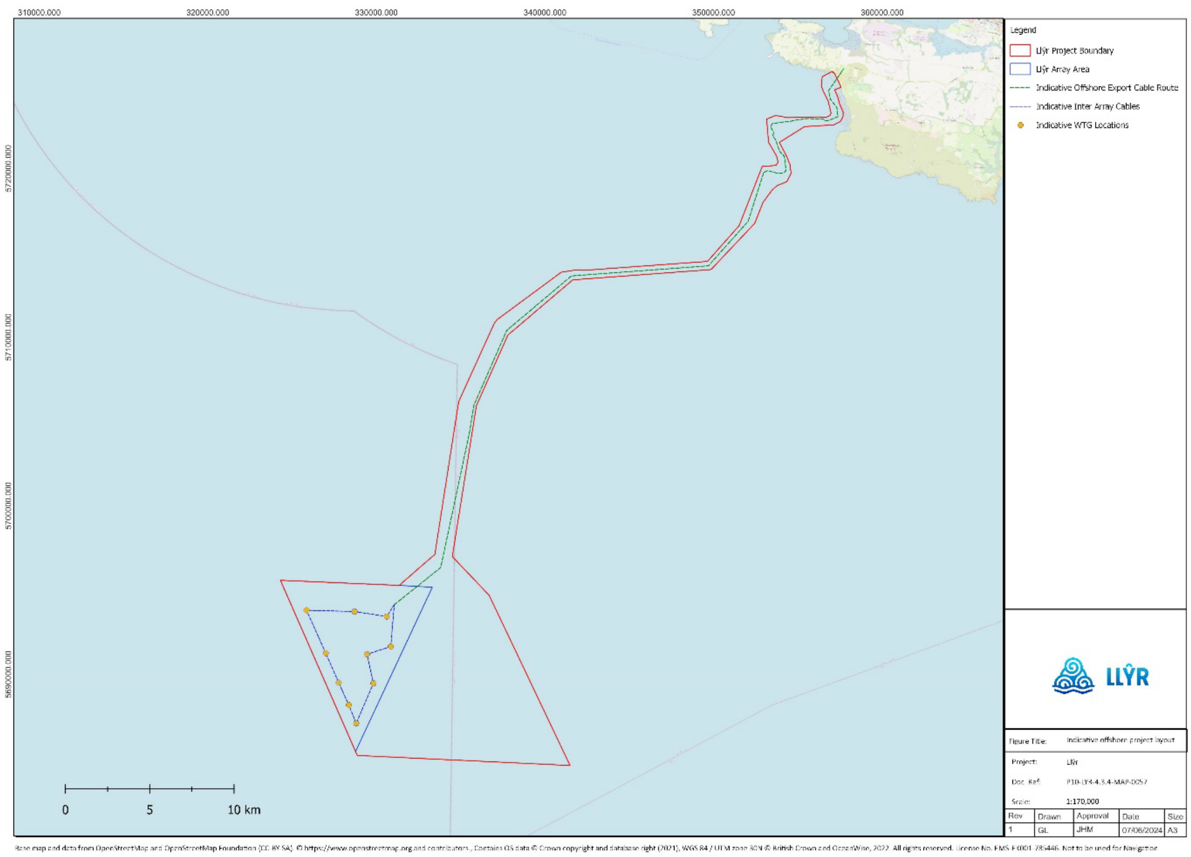

Figure 3 - Indicative Array Area and Offshore Export Cable Route

The cable sizes considered for this report are shown in Table 2.

Table 2 – Cable Nomenclature and Information

Cable	Cable Purpose	Cable Core Area	Cable Core Material
1200 Al	66 kV Subsea Export	1200 sqmm	Aluminium
800 Al	66 kV Static Array	800 sqmm	Aluminium
400 Cu	66 kV Dynamic Array	400 sqmm	Copper
800 Cu	66kV Dynamic Export	800 sqmm	Copper
400 Al	132 kV Subsea Export	400 sqmm	Aluminium

The maximum load current and estimated length of each cable is shown in Table 3. These load currents and lengths were taken from a PowerFactory model used as a base case for this project. The PowerFactory load flow analysis model was based on 7x 16MW turbines operating at curtailed power of 15.6MW each. Taking losses into consideration this gives a maximum generation output at shore of 99MW.

Table 3 – Cable Max load Current and Lengths

Cable	Max load Current	Cable Length
1200 Al 66kV	0.937 kA	50.58 km
800 Al 66kV	0.791 kA	1.5-2.0 km (for each cable)
400 Cu 66kV	0.791 kA	0.28 km (for each cable)
800 Cu 66kV	0.937kA	0.28 km (for each cable)
400 Al 132 kV	0.490 kA	50.58 km

4. Electromagnetic Fields

The change in electric current through a circuit induces a magnetic field in a closed loop around the circuit, as explained by Ampère's Law (Eq. 1), one of Maxwell's equations of electromagnetism.

$$\oint_C \mathbf{B} \cdot d\boldsymbol{l} = \mu_0 \iint_S \mathbf{J} \cdot d\mathbf{S} = \mu_0 I_{enc} \tag{1}$$

Where:

- $\mathbf{B}$ is the magnetic field,
- $\mathbf{J}$ is the total current density,
- μ_0 is the magnetic constant,
- $\oint_C$ is the closed line integral around the closed curve C,
- $\iint_S$ denotes a 2-D surface integral over S enclosed by C,
- $\cdot$ denotes the vector dot product,
- $d\boldsymbol{l}$ is a differential along the curve C,
- $d\mathbf{S}$ is a surface differential of the surface S,
- I_{enc} Is the enclosed current within the cable.

The electric field induced by the cable is negligible outside of the cable due to screens and cable armouring. The magnetic field induced by the electric field within the cable is strong in a relatively small area around the cable but greatly decreases in strength with radial distance from the cable. See Figure 4 below.

The Earth's magnetic field can have a field density between 20-75µT near the ocean floor [5]. For the Celtic Sea this has been assumed to be ~50µT.

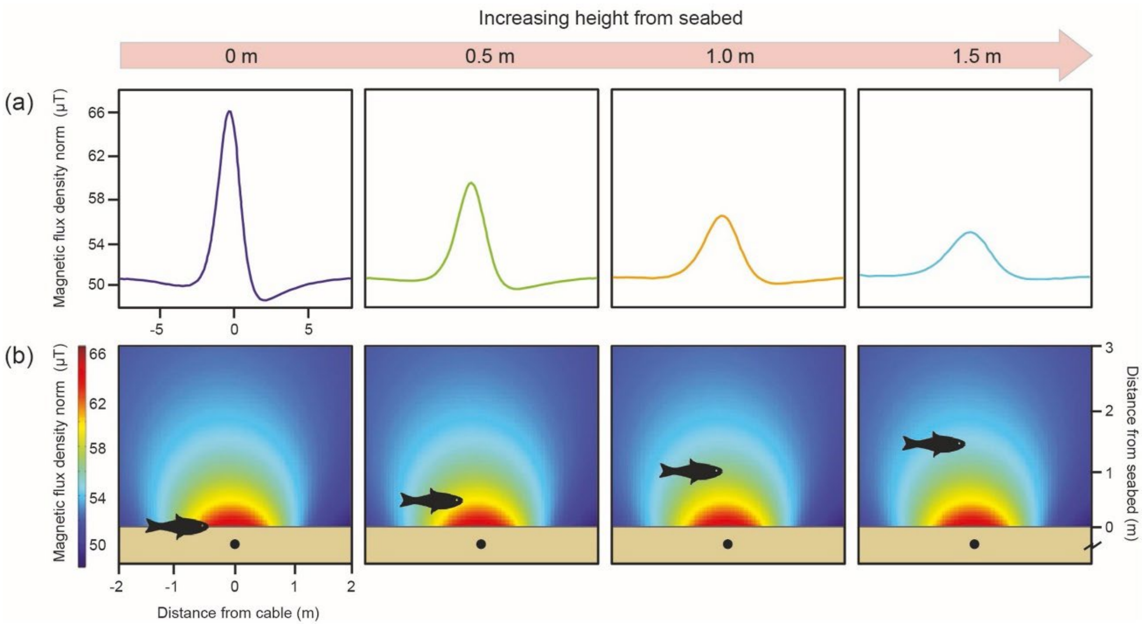

Figure 4 – Example of Marine Fauna Detection of EMF Emissions with Radial Distance from Cable [6]

5. Electric Field

The electric field induced by the cable is negligible outside of the cable due to earth-connected screens and cable armouring [4]. However, an electric filed can be induced by the seawater flow through the magnetic field [3]. The intensity of the field can be estimated based on the following formula:

$$E = \boldsymbol{V_{SW}} \times \boldsymbol{B} \quad (2)$$

Where:

- E is the electric field intensity (in V/m)
- B is the magnetic flux density (in teslas, T)
- V_{SW} is the seawater velocity (in m/s)

6. EMF Emissions of Buried Cables

Cable burial is the most effective mitigation for EMF emission strength at seabed as shown by the relationship displayed in Figure 5.

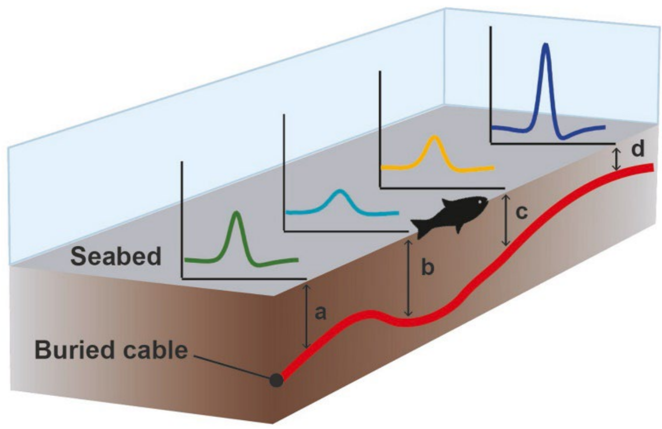

Figure 5 – Burial Depth Relation to Magnetic Field Density [6]

When considering the EMF emissions of cables and their approximate effect on local fauna, buried cables have a significantly reduced EMF signature on the seabed. EMF calculations have been done using the Ausgrid tool used for calculating EMF emission signatures [7]. The EMF emissions measured radially from the seabed for cables buried at a depth of 0.5m and 1.25m are shown in Figure 6 and Figure 7 respectively.

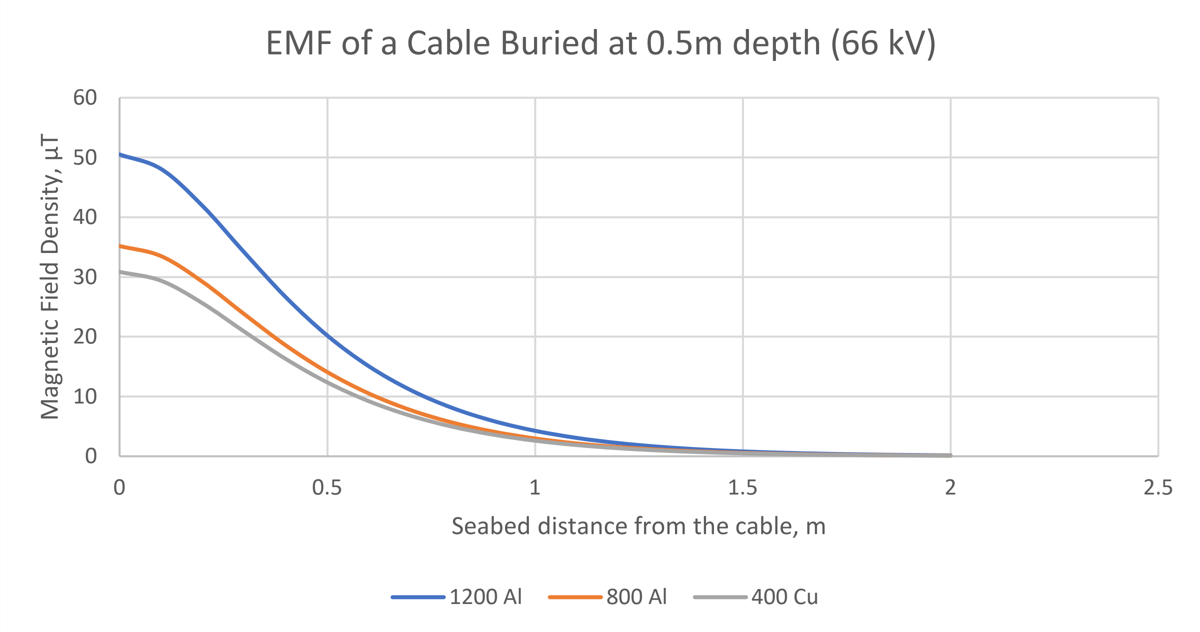

Figure 6 – EMF Emissions Measured at Radial Distance from Seabed Above Cables Buried at 0.5m Depth.

Magnetic field densities at 0, 1, and 2 metres from closest seabed point above buried cable at 0.5m depth is shown in Table 4.

Table 4 – Magnetic Field Density of 66kV Cable Buried at 0.5m Below Seabed

Distance from closest point at seabed	Magnetic Field Density
0 m	50.5 µT
1 m	4.3 µT
2 m	0.1 µT

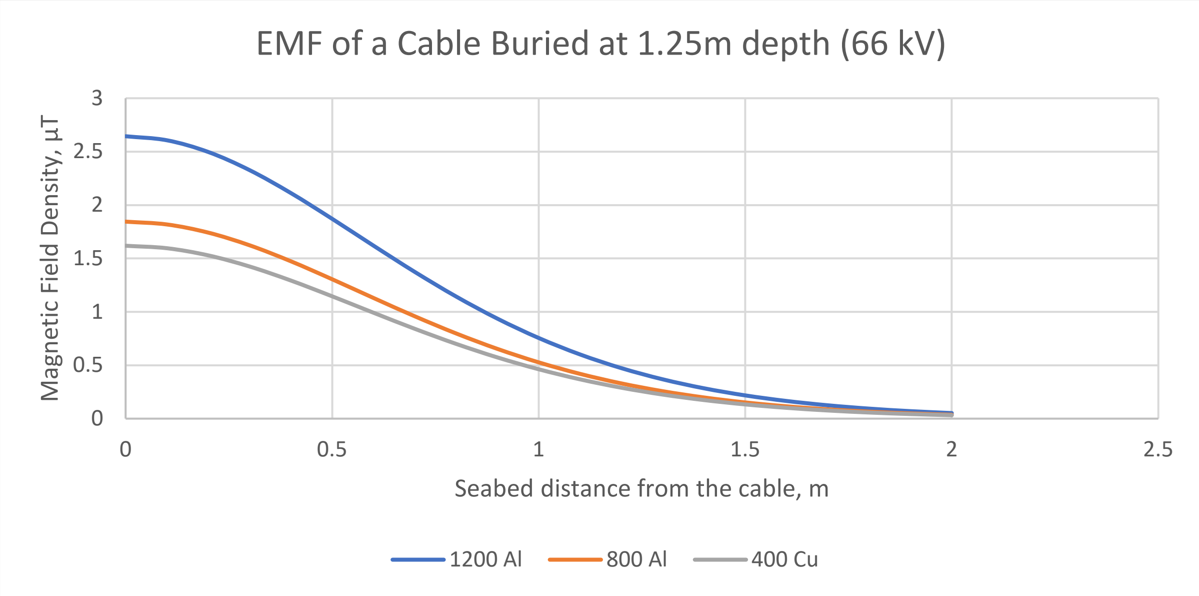

Figure 7 – EMF Emissions Measured at Radial Distance from the Seabed Above Cables Buried at 1.25m Depth.

Magnetic field densities of a 66kV cable buried at 1.25m depth below seabed at 0m, 1m, and 2m from nearest point on seabed above buried cable are shown in Table 5.

Table 5 – Magnetic Field Density of 66kV Cable Buried at 1.25m Below Seabed

Distance from closest point at seabed	**Magnetic Field Density**
0 m	2.6 µT
1 m	0.8 µT
2 m	0.05 µT

It should be noted that 132kV static export cables have also been considered for the Llŷr project. However, the EMF emissions of higher voltage cables are less significant, due to the proportionality of current to magnetic flux density, and higher voltage cables having a lower current at the same power.

7. EMF Emissions at Cable Crossings

EMF emissions can be more significant around cable crossings. This can be due to the cumulative effect of the EMF emissions or the reduced coverage of the crossing cable. For the Llŷr project, the only likely cable crossing is with the Greenlink cable. The Greenlink cable is understood to be a DC cable and is expected to emit EMF magnetic field densities of 21µT directly above the cable [9]. It is likely that the Llŷr cables will be surface laid over the Greenlink cable and then protected using concrete mattresses of 0.45m thickness. It is possible that for the short distance that the Llŷr export cable crosses Greenlink the magnetic field densities will have an additive cumulative effect. The estimated EMF emissions measured radially from the seabed above the crossing of the Greenlink cable are shown in Figure 8. The assessment assumes that the burial depth of the Greenlink cable is a minimum of 1m. The information presented should be considered as a worst-case scenario.

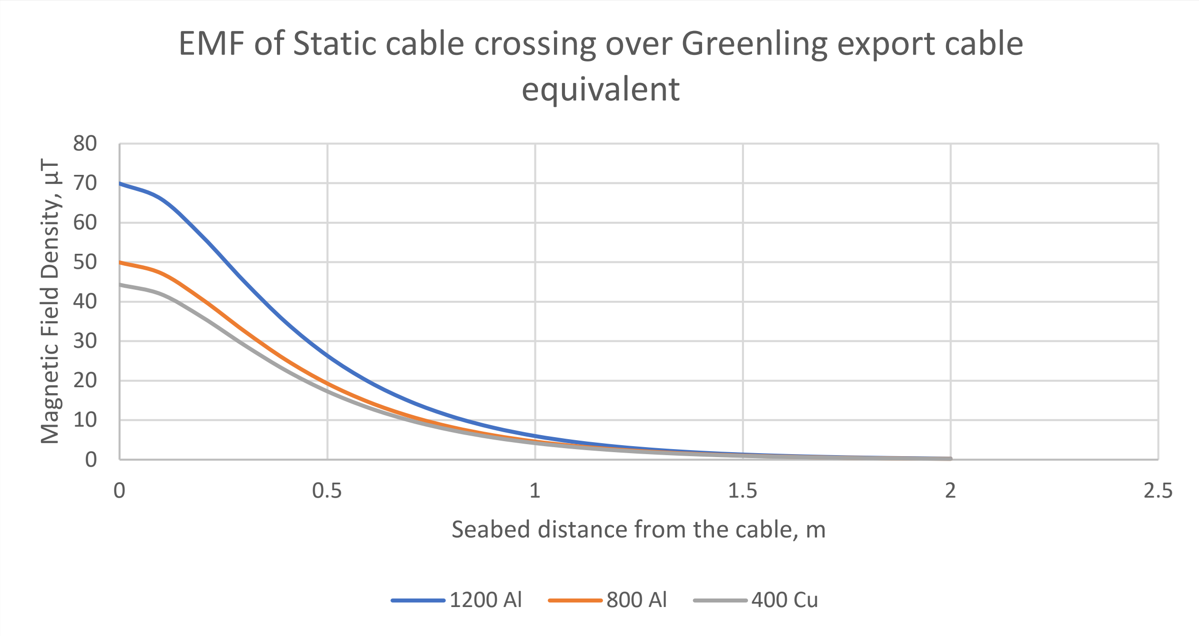

Figure 8 – EMF Emissions of Cable Crossing Measured at Radial Distance from Seabed Above Cables.

8. EMF Emissions of Dynamic or Exposed Cables

The EMF emissions from a cable exposed in the water column such as the dynamic cables connecting from the seabed to a floating WTG (see Figure 1), are more significant than cables that are buried in the seabed. The EMF emissions of a cable exposed in the water column are shown in Figure 9. The EMF emissions are highest at the surface of the cable. Note an 800 Cu option is also shown as this may be necessary to connect the export cable to the first WTG in the array.

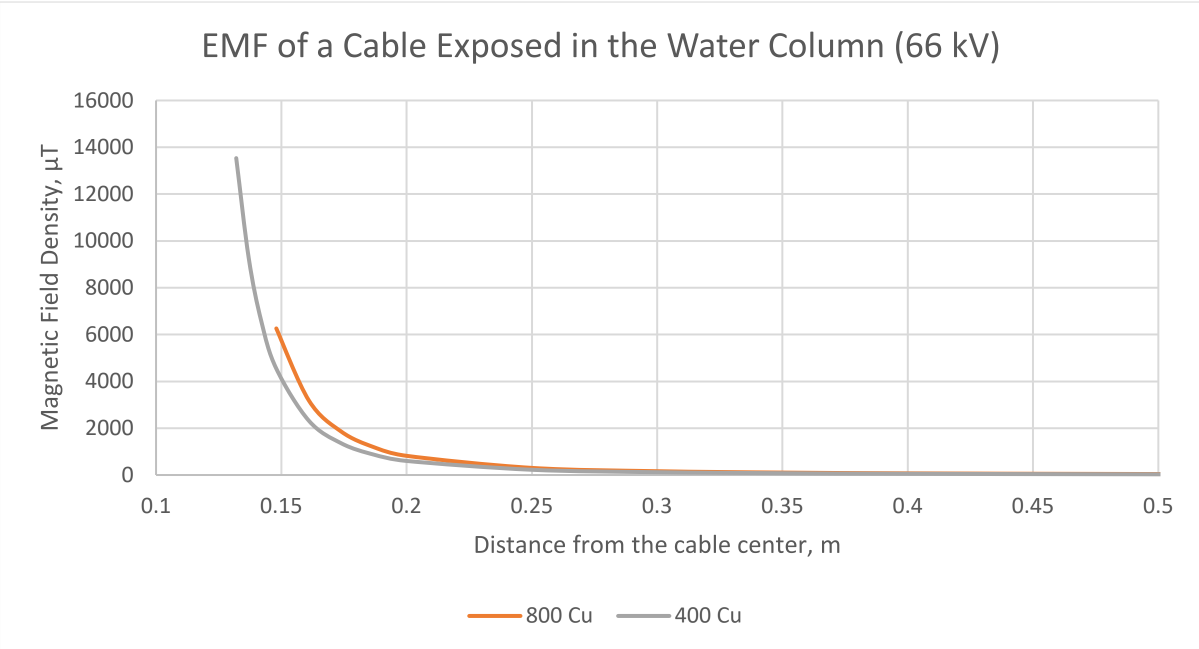

Figure 9 – EMF Emissions Measured at Radial Distance from 66 kV Cables Exposed in Water Column.

For cables in the water column, the EMF radiation in terms of radial distance from the centre of the cable is shown in Figure 10. The "Earth EMF" curve displays the estimated magnetic field density due to the Earth in the Celtic Sea area.

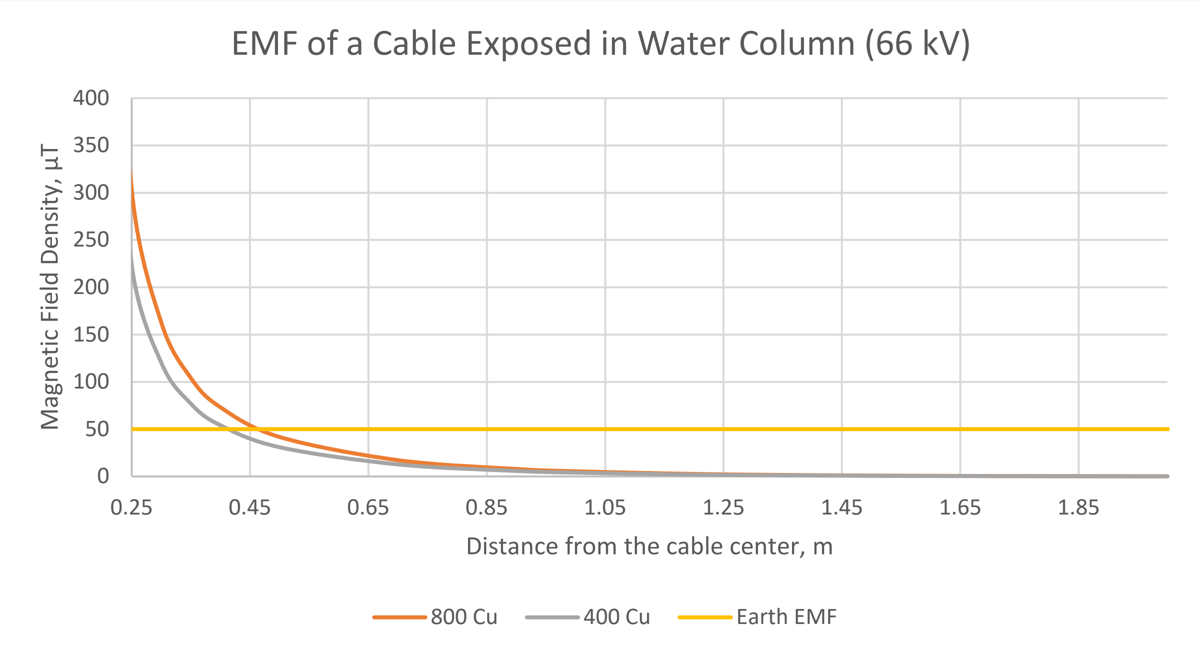

Figure 10 – EMF Emissions of a 66 kV Cable in Water Column

A comparison of distance from the centre of an exposed (dynamic) cable and Earth's EMF is shown in Table 6.

Table 6 – EMF Values for 66kV Cables Exposed in the Water Column (Dynamic)

	Distance from Cable Centre	**Magnetic Field Density**
Cable Surface EMF	~0.15 m	~5.2 mT
Earth EMF	~0.44 m	~50 µT
1% of the Earth EMF	~1.6 m	~500 nT

Another potential issue to consider is the installation of other high voltage equipment on the seabed. Further assessment should be undertaken if subsea transformers or subsea connectors are to be installed on the seabed.

9. Induced electric field

Within the proximity of the cables there are two main sources of magnetic field that can cause the induction of an electric field. The first source is the natural earth's magnetic field. If assumed values (1.03 m/s of water velocity and the earth's magnetic field of 50 µT) are taken into consideration the electric field intensity from the earth's magnetic field is 51.5 µV/m. The second source is the cable itself. The results for the worst case scenario (dynamic cables exposed in the water column) are presented in Figure 11 and Figure 12.

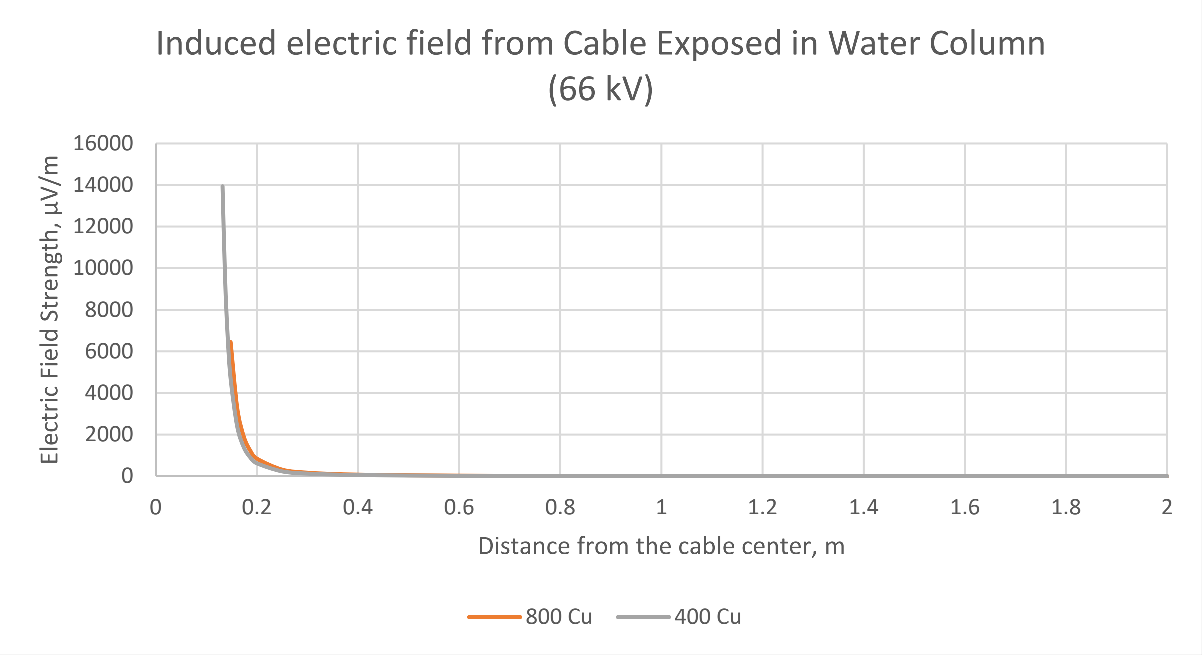

Figure 11 – Induced electric filed within water by a 66kV Cable in the Water Column

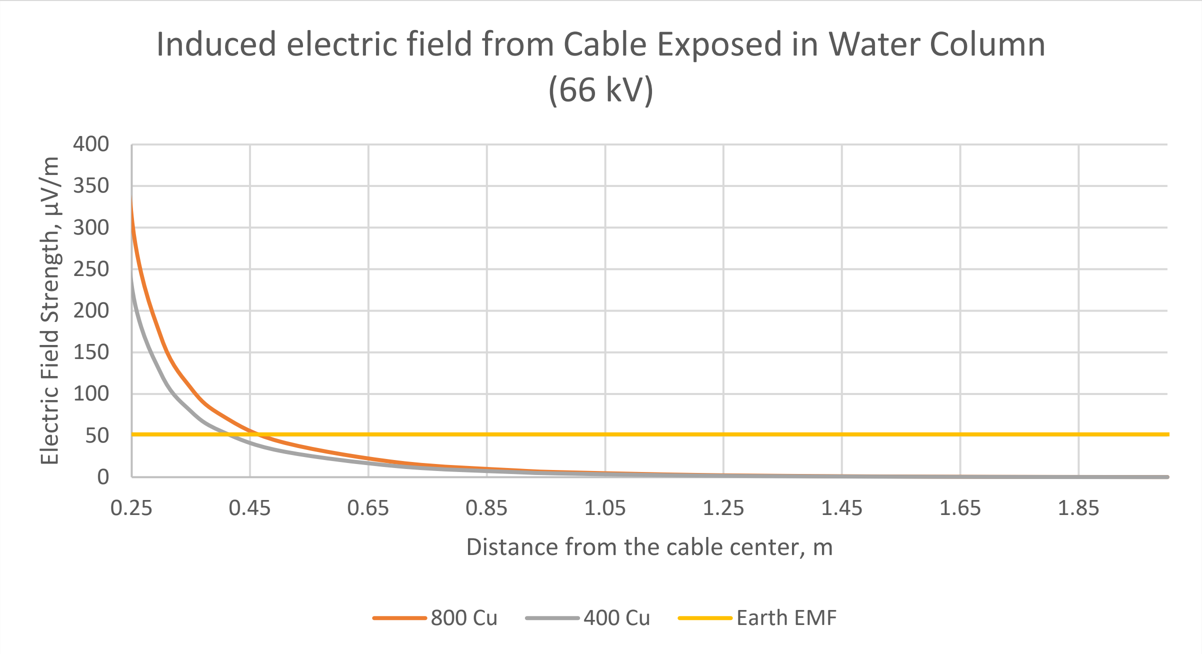

Figure 12 – Induced electric filed within water by a 66 kV Cable in the Water Column compared to the value induced by Earth magnetic field

A comparison of distance and Electric Field strength from the centre of an exposed (dynamic) cable and Earth's EMF is shown in Table 7.

Table 7 – Electromagnetic field magnitude Values for 66kV Cables Exposed in the Water Column (Dynamic)

	Distance from Cable Centre	Electric Field Strength
Cable Surface iE	~0.15 m	~5.4 mV/m
Earth iE	~0.44 m	~51.5 µV/m
1% of the Earth iE	~1.6 m	~515 nV/m

10. Heat Emissions

Power transmission will cause the environment directly adjacent to the subsea cables to increase in temperature relative to the surrounding area. The electric field within the cable excites the materials slightly, losing transmitted power to heat via the vibration of atoms within the cable-layers. This heat is transferred from the cable into the surrounding environment, causing a slight increase in ambient temperature. Examples of heat transfer from a subsea cable for different laying methods are shown in Figure 13.

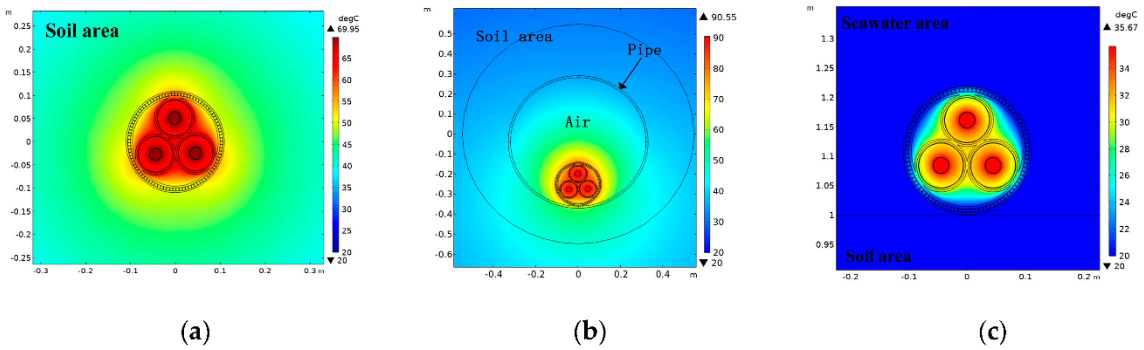

Figure 13 – The Temperature Field Distribution of Submarine Cable for Three Laying Methods. (A) The Temperature Field Distribution of Submarine Cable for Direct Burial Laying. (B) The Temperature Field Distribution of Submarine Cable for Pipe Laying. (C) The Temperature Distribution of Submarine Cable for Sub-Sea Laying. [8]

As can be seen a cable exposed in the sea does not significantly increase the temperature of the surrounding water. This implies that dynamic cables in the water column will not have a significant impact on the temperature of the local environment.

Cables laid within the seabed will increase the temperature of the surrounding sediment.[11][12]

Cable joints, subsea cable connectors, subsea transformers, or the point of burial for static cables are all potential cases where heat emissions should be considered. [1]

11. Conclusions

- EMF emissions from the array cables and offshore export cables for the Llŷr 1 offshore windfarm project have been assessed.
- For Llŷr project static cables buried at 1.25m the maximum magnetic field density at the seabed directly above the cable is calculated to be 2.6µT.
- It is possible that for the short distance where the Llŷr export cable crosses the Greenlink cable the magnetic field density at the seabed directly above the cable could reach a maximum of 70µT.
- Cable burial is an effective method for mitigation of the influence of EMF emissions on the environment.
- For Llŷr project dynamic cables exposed in the water column the maximum magnetic field density at the surface of the cable is calculated to be ~5.2 mT. The electric field strength at the surface of the cable is calculated to be ~5.4 mV/m. At ~0.44 m from the cable centre the Electric Field Strength will be ~51.5 µV/m – approximately equal to the electric field induced by the earth's magnetic field.
- The effects from EMF reduce with distance from a cable and is negligible after 2.0m.
- Dynamic cables exposed in the water column will not significantly increase the temperature of the surrounding water.
- Cables laid within the seabed will increase the temperature of the surrounding sediment.
- Cable joints, subsea cable connectors, subsea transformers, or the point of burial for static cables are all potential cases where heat emissions should be considered.

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