# Preliminary Environmental Information Report Volume 2

## Appendix 2.4 Thermal Emissions Technical Note

LLK1-ARU-REP-ENV-000004_AP2.4

Revision 0.0

October 2025

LIONLINK

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# 1 Introduction

1.1.1 This report is part of National Grid Ventures' (NGV) (the 'Applicant') Development Consent Order (DCO) and Deemed Marine Licence (DML) application to the Secretary of State (SoS) for the construction and operation of the proposed LionLink interconnector (the 'Project'). This report has been prepared during the pre-application stage in parallel with the Preliminary Environmental Information (PEI) Report. It aims to support the Environmental Impact Assessment (EIA) process by establishing through a literature review the anticipated heat emissions associated with the offshore high voltage direct current (HVDC) cables for the Proposed Offshore Scheme.

1.1.2 The Proposed Offshore Scheme would consist of two ± 525kV HVDC submarine cables carrying 1714 amps (A) each leading to a capacity of 2 x 1000MW (2GW total). The HVDC cables will operate in a bipole configuration and will be bundled together in one trench. A separate dedicated metallic return (DMR) would be installed in the same trench as the HVDC cables (the pole cables). Under normal bipole operation the rated electrical current will flow through the pole cables with no current flowing in the DMR. Under fault or maintenance conditions, involving the loss of one of the poles, the other pole and the DMR would carry the rated current. A worst case minimum burial depth of 1m was assumed for the purposes of this review.

## 1.2 Policy framework

1.2.1 The installation and operation of submarine power cables in the United Kingdom (UK) are governed by a range of national policies aimed at balancing the need for renewable energy and cable infrastructure with the protection of the marine environment. There are no thresholds established in UK waters specifically for heat emissions amongst the range of policies and regulations that require environmental impact assessment of effects; as such it is necessary to draw on standards utilised elsewhere in the North Sea.

1.2.2 The guidance proposed by the German Federal Agency of Nature Conservation (BfN), is that the temperature rise above the buried cable in the top 0.2m sediment depth in the general economic exclusion zone (EEZ) should not exceed 2 Kelvin (2K), with a higher threshold of 2K in 0.3m sediment depth in the Wadden Sea. The standard was introduced to prevent the changing of marine aquaculture and biological life and can be achieved under most circumstances with a burial depth of 1m (Ref 1).

1.2.3 In the UK, two tools are routinely used to determine sensitivity of protected features to offshore activities; the Marine Evidence based Sensitivity Assessment (MarESA) and the Feature Activity Sensitivity Tool (FeAST). Both tools consider the pressure 'temperature increase (local)' providing a benchmark as a 5°C increase in temperature for one month period, or 2°C for one year. It should be noted that this pressure and benchmark does not explicitly relate to a temperature increase in sediment, rather it considers evidence of species tolerance to temperature changes either in the water column, or throughout their distribution ranges.

## 1.3 Baseline environment

1.3.1 The ambient water temperature within the North Sea varies through the year with average winter temperatures at the North Sea surface of 5-9°C, while summer temperatures average 12-17°C, with an annual average water temperature 12.6°C. Temperature measurements taken during the marine surveys undertaken in November-December 2024, recorded an average temperature of the sediment, 13cm below the seabed, to be 15.1°C.

# 2 Literature review

## 2.1 Introduction

2.1.1 Operational HVDC cables emit heat due to the Joule effect, where electrical energy is converted into thermal energy. This heat emission can lead to localised temperature increases at the cable surface and the surrounding environment. The extent of heat emission is influenced by factors such as the physical characteristics, type, load, and electrical tension of the cable, burial depth, sediment characteristics (thermal conductivity, thermal resistance), and environmental conditions such as water flow (Ref 12; Ref 5). These are described further in the sub-sections below.

### Cable type and electrical load

2.1.2 HVDC cables typically emit less heat compared to high voltage alternating current (HVAC) cables at equal transmission rates due to lower transmission losses (Ref 9). The maximum allowable temperature of the conductor is typically 70°C (some cable manufacturers offer maximum values up to 90°C), with this temperature only being met where the system operates at full load continuously for an extended period of time (months/years). In reality the system will not be at full load for this long and therefore temperatures will fluctuate and are unlikely to reach the maximums that modelling calculates.

2.1.3 The electrical load on the cable directly influences the amount of heat generated. Higher loads result in greater heat emission (Ref 15).

### Burial depth and sediment characteristics

2.1.4 The heat generated by the cable is dissipated into the surrounding environment, with buried cables causing a more significant temperature increase in the sediment compared to surface laid cables (Ref 15).

2.1.5 The thermal conductivity and resistance of the sediment play a crucial role in determining the extent of heat dissipation (Ref 9).

2.1.6 Sediments with low thermal conductivity, such as cohesive sediments, retain more heat, leading to higher temperature increases around the cable (Ref 7, Ref 15). Emeana et al (2016) (Ref 5) note that the heat transfer and temperature fields generated from submarine high voltage cables buried within a range of sediments are highly variable. Thermal resistance of different sediment types is provided in **Table 2.1** below (Ref 5, Ref 20).

### Table 2.1: Thermal resistivity of sediments

| Sediment type | Thermal resistivity (K*m/W) |
|---|---|
| Gravel | 0.3 - 0.5 |
| Sand | 0.4 - 0.7 |
| Fine Sand | 0.7 |
| Clay | 0.6 - 1.1 |
| Till and lag sediments | 0.3 - 0.4 |
| Mud | 0.5 - 0.7 |

2.1.7 With regards to temperature differences as a result of the differing thermal resistance, coarse silts are shown to be purely conductive, producing temperature increases of >10°C above ambient up to 40cm from the source (source = 60°C); fine sands demonstrate a transition from conductive to convective heat transfer between cf. 20 and 36°C above ambient, with >10°C above ambient heat increases occurring over a metre from the source (source = 55°C ); and very coarse sands exhibit dominantly convective heat transfer even at very low (cf. 7°C) operating temperatures and reaching temperatures of up to 18°C above ambient at a metre from the source at surface temperatures of only 18°C.

#### Water flow

2.1.8 Constant water flow around surface laid or dynamic cables helps dissipate heat, confining it to the cable surface. In contrast, buried cables in comparatively static water conditions can lead to warming of the surrounding sediment (Ref 9).

## 2.2 Case study analysis

2.2.1 Numerical modelling of HVDC cables suggests that temperature increases can vary significantly based on cable specifications and environmental conditions. For instance, a study by Emeana et al. (2016) (Ref 5) indicated that temperature increases of up to 15°C could occur within a few centimetres of the cable surface, depending on the cable's current load and burial depth.

2.2.2 Studies have shown that the heat generated in HVDC cables is primarily due to resistive losses in the conductors and insulation materials. According to research on power transmission, cables can operate at temperatures of up to 70°C, with thermal losses varying according to the cable’s operational current and voltage. For example, Ostergaard et al. (2020)(Ref 13) provide detailed simulations of heat dissipation in submarine cables, highlighting that heat flux from cables buried in sandy or silty seabeds could range from 20 to 30 W/m^2, depending on the cable’s size and operational parameters.

2.2.3 Works by Olofsson et al. (2018) (Ref 14) and Zhang et al. (2021) (Ref 17) provide key models for heat diffusion around buried cables, accounting for factors such as seabed material properties and cable depth. Their models suggest that heat diffusion in the marine environment occurs most rapidly in the immediate vicinity of the cable but decreases exponentially with distance. The presence of sediments, particularly those with high thermal conductivity like sand, can facilitate quicker heat dispersal, while more insulating layers (e.g., clay or silty seabeds) may trap heat.

2.2.4 Kumpel (2014) (Ref 8) provides results from the 600kV DolWin3 HVDC route, revealing a heating of 25°C at the cable location in 1.5m depth. In 30cm depth the heating of the surrounding sedimentation is just 0.53K.

2.2.5 Field measurements from the Nysted offshore wind array, which includes AC cables, showed a maximal temperature increase of about 2.5°C at 50cm directly below the cable (Ref 9). HVDC cables can be expected to have lower thermal radiation due to the decreased transmission losses, similar thermal effects may have the potential to result in localised temperature increases in the sediment

2.2.6 This literature review examines the predicted thermal properties and potential environmental impacts of submarine cables through the lens of eight case studies: Nysted Offshore Wind Farm, Cambois Connection, Viking Link, NeuConnect, GridLink, Eastern Green Link 2, Eastern Green Link 3 and Eastern Green Link 4. These projects provide insights into the likely thermal emissions and potential ecological consequences of submarine cable operations. A range of sediment types have been classified within the case studies, with the majority classified as coarse sediment and sand.

### Nysted Offshore Wind Farm

2.2.7 The Nysted Offshore Wind Farm in Denmark has been extensively studied for its thermal impacts. Measurements of seabed temperature near the 33kV (inter array) and 132kV (export cable) power cables showed that seabed temperatures were generally higher close to the cables. All cables are buried into the seabed, however the targeted cable burial depth of 1 m was not consistently achieved.

2.2.8 The highest recorded seabed temperature was 17.7°C, significantly higher than the ambient seabed temperature (Ref 9). Field measurements confirmed a temperature rise of up to 2.5°C at 50 cm below the cable. The maximum difference between test sensors on the 132kV export cables and the control site was 2.5K, the mean difference was less than 1K (0.8K).

2.2.9 The results during the period of greatest difference for the 132kV are summarized below (taken from Ref 9, temperature references in °C).

### Inset 2.1: Temperature references recorded at Nysted Offshore Windfarm (Ref 8)

Temperatures recorded at the 26th Oct 2006 (date of maximum difference of seabed temperature between the affected site in vicinity of the 132 kV cable and the control site) at Nysted offshore windfarm by IfAÖ Ltd.

| | depth below seabed | 132 kV cable: perpendicluar above the cable | 132 kV cable: 30 cm to the side | reference | Δ T max |
|---|---|---|---|---|---|
| seabed | 50 cm | 14.8 | 13.6 | 12.3 | 2.5 |
| seabed | 40 cm | 14.6 | 13.2 | 12.3 | 2.3 |
| seabed | 30 cm | 14.4 | 12.9 | 12.2 | 2.2 |
| seabed | 20 cm | 13.5 | 12.6 | 12.1 | 1.4 |
| seabed | 10 cm | 12.5 | 12.4 | 12.2 | 0.3 |
| seabed | 0 cm | 12.1 | 12.2 | 12.3 | -0.2 |
| water body | | 12.1 | 12.2 | 12.4 | |

#### Cambois Connection

2.2.10 The Cambois Connection comprises up to four HVDC subsea cables linking the Berwick Bank Wind Farm to Landfall, with a minimum target burial depth of 0.5m. The EIA for the Cambois Connection project (Ref 2) included reference to modelling studies that predicted temperature increases of up to 10°C within a few centimetres of the cable surface, with predicted increases at 0.5m of 2.5°C. The project proposes up to four 525kV HVDC cables, buried at a minimum target burial depth of 0.5m. The conclusions drawn within the EIA are that impacts will be highly localised, with no significant effects anticipated (Ref 2).

#### Viking Link

2.2.11 The Viking Link project is a HVDC electrical interconnector with an approximate capacity of 1400MW. The Viking Link commissioned a report to provide a prediction of likely physical heating effects as manifested by temperature increases within sediments overlying the buried Viking Link cables. The focus of the report was to consider the predicted temperature rise at a sediment depth of 0.2m below the seabed surface, directly above various cable design scenarios, all buried at 1.5m. This relates specifically to national regulations in Germany where there is a requirement to achieve a burial depth which will result in a temperature elevation of not more than 2°C (equivalent to 2K) at a depth of 0.2m within overlying sediments.

2.2.12 The modelling approach used by the 2K Study adopted a number of assumptions relating to both the marine environment and power transmission. The thermal conductivity of the seabed was assumed to be 1.4 W/(K m) and the background temperature a relatively high 15°C (Ref 14). The data collected during the marine surveys undertaken in 2024, showed an average temperature of 15.1°C (Ref 21).

2.2.13 The 2K Study concluded that, depending upon cable design criteria, bundled cables would require between 0.7m and 1.15m of sediment cover before the 2K rule is met (i.e. temperature increase at 0.2m sediment depth is < 2°C).

### NeuConnect

2.2.14 The NeuConnect project is a 1400MW HVDC interconnector project between the UK and Germany, with target burial of 1.5 to 2m. The NeuConnect EIA presented field measurements and modelling studies which predicted temperature increases of up to 8°C within a few centimetres of the cable surface (Ref 10). The EIA noted the potential for thermal radiation to affect sediment properties and benthic communities. The project undertook modelling and implemented cable burial to a depth of 1.5m as mitigation to ensure that the 2K limit is complied with (as applicable at 30cm in the German territorial sea or 20cm in the German EEZ).

### GridLink

2.2.15 GridLink is a 1,400MW HVDC electricity interconnector, linking the existing electricity grids in the UK and France, with an anticipated cable burial depth of between 1.7m and 3.5m (Ref 6). The EIA included detailed modelling of thermal impacts, predicting temperature increases of up to 14°C near the cable surface, and calculated that the maximum calculated temperature at the seabed for bundled cables buried to 1.5m is 15°C, with almost zero increase compared to the ambient seabed temperature. Temperature increases in the upper sediments of the seabed over the cables were calculated to not change compared to the ambient temperature for buried cables and are only anticipated to exceed 2°C within 5m of the cables where cables are transitioning out of buried state to become surface laid. The anticipated burial depth is 1.5 to 2m which is expected to mitigate the thermal emissions.

### Eastern Green Link 2

2.2.16 Eastern Green Link 2 is a 2GW HVDC cable connecting Peterhead in Aberdeenshire and Drax in North Yorkshire, with an anticipated target burial depth of 1.5m, and a minimum depth of at least 0.6m. The EIA for the Eastern Green Link 2 project documented potential thermal impacts on marine ecology, with modelling studies predicting temperature increases of up to 15°C within a few centimetres of the cable surface. Heat dissipation modelling for bundled cables trenched to a depth of 1.5m indicated that within 50cm of the seabed surface the increase in sediment temperature is limited to approximately 3°C which has been calculated based upon a maximum seabed ambient surface sediment temperature of 15°C (Ref 4).

### Eastern Green Link 3 and Eastern Green Link 4

2.2.17 Eastern Green Link 3 is a 2GW HVDC cable connecting Peterhead in Aberdeenshire and Walpole in West Norfolk, with landfall at Anderby Creek, Lincolnshire. Eastern Green Link 4 is a 2GW HVDC cable connecting Fife in Scotland and Walpole in West Norfolk, with landfall at Anderby Creek, Lincolnshire. In English waters the two projects are being consented through a combined Development Consent Order application.

2.2.18 The preliminary environmental information report for the two projects documented potential thermal impacts on marine ecology, with heat calculations being provided for both systems (Ref 18, Ref 19) at 2m burial depth and 6m burial depth (simulating burial beneath sandwaves).

2.2.19 The modelling concluded that, assuming an ambient seabed temperature of 12°C, seabed temperatures at 0.2m immediately above the cables are estimated to be 13 - 14°C, with the cables operating at maximum operating temperatures. It is noted that the actual system is unlikely to reach these temperatures as the system would have to operate at full load continuously for an extended period of time (months/years) to meet these temperatures. In reality the systems would not be at full load for this long and therefore temperatures would fluctuate and not meet the maximums (Ref 18, Ref 19).

# 3 Conclusion

3.1.1 The case studies of Nysted Offshore Wind Farm, Cambois Connect, Viking Link, NeuConnect, GridLink, Eastern Green Link 2, 3 and 4 highlight the potential thermal impacts of submarine cables on the marine environment, which indicate temperature increases can be expected to be at around current accepted limits of 2K or 2°C over a year, over localised areas. The case studies also highlight the standard industry mitigation measure of cable burial which is recognised as dissipating and mitigating the thermal impacts. Cable burial depth to 1.5m can mitigate the exposure of sensitive species to heat emissions, with deeper burial reducing the thermal impact at the sediment-water interface.

3.1.2 While the thermal impacts of submarine cables on marine ecological receptors are less studied compared to other impacts, existing evidence suggests that localised heating can affect benthic organisms and sediment chemistry.

3.1.3 The likelihood of negative ecological consequences depends on the extent of temperature increase, the sensitivity of the affected ecosystem, and the implementation of mitigation measures. With appropriate mitigation, such as cable burial, the likelihood of negative ecological consequences is low, and any negative consequence highly localised with a very low likelihood of broader population level consequences.

# Topic Glossary

| Abbreviation | Definition |
|---|---|
| °C | Degrees Celsius |
| BfN | Bundesamt für Naturschutz (German Federal Agency for Nature Conservation) |
| DCO | Development Consent Order |
| dML | Deemed Marine Licence |
| DMR | Dedicated Metallic Return |
| EEZ | European Economic Zone |
| EIA | Environmental Impact Assessment |
| FeAST | Feature Activity Sensitivity Tool |
| GW | Giga Watt |
| HVAC | High Voltage Alternating Current |
| HVDC | High Voltage Direct Current |
| K | Kelvin |
| kV | Kilo Volt |
| M | Metres |
| MarESA | Marine Evidence Based Sensitivity Assessment |
| MW | Mega Watt |
| NGV | National Grid Ventures |
| PEI | Preliminary Environmental Information |
| SoS | Secretary of State |
| UK | United Kingdom |

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