OCS Study
BOEM 2023-006

Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Heat from Buried Transmission Cables

U.S. Department of the Interior
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List of Abbreviations and Acronyms

AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
COP	Construction and Operation Plans
DC	Direct Current
HV	High Voltage
NEPA	National Environmental Policy Act
OCS	Outer Continental Shelf
U.S.	United States

Executive Summary

Concerns have been raised by stakeholders regarding heat generated by transmission cables in offshore wind farms. Offshore wind farms use a range of cable sizes, voltage levels, and cable types depending on the location and arrangement of the wind farm. Most wind farms bury cables to protect them from boat anchors and fishing operations. The effect of heat from buried transmission cables is influenced by many ranging factors, including submarine terrain, sediment type, water depth, water temperature, and species composition. Many elements in concert make a definitive description of effects from heat radiating from submarine high voltage transmission cables very challenging. Research has been conducted investigating heat transmission through submarine sediment and impacts to sediment dwelling marine life from heated submarine cables, but the overall body of research is limited.

This paper provides information about heat generated by electricity and electrical transmission, the use of buried cables for transmission of electricity, heat generated by buried submarine transmission cables, and what is currently known about the effects to undersea life from the heat generated from buried cables. As more offshore wind farms are developed, further research may illuminate deeper levels of information about how cable heat affects sediment dwelling communities. Based on the current research, studies show that the effects of heat on most sediment and seafloor dwelling species overall are low.

1 Introduction

Wind energy production on the Atlantic Outer Continental Shelf (OCS) is a growing industry. Large-scale offshore wind farms are poised for construction, and many others are in varying stages of Bureau of Ocean Energy Management (BOEM) and regulatory approval. Awareness of how these offshore wind farms are built and operated is increasing, and with this awareness, questions about how components of the wind farms affect the environment are also increasing. One aspect of electrical generation and transmission is the subsequent heat generated by transmission cables. Questions about heat generated by buried transmission cables bringing electricity onshore are being raised by stakeholders more often as offshore wind farms are being analyzed through the Construction and Operation Plans (COP) and National Environmental Policy Act (NEPA) process.

This paper provides information about heat generated by electricity and electrical transmission, the types of cables used in offshore wind, the use of buried cables in offshore wind farms, heat generated by transmission cables, and what is currently known about the effects to undersea life from the heat generated from buried cables. Links to more in-depth resources are noted at the end of the paper and can be accessed in the References Section at the end of the document.

2 Background—Electrical Transmission from Offshore Wind Farms

2.1 Generating Power

A wind turbine generates electricity when the force of moving air causes the turbine blades to move by changing the air pressure on one side of the blade. The moving blades spin a rotor, collecting the kinetic energy, which is transformed to electricity through a generator within the turbine. There are two types of electricity used for powering homes and electrical machines, alternating current (AC) and direct current (DC). Electricity generated by wind turbines is AC, which is the type of electricity used to power homes and businesses in the U.S. Power supplied from a battery source is DC, and in the U.S., DC is primarily used for transmitting electricity over long distances. It is also what powers a laptop computer when it is operating from the battery. Electricity can be changed from AC to DC and from DC to AC, which allows flexibility for transport and use. (U.S. Energy Information Administration, 2021; U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, 2015)

2.2 Transmitting Power

Power generated at an offshore wind farm travels through a series of cables and substations before arriving onshore for use by consumers. Medium-voltage AC electricity is generated within the turbines and collected through inter-array cables, which are routed underwater to a central substation within the wind farm. The substation transforms the medium voltage electricity to high voltage (HV) AC electricity. Depending on the distance from shore, the AC power is either transported directly onshore through HVAC submarine cables or converted to DC on an offshore platform and transmitted to shore through HVDC submarine cables. Figure 1 shows a basic layout for an electrical cable relay from turbines transmitting HVAC power to shore. (Baring-Gould, 2014; U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, 2015)

The majority of proposed and existing U.S. offshore wind farms in 2022 use AC power transmitted onshore through submarine cables. Offshore wind projects choose to transmit AC power because of their proximity to shore, the amount of power being produced, and higher cost of investment in an HVDC system. Power is effectively transmitted through buried AC cable lines up to about 30 miles offshore before power losses and cost make AC increasingly prohibitive. As offshore wind farms get larger and are located further offshore, DC transmission will become necessary in order to transmit power longer distances without substantial and costly power losses. Presently, converting AC power to DC requires at least one HVDC converter platform within the wind farm, and another converter station onshore to transform the DC over to AC for consumer use. The additional equipment for DC power is often cost prohibitive until the transmission distances reach over 30 miles from shore. (BVGassociates, 2019; ICF, 2018; Breseti, Kling, Hendriks, & Vailati, 2007)

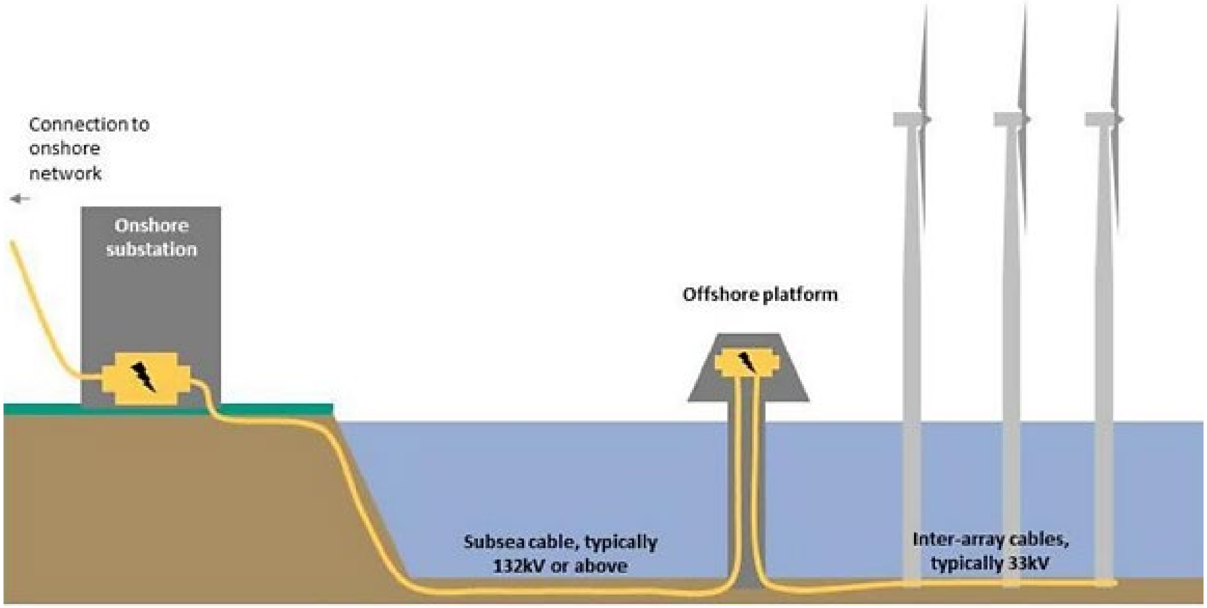

Figure 1. Offshore Wind Electric Cable Schematic from Turbines to Onshore Grid Connection

(Musial, 2018)

2.3 Cables in an Offshore Wind Farm

Inter-array cables conducting electricity from wind turbines to an offshore platform, substation, or converter station can range from 33 to 72.5kV. Cables transmitting power from an offshore platform, substation, or converter station to an onshore substation range from about 200 to 420kV for AC and from 320 to 600 kV for DC (Tetra Tech, 2021). These cables are most often buried in the seafloor as they move the power to substations or converter stations so that vessel anchors or fishing gear do not snag HV electrical cables (Taormina, et al., 2018). The width of the entire cable corridor varies depending on the composition and type of seafloor substrate, water depth, the number of cables being used, and the method of burial (Tetra Tech, 2021). Examples of corridor width include the Sunrise Wind project's inter-array cable corridor, planned to be about 30 feet wide; export cable corridor widths for Sunrise, South Coast, and Vineyard Wind are planned to be 2,280 to 3,280 feet (AECOM, Tetra Tech, Inc. and DNV Energy, USA, Inc., 2021; Epsilon Associates, Inc., 2020; Stantec Consulting Services, 2021). Figure 1 shows a simplified layout of a cable system for an offshore wind farm with inter-array cables and the submarine cable transmitting power onshore.

Cables buried for offshore wind transmission are typically located between 5 and 6.5 feet under the seafloor, but this can vary depending on substrate composition and seafloor topography (Sharples, 2011). Some offshore wind projects use a depth range of 3 feet minimum to 13 feet maximum (AECOM, Tetra Tech, Inc. and DNV Energy, USA, Inc., 2021; Sharples, 2011). In the U.S., a minimum of about 3 feet is recommended for heat dissipation of AC cable, and up to 6 feet for HVDC (Sharples, 2011). Inter-array cables are generally buried from 3 to 8 feet deep; however, some are suspended between platforms in the open water. Because floating offshore wind turbines allow movement of the structures, suspended or "dynamic" cables for inter-array transmission to a fixed offshore substation are used (National Renewable Energy Laboratory, 2022). From the substation, a fixed or buried export cable transmits electricity onshore (Rentschler, Adam, Chainho, Krugel, & Vicente, 2020).

Offshore transmission cables in the U.S. are buried using a variety of machinery, some creating a trench for cable burial, or by horizontal directional drilling, which can reduce disturbance of the seafloor (Sharples, 2011). When cables cannot be buried due to rocky surfaces or other obstacles, cables may be covered with riprap or structures called a concrete mattress, which provide different methods of protecting cable from damage and dislodgement (Levitan and Associates, Inc., 2020). BOEM, the U.S. Army Corps of Engineers, Bureau of Safety and Environmental Enforcement, and some states provide a range of guidance for offshore cable burial within their jurisdictions (Tetra Tech, 2021).

3 Generation of Heat from Transmission Cables

A concern shared by stakeholders is the heat generated by transmission cables. Heat generated from transmission cables varies due to many factors, including cable capacity, AC or DC transmission, length, and the voltage of electricity. The demand for offshore wind energy may not always be consistent, especially during peak or off-peak hours, leading to variable levels of voltage traveling through buried transmission cables. The variable nature of energy flow may produce an inconsistent amount of heat generated from the transmission cables.

When electricity is transported through power cables, a portion of electricity lost in transmission is released as heat (Taormina, et al., 2018). At equal transmission rates, AC cables will emit more heat from transmission losses than HVDC cables; HVDC cables generally can transmit more power than the same size AC line (OSPAR Commission, 2012; Taormina, et al., 2018). As of 2021, the maximum operational temperature tolerance of high voltage conductor cables is about 194 degrees Fahrenheit (°F) (OSPAR Commission, 2012).

Transmission cables are insulated to provide physical protection from water, corrosion, and other elements, and to protect them from damage. The insulation also retains heat in the cable. A common insulation used for offshore wind transmission is called XLPE, which stands for cross-linked polyethylene (Sharples, 2011). These cable surfaces have an upper heat limit of 158°F (Tetra Tech, 2021). An optimal operating range for a cable is between ambient temperature and up to 68°F above ambient (Sharples, 2011). Higher temperatures are generated with larger levels of electricity transmission, and cables will generate more heat as they transmit closer to their transmission capacity (Sharples, 2011). As of 2021, HVAC cables for onshore transmission are being qualified for up to 420 kilovolts (kV) and a maximum operating temperature of 194°F (Tetra Tech, 2021).

A study measuring heat from two AC cables, 33 kilovolts (kV) and 132 kV, was conducted at the Nysted wind farm in 2006 (Taormina, et al., 2018). Sensors were placed near each cable and measurements were gathered and compared to a control site. The substrate was considered medium sand at the measurement sites. Overall, the highest temperature difference between the sensor closest to the 132 kV cable was on average about 4.5°F higher than the control site, and the mean difference was only about 1.8°F. The study showed that temperatures were higher surrounding the 132 kV cable when electricity was being transmitted during the times of maximum wind farm operation. Both power production and ambient water temperature correlated with changes in temperatures measured in the study. Further studies will provide stronger data to help determine more conclusive heating levels of sediment from transmission and inter-array cables. (Meißner, Schabelon, Bellebaum, & Sordyl, 2006; Taormina, et al., 2021)

3.1 Heat Transfer--Water

Underwater cables experience heating from electrical transmission; however, the heat dissipates quickly within the marine environment (Taormina, et al., 2018). Water can absorb heat due to what is called its *high specific heat*, requiring a high level of energy, such as heat from a fuel source or the sun, to increase the temperature, compared to most liquids (U.S. Geological Survey, 2018). The hydrogen in the water molecules is attracted to other hydrogen atoms in surrounding water molecules, and it takes energy (heat) to separate the attractions. This energy is what is absorbed, making water able to dissipate heat more readily than other liquids (Brewer & Peltzer, 2019). Heat transferred through a cable or other object will be transferred through the sea water until the temperature balances out and reaches thermal equilibrium (National Aeronautics and Space Administration, 2021). Because of the ability for water to absorb heat, the amount of heat generated from transmission cables is not enough to create a discernable change in ocean temperature. Ocean temperatures range depending on several factors, including distance from shore, depth, and location within climate zones. Generally, sea temperatures drop with depth to about 39°F at 3,280 feet deep (Ardelean & Minnebo, 2015). Colder water has a high capacity for absorbing heat due to the strong hydrogen bonds (Brewer & Peltzer, 2019).

3.2 Burial Depth and Sediment Type

Research has been conducted to measure the intensity and distribution of heat being generated in buried transmission cables. Most studies have been in a laboratory setting with only a few conducted on offshore transmission lines. The laboratory studies conducted by Emeana, et al. (2016) considered heat flow patterns through varying substrates from the sea floor. Their research showed that in sediments with low permeability, like coarse silts (approximately 0.045 millimeters [mm] or 0.0018 inches[in]), the heat is conducted equally around the circumference of the cable. In these cases, the heat may not be conducted to the surface of the sediments where sea life occurs due to the insulating properties of the substrate. The heat that is not conducted away from the cable may eventually degrade cable insulation from too much heat being concentrated in proximity of the cable. Sediments with medium to high permeability, such as fine sand (0.20 mm or 0.008 in) or very coarse sand (1.23 mm or 0.05 in), showed the heat being transferred upward and away from the cable toward the water-sediment interface. The most permeable sediments allow the most heat to travel to the surface of the seafloor and allow for surface warming. (Emeana, et al., 2016)

4 Effects of Heat on Marine Species

Many elements in concert make a definitive description of effects from heat radiating from submarine cables very challenging. As discussed in Section 3, cable size, capacity, AC or DC transmission, the qualities of water including water temperature, burial depth, and sediment type influence heat generated from transmission cables (Taormina, et al., 2018). In general, transmission cables for offshore wind farms are buried under the seafloor. Although some wind farms may have suspended cables, usually for inter-array connections, due to the heat absorbing qualities of water and the volume of the ocean, effects from heat from suspended cables are low to none (Meißner, Schabelon, Bellebaum, & Sordyl, 2006). Research conducted on heat from submarine cables has shown effects on some types of sediment and species that inhabit that sediment.

4.1 Sediment-Dwelling Species

Most seafloor organism communities inhabit the upper 8 inches of sediment. Overall, research has shown that heat from buried cables is generally dissipated before reaching within 8 inches of the surface when cables are buried 2 to 4 feet deep (Tetra Tech, 2021). Shallow water habitat often has higher water temperatures than offshore due to the smaller area of water absorbing heat, compared to deep ocean habitats with colder water (see Section 3.1). Shallow water sediment dwelling species may be more vulnerable to warmer sediments because less cold water is available to dissipate the heat. Low-mobility species that inhabit coarse, sandy, higher permeability substrate are more likely to be affected by heat from submarine cables.

Studies of heat related impacts specific to sediment dwelling (benthic) species from HV submarine cables are few (OSPAR Commission, 2012). A laboratory study using a heating element to warm sediment showed a benthic polychaete worm (*Marenzelleria viridis)* avoided warmer sediment; however, a crustacean (*Corophium volutator)* was unaffected (Meißner, Schabelon, Bellebaum, & Sordyl, 2006). Both species are tube dwelling, but the crustacean does not burrow as deeply into the sediment and spends more time outside of the tube compared to the polychaete worm (Meißner, Schabelon, Bellebaum, & Sordyl, 2006). The crustacean's ability to spend time away from heated sediments may explain why it does not appear to be as affected by the heat compared to the stationary polychaete worm (Meißner, Schabelon, Bellebaum, & Sordyl, 2006). Both species are native to Atlantic coastlines in Europe but can be found on the U.S. North Atlantic coastline as a non-native species, inhabiting shoreline areas, marshes, and mudflats (Smithsonian Environmental Research Center, NDa; Smithsonian Environmental Research Center, NDb)

Research on deep water benthic species is not presently available to provide insights into effects to those species. Marine life inhabiting permeable sediments above an active buried HV transmission cable could be affected by heat being transferred through coarser sediment grains. Species that are unable to relocate easily may not be able to withstand warmer temperatures. If species cannot move or adapt to warmer sediment, some or all may not survive the heat transfer from the buried HV cables (Emeana, et al., 2016). Some sea life may find the heated area desirable habitat, and it may provide new or expanded habitat for species. Heated sediment may experience altered oxygen content or changes in chemical properties that could affect microorganism profiles and bacterial growth, which could also affect seafloor inhabitants if the conditions of the sediment no longer support life function. Species may be forced to relocate to more hospitable conditions or could perish if the species is not motile. (National Marine Fisheries Service, 2020; OSPAR Commission, 2012; Taormina, et al., 2018; Sharples, 2011)

4.2 Seafloor Species

Mobile species such as lobster, scallops, sand dollars, sea stars, have the ability to relocate if substrate temperatures become too warm or if the chemical structure of the sediment becomes undesirable. Similarly, species that attach to rocks or other substrate above the sea floor, such as anemones and barnacles are not likely to see effects from heated sediment. Distance within the water column from the sea floor is likely to dissipate the heat and have minimal to no effect on these non-motile species. Most species are more disrupted by the overall cable installation and effects from habitat loss within the cable corridor than the effects of a relatively narrow area of 1 to 13 feet of warm substrate above a buried cable (Emeana, et al., 2016).

5 Control of Cable Heat

There are approaches practiced in the U.S. and overseas to help monitor or control the effects of heat from submarine cables. These approaches include the following:

- Optical fibers or other sensors to measure temperature to be included along buried transmission cables. The sensors can alert operators if cable temperatures become too high or help identify if the burial depth of a cable has changed. (Sharples, 2011; Tetra Tech, 2021).
- BOEM's Construction and Operation Plan Guidelines Best Management Practices include cable burial guidance. If cables are buried, lessees and grantees should inspect cable burial depth periodically during project operation to ensure that adequate coverage is maintained to avoid interference with fishing gear/activity.
- The German Federal Maritime and Hydrographic Agency (BSH), in support of the German Federal Agency of Nature Conservation has recommended thermal guidelines for buried cables of no more than a 3.6°F temperature elevation in seafloor sediments located 0.65 feet below the surface to protect benthic organisms (Tetra Tech, 2021).
- A recommended depth of 3 to 10 feet for cable trenching is presented by the Oslo and Paris Conventions (OSPAR) to balance sediment heating and protecting marine vessel anchors and fishing operations (OSPAR Commission, 2012).
- Draft Fisheries Mitigation Guidance, which includes burial depth to a minimum of 6 feet for static cables (June 2022; https://www.boem.gov/sites/default/files/documents/renewable-energy/DRAFT%20Fisheries%20Mitigation%20Guidance%2006232022_0.pdf), as well as other practices for static and dynamic cables to minimize interaction with fishing gear.

6 Summary

Heat from transmission cables is a known aspect of electrical transport, and one that should be taken into consideration as offshore wind farms continue to be evaluated and developed on the OCS. Many factors contribute to the level of heat generated by transmission cables, such as cable type, AC or DC transmission, voltage, length, number of cables, and whether the cables are in the water column or are buried. Cables exposed directly to open water can disperse heat readily due to the heat absorbing properties of water. However, burying electrical cables within wind farms and transmission cables leading onshore is a standard practice in the U.S. and overseas to protect cables from damage by anchors and fishing equipment.

The effects of heat from buried transmission cables are compounded by additional factors, including submarine terrain, sediment type, water depth, water temperature, and species composition. Placement of cables located in areas of seafloor substrate where heat can be dissipated effectively without overheating surface sediments, such as medium grained sands and silts, may reduce the effects of heating of upper layers of seafloor. More insulating substrates, such as fine silts, will retain more heat and reduce surface warming; however, the retained heat can cause damage to cables if temperature exceed cable ratings, about 194°F. Coarse grained sands and sediment allows the greatest amount of heat to radiate to the surface and heat the top layers of sediment where benthic species live. As more offshore wind farms are developed, further research may improve understanding of how cable heat affects sediment dwelling communities. Based on the current research, studies show that the effects of heat on sediment dwelling species overall are low, but considering measures such as burial depth, sediment type, and species presence could help reduce effects of cable heat from submarine cables. Mobile species on the seafloor or free-swimming marine species are anticipated to be unaffected by heat generated by submarine cables due to the species' ability to move from undesired temperatures and because of the dissipation of heat through the cold ocean water.

For a more detailed account of electricity basics, please read the *United States Electricity Industry Primer* from the U.S. Department of Energy (2015). Chapters 1, 2, and 3 provide information about the electrical supply chain, Appendix A provides straightforward graphic depictions of the electrical grid, and Appendix B provides further detail about electricity and power transmission. (U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, 2015).

For more details regarding the specifics of offshore wind submarine cables, please see *Offshore Electrical Cable Burial for Wind Farms: State of the Art, Standards and Guidance and Acceptable Burial Depths, Separation Distances and Sand Wave Effect* (Sharples, 2011) and *Offshore Wind Submarine Cabling Overview, Fisheries Technical Working Group, Final Report* (Tetra Tech, 2021).

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