DISTRIBUTION NETWORK TOPOLOGY ASSESSMENT

Assessment Report

Green Generation Energy Networks Cymru Limited

Report No.: 00391182-R-01-G
Date: 16 September 2025

Project name:	Distribution Network Topology Assessment	DNV Energy Systems
Report title:	Assessment Report	Power Grids & Connections
Customer:	Green Generation Energy Networks Cymru Limited, Hodge House, Guildhall Place, Cardiff. CF10 1DY	5th Floor, Vivo Building, 30 Stamford Street, London. SE1 9LQ
Customer contact:	Jean Lewis	Tel: +44 (0)20 3816 4000
Date of issue:	16 September 2025	Company Number 01503799
Project No.:	10553628	
Organisation unit:	Renewables	
Report No.:	00391182-R-01-G	

Applicable contract(s) governing the provision of this Report:
SF003911820-UKBR-P-01-A

Objective: To provide an independent and factual comparison between overhead lines and underground cables for 132 kV electricity network circuits in GB.

for DNV Services UK Limited

Prepared by:

Daniel Hutton
Benjamin Candlin
Paul Oyegbade
Marina Sergeeva
Maria Tolokonskaya

Verified by:

Stephen Rogers

Approved by:

Stephen Rogers

DNV Distribution:
☒ OPEN. Unrestricted distribution, internal and external.
☐ INTERNAL use only. Internal DNV document.
☐ CONFIDENTIAL. Distribution within DNV according to applicable contract.*
☐ SECRET. Authorized access only.
*Specify distribution: As set out in SF003911820-UKBR-P-01-A

Keywords:
Underground Cable Overhead line OHL UGC distribution comparison

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	20 June 2025	First issue	team	MT, SR	SR
B	08 July 2025	Clarifications added	MS	SR	SR
C	18 July 2025	Comments addressed	team	MG	MG
D	21 July 2025	Clarifications added	DH	SR	SR
E	01 August 2025	Comments addressed	DH	MG	MG
F	05 August 2025	Clarifications added	DH	SR	SR
G	16 Sep 2025	Corrections from data sheets	DH	SR	SR

Table of contents

1 EXECUTIVE SUMMARY

This report presents an independent and factual comparison between two primary methods of constructing 132 kilovolt (kV) electricity circuits in the GB; overhead lines (OHL) and underground cables (UGC). The study was commissioned to support public understanding and inform infrastructure planning, particularly in the context of expanding renewable energy generation and the need for modern, efficient electricity distribution networks.

This report does not contain advocacy for one technology over the other. Instead, it provides a factual, side-by-side comparison to support informed decision-making. The choice between OHL and UGC should be based on specific project requirements, environmental context, community preferences and long-term planning goals.

The assessment contained in this report is based on real-world examples and engineering data from across Great Britain. It evaluates both short-distance (2 km) and long-distance (100 km) circuits, using typical configurations for each technology. The analysis considers technical performance, construction and operational costs, environmental and community impacts and the ability of each method to support future energy needs.

Construction and operational costs

Overhead lines are significantly less expensive to construct and install than underground cables. For a typical 132 kV circuit, the lifetime cost of an underground cable can be up to six times higher than that of an equivalent overhead line. This cost difference increases further for longer distance or higher-capacity underground installations. The higher cost of UGC is due to the complexity of installation, the need for extensive excavation, and the use of more materials and protective infrastructure.

Operationally, underground cables have slightly lower energy losses over time, which can reduce long-term running costs. However, these savings do not offset the much higher initial capital expenditure. Additionally, underground cables are more difficult and time-consuming to repair in the event of a fault, potentially leading to longer outages.

Visual impact

Overhead lines are visually prominent, especially when supported by tall steel lattice towers. These structures can affect the landscape, particularly in rural or scenic areas. In contrast, underground cables are largely invisible once installed, making them more acceptable in urban environments or areas of natural beauty.

However, the construction of underground cables can cause significant short-term disruption due to the need for wide trenches, joint bays, and access roads. These impacts are temporary but can be extensive, especially for long routes.

The restriction on tree planting on or near cable routes and for long cables, the need for voltage support stations, may have visual impact for the operational life of the cable.

Environmental impact

Both technologies have environmental impacts but they differ in nature and scale. Overhead lines require less ground disturbance during construction but have a lasting visual presence. They also require ongoing vegetation management along their routes.

Underground cables, while hidden from view, involve more intensive construction activities. These can lead to soil disruption, habitat loss, and potential impacts on groundwater and drainage. The environmental footprint is particularly significant for long underground routes, which require continuous access and maintenance corridors.

In both cases, careful planning and mitigation strategies are essential to minimise environmental harm. The report outlines best practices for reducing impacts during both construction and operation.

Power transmission capability

Overhead lines can carry significantly more electrical power than underground cables of the same voltage. Modern overhead lines using advanced conductors can transmit up to 1,677 MVA, compared to a maximum of 274 MVA for a single underground cable circuit. This makes OHL more suitable for high-capacity or long-distance transmission.

Underground cables are limited in length, typically up to 20 km before requiring additional equipment to manage electrical characteristics. This makes them less flexible for long-distance applications without added complexity and cost.

Scalability and flexibility

Overhead lines offer greater flexibility for future network expansion. They can be uprated by replacing conductors or increasing voltage, and their routes can be more easily diverted or reconfigured. This makes them well-suited for adapting to changing energy demands and integrating new renewable generation.

Underground cables, once installed, are more difficult to modify or expand. Their capacity is fixed by the conductor size and installation method, and rerouting is costly and disruptive. While they are robust and reliable, their long-term adaptability is limited compared to OHL.

Supply chain and sustainability

The supply chains for both overhead lines and underground cables are under increasing pressure due to global demand for electrical infrastructure, rising raw material costs, and limited manufacturing capacity. Underground cables, in particular, face longer lead times due to the complexity of their components and the limited number of global suppliers. Some cable orders are currently scheduled several years in advance.

Sustainability considerations also differ between the two technologies. Overhead lines use less material overall and are easier to refurbish or upgrade, which can extend their service life and reduce waste. Underground cables, while more visually discreet, require more intensive use of materials such as copper, aluminium, and specialised insulation. Their installation also generates significantly more construction waste and soil disturbance.

Both technologies rely on skilled labour for installation and maintenance, and the industry faces a growing shortage of qualified workers. This challenge affects the timely delivery of projects and highlights the need for workforce development alongside infrastructure investment.

2 INTRODUCTION

DNV Services UK Ltd. (“DNV”) has been commissioned by Green Generation Energy Networks Cymru Ltd. (the “Customer”) to undertake an independent assessment of distribution network topology. This assessment focuses on 132 kilovolt circuits constructed as both underground cables (UGC) and overhead lines (OHL). The methodology follows a similar approach to the Network Topology Assessment report previously written by DNV for NESO. The Customer has indicated that this report will be made publicly available as an independent study and may also be used to support planning applications and the design of distribution network infrastructure.

Electricity in the United Kingdom has traditionally been generated at large power stations using sources such as coal, oil, gas, and nuclear energy. It was then transmitted across the country via the high voltage transmission network, typically operating at 400 kilovolts and 275 kilovolts. As electricity approached urban areas, the voltage was reduced at substations and entered the distribution network, which operates at voltages between 400 volts and 132 kilovolts. This network includes a combination of OHL supported by steel towers or wooden poles and underground cables. The electricity is then delivered to homes, businesses and industrial facilities.

In recent decades, the growth of renewable energy has led to significant changes in how electricity is generated and connected to the network. Increasingly, generation is connected directly to the distribution network, a practice known as embedded generation. This shift has introduced new technical and operational challenges, including instances where electricity flows from the distribution network back into the transmission system.

As renewable generation facilities have increased in scale, they have been connected at higher voltages to reduce energy losses and the size of conductors required. This growth has led to congestion at existing connection points and an increasing need for reinforcement of existing circuits, as well as the development of new ones.

Renewable energy is central to the United Kingdom’s strategy for achieving net zero greenhouse gas emissions by 2050. The Climate Change Committee has estimated that up to 125 gigawatts of renewable capacity may be required by mid-century. The UK Government has also set an interim target of 50 gigawatts of wind generation by 2030. Meeting these targets will require an electricity network that can connect new generation efficiently, while also addressing environmental and community considerations.

To support this transition, both the transmission grid and distribution network must evolve. Distribution networks must ensure adequate capacity to connect embedded generation to either transmission hubs or directly to demand centres, helping to reduce the need for extensive transmission upgrades.

This study uses past examples and previous work in Great Britain (GB) to explore different approaches to designing 132 kV electricity circuits. These included both OHL and UGC. The results were used to highlight the pros and cons of each option. The scenarios were based on realistic upgrades to existing infrastructure and likely future requirements, aiming to connect power generators and customers.

The assessment compared OHL and UGC, explaining the benefits and drawbacks of each. DNV also provided a description of composite circuits, those that used both OHL and UGC. This included installation methods and the specialised equipment needed to transition between them. The study focused on key factors such as cost, ease of construction, technical performance, and the potential impacts on the environment and local communities.

To support this comparison, DNV developed example circuit designs that reflected common real-world situations, including:

- Short and long OHL
- Short and long underground cables
- Circuits that transitioned between cable and overhead line to cross obstacles such as rivers, roads, and railways

The lengths of these circuits were selected to reflect both current and anticipated future requirements for connecting generation to demand across the electricity distribution network. The power capacities used in the examples were based on typical values for these types of connections.

For underground cables, DNV reviewed several installation techniques and compared them based on technical, environmental, social, and economic considerations. These methods included:

- Trenching for direct burial or ducted installation
- Mole ploughing
- Cut-and-cover tunnelling
- Horizontal directional drilling

For OHL, DNV examined various structure types and installation methods, including wooden poles, lattice towers, and modern alternatives used in Great Britain. The assessment also considered different conductor types, such as aluminium conductor composite core (ACCC) and all-aluminium alloy conductor (AAAC).

The findings presented provide a balanced overview of the available network options and their implications. However, DNV did not make specific recommendations. The selection of the most appropriate solution would require detailed, location-specific analysis for each individual project.

This review does not assess whether new circuits are required. Instead, it provides a factual comparison of underground cables and OHL, outlining the respective advantages and disadvantages of each. As an independent consultant, DNV does not make recommendations regarding the preferred method of construction. Such decisions rest with the relevant planning and design authorities.

A comprehensive glossary with technical terms and used abbreviations can be found in Appendix A.

A detailed description of environmental and community impacts and mitigations can be found in Appendix B.

3 COMPARISON TABLE

The aim of this assessment is to provide an unbiased review of 132 kV circuits being installed as Underground Cable (UGC), Overhead Line (OHL) or a composite of the two. Table 3-1 below lists a comparison summary between OHL and UGC derived from the detail contained in the filler text of each section.

Table 3-1: Comparison Summary

Characteristic	132 kV AC OHL	132 kV AC UGC
Maximum continuous capacity	• 1,677 MVA (ACCC)[1] • 592 MVA (ACSR)[2] (two circuits twin bundle)	• 274 MVA (single core trefoil copper cable)[3]
Maximum technically feasible route length	Unrestricted in the context of this report and assessed circuit length.	20 km Beyond around 20km an AC underground cable circuit would need reactive compensation which technically, interfaces with the network and becomes increasingly complex and costly
Lifespan	60 to 80 years[4]	40 to 50 years[5]
Infrastructure operational footprint	• 50-70 m² land-take per tower, with a span of approximately 300m between towers.[6] This span would be greater for ACCC. • Building beneath the overhead line route permanently discouraged, though many agricultural /rural land uses can resume • Periodic vegetation management required but can over sail many trees if properly maintained and safety distances are maintained.	• Building and excavations would be permanently discouraged within, typically, a 25 m wide cable swathe along the entire route of the UGC. Many rural and agricultural land uses above ground can resume. This resumption may be subject to restrictions such a limiting the depth of any work. Asset owner must be notified to arrange monitoring. • Periodic vegetation management may be required and restrictions on planting may be enforced within cable swathe.

Future scalability for long-term planning	• Can be uprated at refurbishment subject to planning consents to allow:
	  ○ Higher voltage distribution using longer support insulators
	  ○ Additional capacity using thicker conductors.
	• Route diversion possible
	• Less cost and disruption to connect additional generation and demand in the future
		• No uprating only replacement
		• No Route diversion
		• More cost and disruption to connect additional generation and demand in the future

[1] https://ctcglobal.com/datasheets/

[2] Atanasovski, M., Arapinoski, B., Kostov, M., & Trpezanovski, L. (2019). Comparison of ACSR, ACCC and AAAC Conductors for Overhead Transmission Lines. Presented at ICEST 2019, Ohrid, North Macedonia, 27-29 June 2019. Available in the uploaded file "ICEST_2019-Atanasovski.pdf"

[3] 132kv-copper-large-conductor-xlpe-csa-pe-hs-cables_0.pdf

[4] CIGRE Study Committee B2 – OHL

[5] CIGRE TB 912 - Condition Evaluation and Lifetime Strategy of HV Cable Systems

[6] https://telcontar.net/Power/pylons/L7

Characteristic	132 kV AC OHL	132 kV AC UGC
Planning and consents	• An application for a Development Consent Order (DCO) or Development of National Significance (DNS) is required • Section 37 Consent required • TCPA may be required for smaller projects not subject to DCO or DNS. • Process complex and time-consuming, could sometimes lead to public inquiry • Suitable rights over land (wayleaves or easements) are needed, often granted voluntarily • Compulsory Acquisition may be used in special circumstances	• May be classed as 'permitted development' in certain circumstances where there is little environmental impact. • TCPA may be required for smaller projects not subject to DCO. • Any sealing end compounds may require planning permission • Suitable rights over land (wayleaves or easements) are needed, often granted voluntarily • Compulsory Acquisition order may be used in special circumstances
Reliability, availability and maintainability	• Robust operation, can use auto-reclose for lightning strikes • Physical damage normally repaired within hours or days (excessive damage within weeks) • Maintenance; 3 days per year • Generally expected to have a failure rate of 0.1 to 0.3 faults per 100-circuit-km-year	• Reliable operation • Physical damage repaired within days (excessive damage within weeks) • Maintenance; 1 day per year • Fault identification is more challenging • Cigre analysis[7] had reported that the failure rate for 132 kV XLPE UGC is 0.108 faults per 100-circuit-km-year
Provision of restoration Services *(all of these require an intact source of energy at one end)*	• Inherent, ideal • Applies sequential switching; energising blocks of load, during which care must be taken to control the stability of the system due to risk of re-collapse • Switching is a well proven technique for system restoration	• Inherent, fair • Applies sequential switching; energising blocks of load, during which care must be taken to control the stability of the system due to risk of re-collapse • Switching is a well proven technique for system restoration
Construction	• Traffic noise and dust • Access and excavation may impact vegetation/habitats but this is usually limited • Potential impact on biodiversity and habitat loss • Construction activities contribute to Greenhouse Gas (GHG) emissions • Minimal traffic disruption • Land use disruptions	• Traffic noise and dust • Excavation activities may lead to extensive soil disturbance, vegetation removal and habitat loss • Construction activities contribute to GHG emissions • Traffic disruption • Land use disruptions due to cable trenching (depending on the route selected)

[7] Cigre. UPDATE OF SERVICE EXPERIENCE OF HV UNDERGROUND AND SUBMARINE CABLE SYSTEMS – Table 10d. Sep 2020

Characteristic	132 kV AC OHL	132 kV AC UGC
Operational	• Acoustic noise (poor weather crackle) • Potential impact on bird species (collision risk) • Tower ground footprint occupied • Potential to depress property values • Building on route permanently discouraged. • Potential visual impact • Potential 50Hz EMF exposure can affect wildlife	• Cable access points (one every 500 to 1000 m) will require vegetation clearance • Building and tree planting on cable route restricted • Potential 50Hz Electro-Magnetic Field can affect wildlife • There is a potential to reduce land value due to the restrictions on land development on or near cable routes • Potential impact to soil and hydrology; ground water paths, water retention, artificial drainage paths and sensitive environments
Lifetime archetype costs:	x 1	x 4.7
Lifetime losses costs:	x 1	x 0.8

4 ARCHETYPAL CIRCUITS

This section sets out the proposed archetypal circuits that will be used for comparison in the distribution network topology comparison. This includes the reasoning behind selection of the circuits their parameters and the exclusion of others.

The aim is to fairly compare OHL and UGC circuits for the future build out of the network by Distribution Network Operators (DNO), Independent DNO (IDNO) and third parties. This is based on the understanding of current installed infrastructure, technologies that are likely to be used for the growth of the network and engineering judgment of likely changes to networks to accommodate future generation and demand.

4.1 Scope of architypes considered

The circuits to be considered are:

- Short distance circuits – typically connecting a generator to the point of connection, most commonly achieved by an UGC in GB
- Long distance circuits – to encompass future developments, the longest feasible AC circuit for either OHL or UGC
- Composite circuits containing sections of both OHL and UGC for a diverse range of reasons.

Only circuits with 100% UGC or OHL can be practically compared omitting composite circuits from the comparison table. The proposed composite archetypal circuit is still included as it will be the basis of comment in the reports description if there is a requirement for mixed OHL and UGC circuits.

4.2 Data sources

The proposed circuit parameters are based on analysis of DNO available data from nine distribution licence regions, these are operated by NGED, NPG and UKPN. A sample of 500, 132 kV circuits was taken from the Long-Term Development Statements (LTDS) of each DNO region, this encompasses nine of the fourteen distribution network regions as illustrated in Figure 4-1 below.

Circuits with a length less than 500 m were removed as these would overwhelmingly include the circuits internal to DNO substations which are not the subject of this study. Circuits were then analysed in conjunction with the publicly available open infrastructure mapping[8] and the open data portals of the relevant DNOs to determine whether the circuit was an OHL, UGC or composite circuit. This information is used in the determination of archetypal circuit comparison.

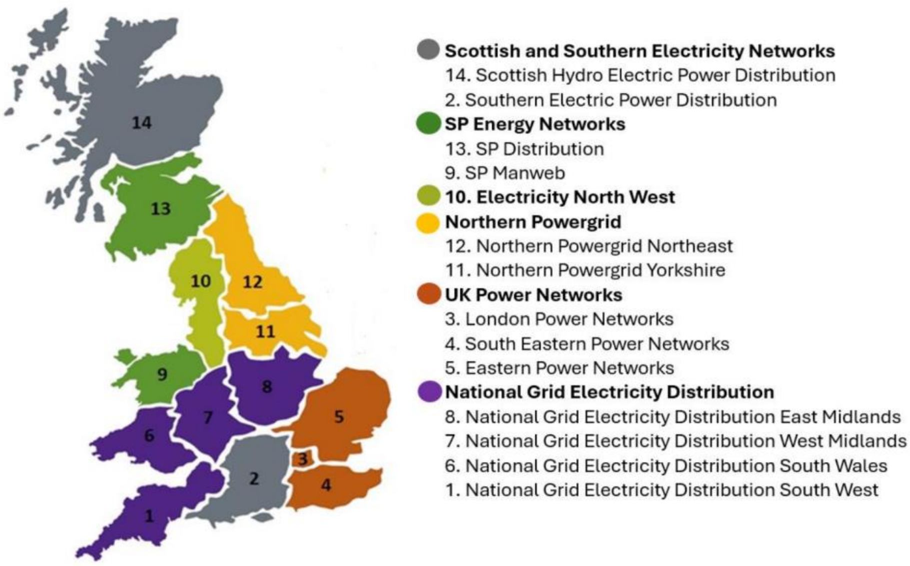


Figure 4-1: GB DNO regions and ownership 2025[9]

[8] https://openinframap.org/#5.87/54.174/-2.679 (accessed on 16 March 2025)
[9] Ofgem. RIIO-2 Electricity Distribution Summary Annual Report: 2023-24. No rev. not dated

4.3 Circuit Length

To ensure a fair comparison between overhead line (OHL) and underground cable (UGC) circuits, both circuit types use the same length. DNV determined this length by calculating the average of existing long- and short-distance circuit samples currently in operation. The average length of the long-distance samples was 21.79 kilometres, while the short-distance samples averaged 1.92 kilometres.

4.3.1 Short distance circuits

Short-distance circuits typically connect renewable generation sites or individual demand centres to the most convenient point of connection on the network. These circuits vary significantly in length. Some span only tens of metres, such as those making a tee connection to a nearby 132 kV circuit, while others extend several kilometres to reach a suitable Bulk Supply Point (BSP) substation. Developers and operators generally select locations based on ease of connection, so future facilities are expected to face similar connection conditions and result in circuit lengths comparable to those currently in use.

To define a representative short-distance circuit, DNV based its assessment on the calculated average of the lower quartile of operational circuit lengths. For simplicity, this value has been rounded to the nearest kilometre, resulting in a typical circuit length of 2 km.

4.3.2 Long distance circuits

The top quartile of long-distance circuits reflects infrastructure that operators have already installed and currently operate. Over the past 20 years, the growth of embedded generation has demonstrated that the traditional top-down model—where generation feeds demand through the transmission network, is no longer adequate for the evolving needs of the GB electricity network. Given this shift, it is important to consider the factors that may influence the future length of 132 kV circuits.

Operators typically transfer bulk power by connecting to a Bulk Supply Point (BSP) or Grid Supply Point (GSP) substation, transporting electricity across the transmission network to areas of demand, and then distributing it from another BSP or GSP. This process often involves multiple circuits and substations along the route. However, large renewable generators, such as wind farms along the west coast or hybrid generation hubs, can connect directly to major cities at 132 kV. This approach reduces the need to allocate capacity on the transmission grid.

Independent Distribution Network Operators (IDNOs) can enhance grid reinforcement and security of supply by linking different Distribution Network Operator (DNO) licence areas without relying on the transmission system. New 132 kV circuits can also relieve overloaded 33 kV and 66 kV feeders, enabling more localised power delivery and forming a backbone for distribution. Planners can use these circuits to support future housing and commercial developments through dedicated distribution corridors that complement existing transmission infrastructure.

Integrating renewable generation remains essential to achieving the UK net zero targets and the objectives outlined in the Clean Power 2030[10] strategy. Connecting Offshore Transmission Operators (OFTOs) to distribution networks and demand centres can further support this goal and reduce pressure on the transmission grid. This approach also enables interconnection between generation hubs.

Network operators can improve voltage support by using 132 kV circuits to optimise multiple 33 kV substations. This strategy enhances network stability and is more effectively implemented through the distribution network than through higher transmission voltages.

In Scotland, 132 kV circuits already integrate with the transmission network. Connecting at this voltage allows operators to deliver power to demand centres without stepping up to the transmission voltages used in England and Wales. This approach offers benefits such as equipment standardisation, alignment of operations and maintenance practices, and improved availability of spare parts.

Globally, the longest HV alternating current (HVAC) cable currently in operation spans 174 km[11], connecting mainland Greece (Peloponnese) to Crete, with a 132 km submarine section meaning only 42 km is UGC. Excluding subsea cables, (totally land

[10] https://www.neso.energy/document/346651/download accessed April 2025

[11] Greece tests Peloponnese-Crete link – world's longest undersea AC cable

based UGC) the longest buried HVAC cable[12] measures 40 km and forms part of the Shinkeiyo–Toyosu project in Tokyo. Overhead HVAC lines are significantly longer, with the Ekibastuz–Kokshetau line[13] in Kazakhstan extending 430 km. High-voltage direct current (HVDC) OHL are even longer but fall outside the scope of this analysis.

To ensure a balanced comparison, DNV selected a long circuit length that remains technically feasible for both underground cables and OHL. Based on engineering judgement and the future use cases described above, DNV identified 100 km as a representative long-distance circuit length. This figure aligns with the approximate maximum length currently achievable for alternating current underground cable systems using existing technology. While this estimate does not rely on a fixed reference point and may be considered subjective, it provides a reasonable basis for the analysis presented in this report.

4.4 Circuit capacities

The capacities of the different circuits are detailed in the report within each circuit type section. For the archetypal comparison, the capacity of modern UGC and OHL shall be compared for each circuit distance. For the OHL circuit ACCC conductor shall be used as the basis for capacity comparison with UGC.

4.5 Archetypal circuit comparison

For the reasoning set out above, the following four circuits shall be compared in an archetypal comparison table:

1. 2 km distance single circuit ACCC OHL on a wooden pole
2. 2 km distance single circuit UGC
3. 100 km distance double circuit ACCC OHL on a steel lattice tower
4. 100 km distance UG Cables – two circuits

[12] WETS07 - T1-04 - S-Swingler_UK_.pdf
[13] wiki-gateway.eudic.net/wikipedia_en/Ekibastuz–Kokshetau_high-voltage_line.html

5 COST ESTIMATES

Electricity distribution costs are affected by many variables, including component and raw materials prices, the cost of labour, the availability of manufacturer, supplier, and installer capacity, and financing and insurance costs. These, along with international economics, geopolitics, and the levels of global demand for transmission network development, all introduce uncertainty into future cost estimates.

It is not the intention of this document to estimate specific distribution prices, such an exercise in the absence of a specific circuit route is likely to have very limited value. However, when comparing technology archetypes, it is helpful to have a feel for the comparative costs of the solutions being considered. This section presents a brief approach to our capital cost and lifetime running cost estimates followed by an indicative cost magnitude comparison table.

5.1 Approach to cost estimating

The values of distribution construction projects are normally kept confidential to protect the commercial interests of various stakeholders. Our approach to providing an indicative cost magnitude comparison for 132 kV distribution circuits has therefore been to turn to publicly available sources. There is no one single source of distribution cost data that is publicly available, therefore we have used a range of sources to compile our cost database. Specifically, we have used cost studies from Scottish Power Energy Networks (SPEN) and Scottish and Southern Energy Networks (SSEN). We have used the Institution of Engineering and Technology's Electricity Transmission Costing Study[14] to extract specific cost ratios and use them as a general sensitivity check by adjusting down the estimates from 400kV to 132kV, applying a discount factor to account for the difference in voltage levels.

To account for inflation and ensure all the costs are comparable, we have applied the Manufacture of Electrical Equipment indices published by the Office for National Statistics[15].

The lifetime cost includes both capital expenditure (CAPEX) and operational expenditure (OPEX) over the lifetime of the equipment. We assumed a 40-year equipment life for each technology archetype. OPEX include both Operation and Maintenance costs, as well as energy losses.

Our estimates do not include the costs for:

1. Project financing
2. Consents, easements, and public inquiries
3. Environmental assessment and mitigation.

These factors depend so much upon the specific application and the chosen project approach that to consider them in isolation would be misleading. They should not be disregarded during an actual distribution development project, as they can significantly impact the overall project budget.

We acknowledge that the material and labour costs for different asset types have risen at different rates. However, this difference has not been studied for the purpose of this report, as this would require knowing the exact route and design details.

5.2 Cost magnitude comparison

The following table provides cost comparison for the four archetypes studied in this report. It should be note that these comparisons are based upon many assumptions and are indicative only since they are not associated with a specific application

Table 5-1: Lifetime cost magnitude comparisons for 132kV OHL and UGC

	Single circuit ACCC OHL on a wooden pole	Double circuit ACCC OHL on a steel lattice tower	Single circuit UGC	Two circuits UGC
Lifetime cost	x 1	x 3	x 6	x 14

[14] https://www.theiet.org/media/axwkktkb/100110238_001-rev-j-electricity-transmission-costs-and-characteristics_final-full.pdf

[15] https://www.ons.gov.uk/businessindustryandtrade/manufacturingandproductionindustry/timeseries/jqg2/diop

6 OVERHEAD LINES

Historically, Aluminium Conductor Steel Reinforced (ACSR) lines have been used as phase conductors in transmission and distribution systems around the world. These lines use a central steel core to add strength to the outer aluminium conductor and reduce thermal sag. Thermal sag happens when OHL heat up either from the electrical current flowing through them, sunlight, or warm weather. As the wires get hotter, they expand and stretch slightly, which causes them to hang lower between the towers. ACSR OHL use many circular aluminium conductors wrapped around a central core of bunched circular steel reinforcement. This layout leaves gaps within the line and therefore limits the useful material content in the cross section, leading to a conductor Cross-Sectional Area (CSA) that is lower than expected for the line diameter. These lines have high tensile strength and can withstand extreme environmental conditions. However, the air gaps around the steel core can lead to expediated corrosion over time.

Other types of conductors can be used as alternatives to ACSR, such as All-Aluminium Alloy Conductors (AAAC), which feature a full aluminium alloy design. These conductors take advantage of the entire cross-sectional area for conduction and offer a better strength-to-weight ratio compared to ACSR. However, AAAC tend to sag more under heat than ACSR wires with the same cross-sectional area, so they require a larger diameter to carry the same capacity.

A more recent innovation in OHL conductors is the Aluminium Conductor Composite Core (ACCC) lines. These use an aluminium alloy as the electrical conductor with a central composite core made of carbon and glass fibres embedded in a matrix. Due to the thermal and elastic properties of the central core when compared to steel, an ACCC line will have almost double the transmission capacity of an ACSR line of equivalent diameter. The reduced thermal sag allows the line to reach higher temperatures before significant deformation (lengthening) of the line occurs. This reduced thermal sag can lead to increased spacing between towers, reducing the environmental and visual impacts and allow for more power to be transmitted across existing infrastructure.

Uprating ACSR OHL with those of a similar type, necessitates the reinforcement of the supporting mechanical infrastructure such as towers and insulators due to the significant increase in weight of the conductors, this will come at significant cost. Replacing ACSR conductors with those of a lower weight, ACCC or AAAC, allows for circuit uprating without significant additional infrastructure spending.

When installing new lines, the benefits and drawbacks of all constructions should be considered. The abundance, cost and strength of ACSR should be compared to the thermal sag, capacity and weight saving advantages of ACCC and AAAC constructions.

A comparison of the conductor types is summarised in the extract from a 2019 study[16] in Table 6-1 below.

Table 6-1: OHL conductor comparison

Mechanical and Electrical Characteristics	ACCC Glasgow	AAAC/TW 300	ACSR 240/40
Cross section Al/core (mm²)	236.7/47.1	323.98	243/39.5
Total cross section (mm²)	283.8	323.97	282.5
Diameter (mm)	19.53	21.7	21.9
Mass of conductor (kg/km)	731.3	893	987
Weight of conductor (daN/m)	0.717	0.876	0.968
Specific weight 10-³ (daN/m,mm²)	2.526	2.704	3.426
Coefficient of linear expansion 10⁶ (°C-¹)	17.1	23	18.9
Modulus of elasticity (daN/mm²)	6700	6800	7700
Tensile strength (daN)	11500	9560	8640
Normal tension (daN/mm²)	16.2	12	13
Tension (daN/mm²)	30.4	22	24.5

16 Atanasovski, M., Arapinoski, B., Kostov, M., & Trpezanovski, L. (2019). Comparison of ACSR, ACCC and AAAC Conductors for Overhead Transmission Lines. Presented at ICEST 2019, Ohrid, North Macedonia, 27-29 June 2019. Available in the uploaded file “ICEST_2019-Atanasovski.pdf”.

Mechanical and Electrical Characteristics	ACCC Glasgow	AAAC/TW 300	ACSR 240/40
DC resistance at 20 °C (Ω/km)	0.1184	0.1022	0.119
Rated current at 80 °C (A)	570	775	530
Rated current at 100 °C (A)	692	951	648
Rated current at 180 °C (A)	1027	–	–
Maximum working temperature (°C)	180	90	80

6.1 Archetype description

Overhead Alternating Current (AC) distribution makes up the majority of the distribution network in the UK. UGC are predominantly used when OHL are impractical, such as in densely populated areas, or undesirable, such as in areas where towers and lines would significantly detriment the environment or local aesthetics. The distribution network in England and Wales operates at 132 kV and below with higher voltages being part of the Transmission network.

Distribution networks both globally and in the UK utilise OHL due to the lower cost and ease of installation. Maintenance of OHL is also simpler than with UGC due to the ability to access them directly, this is significantly more challenging with buried and ducted UGC. However, as OHL are more exposed to the environment, this leads to a greater requirement for regular maintenance. The additional cost associated with this maintenance is considerable and should be considered along with the original cost savings of implementing the circuit as an OHL rather than as a UGC.

Figure 6-1: 132 kV double circuit OHL on steel lattice tower

The UK government's position is that "OHL should be the strong starting presumption for electricity networks development in general"[17]. It is noted that the planning process for large power connections in Wales differs from that of England administered by Planning and Environment Decisions Wales (PEDW) on behalf of the Welsh Ministers. Planning Policy Wales (Edition 12) states that the Welsh Government's preferred position on new power lines is that, where possible, they should be placed underground. The policy does, however, recognize that this may not always be possible and that a balanced view must be taken against costs to ensure that acceptable projects do not become unviable.

The general presumption is to avoid OHL in nationally designated landscapes, such as National Parks. However, if rerouting or undergrounding the circuit in a specific area proves unfeasible, then this requirement does not apply.

OHL can take various constructions, with the main options summarised above. These constructions can be installed for all distribution voltages from 11 kV to 132 kV. To support OHL at safe distances above the ground steel lattice towers are most commonly used. The HV lines are suspended from these towers using ceramic or glass insulating strings to prevent a short circuit between the line and the tower. Steel lattice towers are cost effective and quick to produce and assemble. Their strength and resistance to extreme weather conditions makes them ideal in many situations. Towers in GB, usually support two circuits. This is beneficial for either increasing the redundancy and capacity of a connection. The larger steel lattice towers can support up to four bundled conductors per phase which greatly increases the power capacity of the circuit.

The alternative to steel lattice towers is utility wooden poles. These have a single three phase circuit, supported on top of the poles by insulators on a cross beam rather than suspended from the structure. These are generally used for lower voltage distribution (33 kV and below) but have been used in specific applications for lines at 132 kV. Wooden pole OHL are not as tall as steel lattice towers and support only one conductor per phase. The circuit capacity for wooden pole OHL is significantly less but with the pole height being shorter, they are less visually impactful. The wooden pole construction means that the OHLs will have a shorter design life that a steel tower.

[17] Policy paper - National Policy Statement for Electricity Networks Infrastructure (EN-5) - Updated 17 January 2024

A more modern pylon type is now in operation in the UK, known as a ‘T-pylon’ due to its shape, these are currently used only in larger transmission systems. Rather than steel lattice, the T-pylon uses a monopile design roughly one-third shorter than transmission steel lattice equivalents at around 35 m high compared to the transmission lattice structure’s 46.5 m. This reduction is offset by their overall width of around 31 m compared to the lattice structure’s narrower 18.2 m[18]. The T-Pylon monopiles have a 10 square metre ground footprint that is completely enclosed, whereas the transmission lattice tower base can cover between 50 and around 70 square metres of relatively open space.

Lattice towers used in distribution 132 kV systems are significantly smaller than those used for transmission at 275 kV and 400 kV. The width of the square base is between 4.8 m, and 8.2 m but may increase up to 10 – 12 m for tension towers where the overhead line route changes direction or needs to clear a particularly tall obstruction[19]. For example, towers may be higher at motorway and river crossings than when crossing flat, rural countryside. Distribution towers have a significantly lower visual impact than the much larger transmission towers.

There are over 90,000 steel lattice transmission and distribution towers in Great Britain. The standard 132 kV distribution tower was designed in the 1960’s and the design has not been updated much since then. The normal span (distance between towers) is 305 m but can be 265 m for some line types.

The T-Pylon design is the result of an international competition to find a tower with a lower visual impact on the surrounding landscape. The first operational examples were commissioned in 2022 on a section of overhead line between Bridgwater and Loxton, in Somerset. All 116 of the T-Pylons were used on the new Hinkley Point–Seabank transmission route and were installed by August 2023.

Maintenance and repair of T-Pylons is more challenging than steel lattice towers. The monopole design requires a single foundation that is larger and deeper due to the tortional loads. In construction, these are delivered in modules that require lifting into place and hance, require more robust access tracks and carne pads compared to lattice towers. The simplicity of the lattice design and the materials used make life extension of steel lattice towers affordable and efficient. T-pylons do not have this option and any replacement or life extension process could take the tower out of operation for several weeks. According to NGET, “The operational life of a T-pylon is about the same as a traditional lattice pylon at around 70-80 years. The conductors, insulators and fittings normally last for about 40 years, and are replaced mid-life cycle”[20]. All T-Pylons currently in operation are utilised as part of the transmission network but there could in the future be scope to utilise the design on the distribution network.

Steel lattice towers and T-Pylons in Great Britain generally support two electrical circuits, one on each side of the tower. In this way, one circuit, which comprises three separate phase conductors, can continue to supply customers whilst the parallel circuit on the tower is out of service. This double-circuit approach to system design helps the system operator to continue to deliver secure electricity supplies even in the event of a circuit fault. This arrangement also allows multiple circuits to follow a similar route on the same tower, reducing costs and visual impact on the surroundings.

OHL are designed as a series of straight-line sections. The towers use concrete foundations to enclose the four steel foundation footings. The lattice structure is erected on to the steel footing stubs and the six insulator strings are hung from the ends of the tower arms. Once a straight-line section of towers has been constructed, the conductors are pulled along the section and secured to the insulators, whilst precisely adjusting the sag in each span and carefully ensuring that no damage occurs to the conductor surfaces. An exclusion swathe will be in place during the conductor stringing process. This swathe will be a few metres wider than the 12 m – 13 m tower cross arm width, this is a temporary arrangement, with the only permanent exclusion area being directly around the tower base.

6.1.1 Circuit capacity

Circuit capacity, a measure in either Amps (A) or megavolt-amps (MVA), is the physical capability of that circuit to transfer electrical power. The capacity of a circuit will vary over time and depends upon several factors including:

- Ambient temperature (varies with seasons);

[18] https://www.nationalgrid.com/document/342951/download

[19] https://telcontar.net/Power/pylons/docs/SSE%20-%20Beauly%20to%20Mossford%20proposal%2C%20figure%20NTS%202%20%28December%202011%29.pdf

[20] https://rebuild.nationalgrid.com/stories/energy-explained/what-is-a-T-pylon#:~:text=The%20operational%20life%20of%20a%20T-pylon%20is%20about,mid%20life-cycle.%20When%20were%20the%20first%20T-pylons%20energised%3F

- Recent loading history
- Conductor type
- CSA and bundle quantity
- Operating temperature (sag)
- Design capacity of the lowest rated component in the circuit.

From analysis of 500, 132 kV circuits across nine GB distribution networks, a HV distribution circuit's pre-fault continuous summer rating design capacity can range from 35 MVA to 250 MVA, with 50% of the circuits analysed being between 60 and 105 MVA. The capacity of every overhead line will be part of the circuit design and selected on an individual basis to be compatible with the surrounding infrastructure and account for any anticipated future development.

When powering a circuit, the capacitance of that circuit means that there is an initial charging effect and ongoing reactive losses. OHL have low charging currents, typically less than 1 A/km/phase, this means they can successfully operate over many kilometres without needing separate reactive compensation. This same characteristic makes OHL ideal for reconnecting the network together during system restoration (following a blackout).

The maximum capacity of a single OHL relies on the factors listed above. Maximising the number of conductors and CSA for an ACCC OHL using the following assumptions to calculate circuit capacity:

- Two circuits
- 2 bundled conductors per phase
- ACCC Hamburg (1,626.8 kg/km, 1,834 A at 180℃)

Using the above metrics the highest capacity for a 132 kV ACCC overhead line would be 12,706 A.

An ACSR line of similar weight has a CSA of 420 mm^2. This would still allow for 2 circuits with 2 bundled conductors per phase to be supported by 132 kV towers, as each line has a weight of 1,621 kg/km. This conductor type allows only 693 A at 85°, the lower temperature used here due to this not being a HTLS type conductor. This gives a total capacity for an ACSR circuit of 4.801 A, considerably lower than the ACCC alternative.

6.1.2 Lifespan

OHL have a design life of 30 – 40 years but can last longer[21]. Replacing individual components of the OHL circuits at the end of their lifetime can significantly increase the service life of the whole circuit and comes at a significant cost saving over complete replacement.

Steel lattice towers are proven to have a lifetime potentially far exceeding the 40 years of the circuit. Some papers, including the 2021 paper by Fathoni Usman and Khalid Nor, suggest that towers can have a life expectancy of 60 to 80 years[22], although this can vary dramatically depending on environmental conditions, tower maintenance and damage incurred over its service life.

A benefit of the towers and their foundations is that, even where general wear and tear, ageing or direct damage have occurred, the affected element can be repaired or replaced 'piecemeal', on demand, without needing to replace the whole overhead line. Some of the smaller maintenance tasks can even be undertaken without taking the overhead line out of service.

It should be noted that a major refurbishment, such as that mentioned above, that includes replacement of the conductor system, would also provide an opportunity to uprate the overhead line conductor, if this is beneficial and in line with the network plan.

6.1.3 Limitations

The limitations of OHL relate to their space requirements, the visual intrusion on people who need to live close to them, and public concern about the electromagnetic fields (EMFs) they create. The projects national significance guidelines change for areas of natural beauty to recommend that underground cables are used instead of OHL. For these reasons, the process of

[21] Western Power Distribution, Lifetime Costs Report, Brecha Forest Connection Project, February 2014

[22] Usman, Fathoni & Nor Khalid, Nor. (2021). Predicting remaining life of lattice steel transmission tower based on condition assessment and corrosion hazard data. E3S Web of Conferences. 325. 01011. 10.1051/e3sconf/202132501011.

routeing new OHL (and even of upgrading existing ones) has become increasingly complex and time-consuming. Public awareness of environment and landscape heritage means new overhead line planning applications are more likely than ever to become the subject of public inquiries, with such inquiries potentially leading to significant delay of the circuits.

There are situations where domestic and / or commercial buildings have been erected close to, if not beneath, existing OHL. Such circumstances generally represent a greater risk to security of supply due to the potential for events under the line to disrupt the lines for significant periods of time, for example, a heavy vehicle was to hit a tower, or if thick smoke from a fire were to cause a fault across the conductors.

6.1.4 Future scalability for long-term planning

OHL are a mature and versatile electricity distribution technology, being equally applicable both to the main interconnected transmission network, which benefits many network users and to connections used exclusively by a specific generator or large consumer.

OHL capacity can be uprated, either by replacing their conductors with a larger cross-section, increasing the bundle number, higher operating temperature design or raising the overhead line operating voltage. These upgrades can all be carried out without significant implications on surrounding area.

An overhead line route may be diverted to avoid a major new development project more simply than with an UGC, the exact specifications of the new route being first taken through consultation with communities and statutory partners. Also, as network requirements change, may be simpler compared to an underground cable circuit, to reconfigure an overhead line circuit's terminating connection so that it can be connected at a more convenient substation busbar. Equally, if new generation or demand is to be connected to the transmission network, it is normally much easier to reconfigure overhead line for this purpose than underground cable.

6.2 AC overhead line costs

Factors affecting overhead line construction costs include ease of access to tower locations, the ground conditions for tower foundations, and the numbers and types of traffic crossings on the overhead line route. On this latter point, normally, temporary scaffolding bridges are built to protect roads and railways during conductor stringing, to keep their traffic flows running smoothly; where there are many crossings, particularly of major motorway or rail routes, these bridges can add significantly to the project budget.

The type of tower will also have a significant impact, with steel towers being more expensive than wooden poles. However, wooden poles typically have lower capacity and may require more frequent replacement. Other capital costs to keep in mind include those of environmental assessment and impact mitigation, public consultation and public inquiry, and consents and wayleaves.

The most significant operational cost of OHL relates to lifetime losses. Other external factors, such as adverse weather conditions, might lead to additional maintenance and repair costs.

6.3 Deliverability and operability

Overhead line technology is mature and the challenges for implementing and operating a new line are largely understood. However, increasing pushback against OHL, means that obtaining planning consent remains a large source of uncertainty in delivering an OHL. Additionally, the option to deploy alternative High-Temperature Low-Sag (HTLS) such as ACCC conductor types changes what must be considered, especially if the HTLS type has not been widely deployed across grids with several years of proven service experience.

This section discusses the following: obtaining planning consents; incorporating HTLS conductors into an OHL project; reliability, availability and maintainability; flexible circuit rating; and system restoration capability.

6.3.1 Land options and planning consents

For 132 kV distribution networks in Wales, DNOs typically negotiate voluntary wayleave agreements with landowners and occupiers for the installation and maintenance of OHL. If voluntary agreements cannot be reached, the Electricity Act 1989 provides different mechanisms for securing rights over land for electricity infrastructure. The two options for securing land for OHL are listed in Table 6-2 below.

Table 6-2: Acquisition of Land rights via Compulsion

Option	Description	Process	Scope
Compulsory Acquisition Order (Schedule 3)	Allow electricity companies to acquire land or rights over land outright when required for construction and operation of electricity infrastructure.	The DNO must apply to the relevant authority for a CPO. This process includes public consultations and the opportunity for objections to be heard. If granted, the CPO gives the company the legal right to acquire the land or rights, even if the landowner objects.	CPOs are generally used for acquiring larger areas of land or more extensive rights than necessary wayleaves, and they provide a more permanent solution.
Necessary Wayleave (Schedule 4)	Used to secure rights to install and maintain OHL over or on private land when voluntary agreements cannot be reached with landowners.	The DNO must apply to the relevant authority for a necessary wayleave. This involves a formal application process, including a hearing where both parties can present their case.	Necessary wayleaves can be temporary or permanent and are specific to the installation and maintenance of OHL.

Since the Wales Act 2017 was introduced, any OHL associated with the construction or extension of a devolved Welsh generating station granted planning permission or consented to on or after 1 April 2019, located wholly in Wales and at voltages of 132 kV and below requires consent from the Welsh Ministers. Guidance has since been published outlining that for some applications, the appointed inspector makes the final decision[23]. This is part of the process for Developments of National Significance (DNS)[24] being large-scale infrastructure projects. This process requires applications via the Planning and Environment Decisions Wales (PEDW).

For OHL that do not fall under the DNS regime, the relevant authority for development permission is the Secretary of State. In these cases, the National Policy Statement for Electricity Networks Infrastructure (EN-5) that came into force in January 2024 takes precedence. The preference for using OHL for electricity transmission in Great Britain is formalised this legislation. Paragraph 2.9.20 confirms the Government's position stating that "… *overhead lines should be the strong starting presumption for electricity networks developments in general*." However, the same paragraph clarifies that this presumption does not apply where OHL would cause harm to the landscape, visual amenity, or natural beauty of designated areas. These areas include National Parks and Areas of Outstanding Natural Beauty (AONBs).

The Wales Act 2017 increased the upper generating capacity threshold for DNSs to 350 MW. DNSs were introduced by the Planning (Wales) Act 2015. OHLs were brought into the DNS regime by The Developments of National Significance (Specified Criteria, Fees and Fees for Deemed Applications) (Wales) (Amendment) Regulations 2019.

6.3.2 Choosing HTLS

The adoption of High-Temperature Low-Sag (HTLS) conductors are considered when addressing challenges such as increased demand, integration of renewable energy sources, and environmental constraints. HTLS conductors offer the advantage of higher current-carrying capacity without necessitating significant changes to existing infrastructure. This is particularly beneficial in areas were obtaining new wayleaves or constructing taller structures is impractical due to environmental or planning considerations.

[23] https://www.gov.wales/developments-national-significance-dns-procedural-guidance-html

[24] https://www.gov.wales/developments-national-significance-dns-procedural-guidance-html

The implementation of HTLS technology depends wholly on the specific HTLS type chosen but will always involve higher initial costs. In some cases, specialised installation procedures and additional training for maintenance crews is required. In other cases, such as for ACCC the installation can be easier than conventional ACSR due to the higher flexibility of the alternative conductor[25]. Additionally, the pulleys and rolls diameter needed can remain the same with no need for special installation devices or tools. One important note for the installation of HTLS is to be mindful of the higher temperatures that they can reach. As such, installation accessories must be designed to ensure no degradation by temperature or mechanical anchorage. The accessories required for ACCC conductors are very similar to those for ACSR, though an extra sleeve of aluminium is used for extra protection of the carbon fibre.

6.3.3 Reliability, availability, maintainability

The reliability, availability and maintainability (RAM) of 132 kV OHL are influenced by factors including design standards, environmental conditions, and maintenance practices. OHL are a mature and robust technology that have over a century-long record of reliable service. Most unplanned outages are caused by lightning strikes but these rarely result in significant supply disruption due to several key circuit characteristics:

- **Resilience**: The robust design of OHL and associated equipment typically prevents permanent damage from lightning strikes.
- **Automatic Reclosure**: Lines struck by lightning are immediately isolated but most circuits are equipped with automatic reclose systems that restore service within seconds.
- **Rapid Repair**: Physical damage is usually easy to locate and repair within hours or days. In cases of major damage, repairs can take up to two weeks but temporary towers are sometimes deployed to restore both circuits during this period. Planned maintenance and spare equipment stocks help minimise downtime and maintain high availability.

Cigre, is a global organisation that brings together experts, utilities, manufacturers, academics, and researchers from around the world to collaborate on the development and sharing of knowledge related to high-voltage electricity systems. Whilst data regarding the installation and failures of UGC have been published, there is no such publication for OHL. It is ‘generally accepted’ across industry that failure rates for OHL are anything from 0.1 to 0.3 faults per 100-circuit-km-year. This is a significant variation in the ‘accepted’ failure rate and as such is of limited use for comparison analysis.

Maintenance is a continuous process throughout the life of the overhead line. Each component is regularly inspected, maintained, and replaced as needed. Inspections are conducted on foot, by helicopter, or drone, depending on the terrain and requirements. For example, helicopters or drones with infrared cameras can detect overheated joints, enabling preventative maintenance before faults occur.

Routine patrols also ensure that nearby activity, such as construction and tree growth does not create a risk of flashovers. These events pose both safety hazards and risks to network stability. To prevent them, inspection teams advise landowners, monitor potential hazards, and arrange vegetation management, such as tree cutting, where necessary.

6.3.4 Flexible circuit rating

The power-carrying capacity (or ampacity) of OHL depends primarily on the conductor temperature which is influenced by factors such as ambient temperature, wind load and solar irradiance. These conditions tend to be more challenging during the summer months, so line ratings must be sufficient to meet demand during this period. However, during winter, when energy demand is higher these same lines can transmit greater amounts of power.

In emergency situations, such as following an unplanned equipment outage, 132 kV OHL are often required to carry temporary overloads. As current increases, so does conductor temperature, leading to thermal expansion and increased sag between towers. To maintain statutory safety clearances, each circuit is assigned a maximum permissible operating temperature, typically between 50°C and 90°C for conventional conductors.

As discussed in previous sections, High-Temperature Low-Sag (HTLS) conductors offer significant advantages in this context. These advanced conductors can operate at temperatures exceeding 200°C without breaching clearance limits, thanks to their

[25] SM Ueda, Cam Nascimento, M Takayama, “*Flexible HTLS – High Temperature Low Sag Conductor*”. Presented at CIGRE Paris Session 48. 2020. https://www.nationalgrideso.com/industry-information/balancing-services/electricity-system-restoration-standard

reduced thermal elongation and high-strength core materials. This allows for substantially higher current ratings and operation even with extremely high ambient temperatures.

In addition to their steady-state ratings, HTLS and standard conductors alike have defined short-term thermal limits that allow them to be safely overloaded for limited periods. Depending on the operator, during a network fault the short-term ratings of conductors can reach 110% to 120% of their OHL rating. This thermal headroom provides system operators with crucial flexibility during fault recovery, ensuring continued supply while corrective switching or network reconfiguration is undertaken

Dynamic Line Rating (DLR) is a technology that determines the real-time current-carrying capacity of OHL based on actual environmental conditions. Unlike static ratings, which are based on conservative assumptions about worst-case conditions, DLR reflects the actual thermal state of the conductor at any given moment. This allows network operators to identify periods when lines can safely carry more power without exceeding thermal or mechanical limits.

DLR can improve operational flexibility by providing additional transmission capacity during favourable conditions, which is particularly useful during peak demand periods or when integrating variable renewable generation. It also supports contingency management by allowing temporary increases in line loading following faults or outages. However, it introduces variability into system operations, as capacity fluctuates with weather. Effective use of DLR requires accurate sensing, robust communication systems, and real-time monitoring. DLR has been deployed successfully in several countries, such as across parts of Slovenia's 110 kV network[26], and is considered a viable tool for enhancing OHL utilisation.

6.3.5 System restoration capability

In the event of widespread power outages, restoration of electricity supply is a critical function of the distribution network. System restoration requires connections that are simple, low in energy demand, operable without supply at both ends, and immediately available. 132 kV OHL meet these needs and are therefore well suited for transferring restoration power[27]. They are generally preferred over underground cables and HVDC links, as they place minimal load on a weakened network while effectively transmitting power.

6.4 Environmental impacts

As part of this section, DNV has applied the knowledge of international best practices, such as International Finance Cooperation (IFC) Performance Standards[28], IFC Environmental Health and Safety (EHS) Guidelines and EHS Guidelines for Electric Transmission and Distribution (EHS ETD Guidelines)[29]. In the UK, and specifically in Wales, this assessment also considers the requirements of the Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017, as well as professional best practice guidance such as that from the Institute of Environmental Management and Assessment (IEMA), to ensure that environmental and community impacts are identified, assessed, and addressed in a manner consistent with statutory EIA processes.

This chapter summarises the most prominent environmental impacts to be considered during construction and operation phase for this archetype:

- 2 km single circuit ACCC OHL on wooden pole
- 100 km double circuit ACCC OHL on steel lattice tower

The impacts outlined below will largely be dependent on the route of the transmission line, therefore some may or may not be applicable and level of impact and will vary accordingly. For theoretical purposes, the following impacts are indicative of those typically associated with similar OHL projects. This list is not exhaustive and, for projects that meet the relevant thresholds under the Town and Country Planning (Environmental Impact Assessment) (Wales) Regulations 2017, the specific topics to be assessed would be defined through a Scoping Direction issued by the relevant authority. Additional mitigation measures can be found in Appendix B. A summary of applicability for the above archetype is provided in the table below:

Table 6-3 Summary Table: Applicability of Environmental Impacts

26 SmartWires, "System-wide use of SUMO: Eles, Slovenia," 2025. [Online]. Available: www.smartwires.com. https://www.nationalgrideso.com/industry-information/balancing-services/electricity-system-restoration-standard

27 https://www.nationalgrideso.com/industry-information/balancing-services/electricity-system-restoration-standard

28 Performance Standards (ifc.org)

29 Final - Electric Power Transmission & Distribution.doc (ifc.org)

Impact Category	2 km Single Circuit (Wooden Pole)	100 km Double Circuit (Steel Tower)	Notes
Resource Use (Materials & Waste)	Moderate (wood, small-scale aluminium conductors)	High (steel, concrete, large-scale conductors)	Steel towers and larger spans require more resource-intensive materials.
Energy Use (Construction & Transport)	Low (short distance, fewer deliveries)	High (due to volume and route length)	Driven by material transport, equipment, and duration of installation.
Pollution Potential (Air, Water)	Low	Moderate	Includes dust, machinery emissions.
Soil Impacts (Compaction, Erosion, Disturbance)	Localised, minimal	Higher than wooden poles due to cumulative impact	Soil erosion, compaction, and sediment runoff more significant over long routes.
Groundwater Interaction	Low	Moderate	Especially relevant if works are near shallow water tables or wetlands.
Ecological Impact (Habitat, Species, Bird Risk)	Minor (localised vegetation clearance)	High (cumulative across long route)	Longer route increases ecological risk and disturbance area.
Visual Impact	Moderate (lower profile, small scale)	High (tall towers, multiple viewpoints affected)	Visibility more widespread in open landscapes.
Noise and Dust (Construction Phase)	Localised and temporary	Higher due to extended construction window	Use of heavy machinery and transport over a larger area.
Site Access During Construction	Temporary and limited	Extensive, including access road network	Access planning critical to reduce footprint.
Site Access During Operation	Periodic (for inspection and repairs)	Frequent (vegetation clearance, inspections, patrolling)	Maintenance and vegetation management needed regularly.
Climate Resilience (Extreme Weather, Temperature)	Low sensitivity	High sensitivity	Frequency of extreme weather events increases the risk to tall structures exposed to wind loading, corrosion, thermal expansion.
Cumulative Impacts	Low	High	Includes repeated ecosystem crossings, and landscape effects.
Land Use / Community Impacts	Low and short-term	Moderate to high	Largely dependent on the geographical location of the OHL route

6.4.1 During the Construction Phase

6.4.1.1 Resource efficiency & waste

The following should be considered:

- **Raw Materials Consumption**: The construction of overhead line conductors, insulators and support structures requires significant amounts of materials (including steel, aluminium, concrete, wood and porcelain or glass, as well as other raw materials), which can lead to resource depletion and environmental impacts associated with material extraction, manufacturing, and transportation.
    - These materials are also used in road access works, tower foundations, and temporary construction platforms.
    - The steel and aluminium used for towers and conductors should be assessed for responsible sourcing, considering the environmental and social impacts of mining and refining activities.
    - For wooden pole installations, ensure the wood is sustainably harvested from certified sources (e.g., FSC-certified forests), to prevent contributing to deforestation and biodiversity loss.
    - Where possible, a traceability and sustainability assessment should be conducted on key material suppliers, especially for large-scale projects involving international procurement.

- **Waste Generation:** Waste will be generated from packaging, surplus construction materials, and earthworks. Soils represent a major construction waste stream and should be prioritised for reuse where suitable. Packaging and conductor drums are frequently recycled or reused by suppliers although some unrecyclable waste is still produced.
- The impact of a 2km Single Circuit is expected to be moderate, in comparison to the 100km Double Circuit, where the impact is expected to be higher due to the longer route making it more resource intensive.
- **Energy Consumption**: Energy-intensive activities, such as manufacturing components, transportation of materials and equipment, and installation processes contribute to energy consumption and greenhouse gas emissions, especially where these activities are supported by non-renewable energy sources.

The impact of a 2km Single Circuit is expected to be low, in comparison to the 100km Double Circuit, where the impact is expected to be higher due to the longer route and volume.

6.4.1.2 Pollution prevention

The following should be considered:

- **Soil and Groundwater Pollution:** Soil disturbance from excavation and tower construction can cause erosion or alter soil structure. Accidental spills of fuel or lubricants from machinery can pose contamination risks. While these risks are typically localised, appropriate spill response measures, containment systems, and contingency planning should be implemented to minimise environmental harm.

The impact of a 2km Single Circuit is expected to be low and localised, in comparison to the 100km Double Circuit, where the impact is expected to be higher and more widespread due to the longer route, thus needing to consider cumulative impact.

6.4.1.3 Impacts on biodiversity

The following ecological impacts should be considered:

- **Habitat Loss and Fragmentation**: Impacts associated with fragmentation are mostly limited to the construction phase. Vegetation clearance during the construction phase can lead to the direct loss of habitats. In some cases, the linear nature of OHL infrastructure may cause temporary fragmentation of landscapes, potentially hindering wildlife movement and reducing ecological connectivity during works. These impacts are typically short-term and reversible, particularly where appropriate reinstatement and habitat management measures are applied.
- **Disturbance of Ecological Processes:** In general, overhead line construction is unlikely to significantly disrupt broader ecological processes. However, localised impacts may occur in sensitive habitats, such as woodland, wetlands, or species-rich grasslands, where construction activities could affect vegetation structure or species interactions. These potential effects should be considered in route planning and mitigated through habitat-sensitive construction practices.
- **Disturbance to Wildlife:** Noise, vibration, lighting, and human activity during construction can disturb fauna, potentially displacing species or affecting breeding behaviour. Additionally, earthworks and vegetation removal can cause erosion, increasing sediment input into watercourses, which may negatively impact aquatic habitats.
    - **Nesting Site Disturbance**: Vegetation clearance could remove nesting habitat or disturb active nests.
- **Watercourse and Wetland Impacts:** Works near or across wetlands and rivers can alter hydrological function and degrade associated habitats.
- **Invasive Species Spread:** Ground disturbance and vehicle movement may increase the risk of introducing or spreading invasive non-native species (INNS), which can outcompete native flora and fauna.
- **Collision Risk:** Birds may collide with unmarked overhead wires, especially during poor visibility or migratory periods.

Where bird sensitivity is expected, seasonal vantage points and species-specific bird surveys should be undertaken. These should inform mitigation measures such as line marking, route adjustments, or nest protection protocols.

The impact of a 2km Single Circuit is expected to be minor with localised vegetation clearance and ecological interference, in comparison to the 100km Double Circuit, where the impact is expected to be higher due to the longer route, thus needing to consider cumulative impact.

6.4.1.4 Impacts of excess noise and dust

The following impacts should be considered:

- **Air Quality:** Dust generation from excavation or construction machinery can contribute to air pollution. Air emissions expected during the construction of the project may include both airborne dust resulting from earthworks and exhaust emissions from construction machinery such as power generators, excavators, cranes and delivery vehicles Dust particles in the air may temporarily affect local air quality and can settle on nearby vegetation, soil, and water bodies, with the potential to cause minor, short-term impacts on surrounding ecosystems and communities if not effectively managed. Excess dust will also contribute to the overall emissions generated as part of the project which is highlighted as part of the climate change impact section below.
- **Noise Pollution:** Construction activities can generate significant noise levels, potentially impacting nearby communities. Construction activities, including excavation, foundation work, and material handling, can create noise, particularly during the assembly and erection of overhead line structures. Proper planning, use of noise-reducing equipment, and adherence to noise regulations can help mitigate noise pollution.
- **Traffic and Transportation:** Increased traffic and transportation associated with the delivery of construction materials, equipment, and personnel to the construction site can contribute to noise generation.

The impact of a 2km Single Circuit is expected to be localised and temporary, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the extended construction window.

6.4.1.5 Accessibility to site

The following impacts should be considered:

- **Construction access:** The construction activities associated with overhead line installations may result in restricted access to certain areas close to the site. For example, depending on the location and extent of the construction activities, temporary road closures, lane restrictions, or traffic diversions may be required. This can impact local transportation routes and accessibility for nearby communities.
- **Construction Site Infrastructure:** The construction phase may involve the establishment of temporary infrastructure, such as site offices, storage areas, or construction laydown yards. These temporary facilities will occupy space and potentially affect access to surrounding areas.
- **Material Transportation:** Transporting construction materials, equipment, and machinery to the site can temporarily impact access routes, especially if the project requires large deliveries or specialised vehicles.

The impact of a 2km Single Circuit is expected to be localised and limited, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length and access road network.

6.4.1.6 Land use and community impacts

It is important to understand the current land use on the length of the overhead line and the presence of any residential areas or cultural heritage sites that may be affected. This should be undertaken during the environmental impact phase of the pre-application period. If the land which will be utilised for the construction of the overhead line is currently occupied, a resettlement/reallocation of land process will need to take place, following a standard community engagement process and notice period to allow the community to make any claims. However, the likelihood of this will be relatively low (if avoidable), as the route planning exercise will consider the options with the least impact, such fields rather than densely populated urban areas. Additionally, the following impacts should be considered:

- **Land Use Disruptions:** Construction activities may require temporary land use changes, including access roads, construction staging areas, and storage of construction materials. These changes can disrupt existing land uses and activities in the area. Dust and noise impacts may also be significant on nearby communities as well as increased traffic inflow due to transportation of materials. Additionally, Construction activities associated with OHL, such as excavation for foundations or installation of support structures, can disturb archaeological sites of cultural significance.
- **Employment and Economy:** The construction phase can provide employment opportunities and contribute to the local economy through job creation, supply chain involvement, and ancillary services.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length of the circuit and potential exposure to more communities. However, this is largely dependent on the geographical route of the OHL line.

6.4.2 During the Operational Phase

6.4.2.1 Impacts on biodiversity

During the operational phase of the overhead line there are several impacts to biodiversity, namely for birds:

- **Collisions:** Birds in flight may collide with power lines, especially during low visibility conditions or when the lines are not clearly visible.
- **Electromagnetic fields:** There is some evidence to suggest that there some adverse impacts on birds and species from EMF, specifically around, behavioural effects, magnetic field sensitivity, health effects and species variability[30].

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due to the longer route, thus needing to consider cumulative impact.

6.4.2.2 Accessibility to site

The following activities should be considered:

- **Maintenance and Repair:** Accessibility for routine maintenance and inspection activities is crucial to ensure the ongoing reliability and safety of the distribution line.
- **Vegetation management:** Vegetation growth around an OHL can impede access and pose safety risks such as keeping a 4 m to 5.2 m wide corridor free of trees and shrubs that can catch fire or lead to a safety violation due to sag or swing[31].

The impact of a 2km Single Circuit is expected to be localised and limited, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length and access road network.

6.4.2.3 Climate change impacts

Climate change is expected to influence the performance and resilience of OHL infrastructure in several ways:

- **Extreme Weather Events**: Increased frequency and severity of storms, high winds, and lightning events may damage towers, poles, and conductors.
- **Increased Temperature and Heatwaves:** Higher ambient temperatures can increase electrical resistance in conductors, resulting in greater transmission losses. Refer to Section 4.2 for further details on losses.
- **Sea-Level Rise and Coastal Erosion (if located near the coast):** Rising sea levels can corrode metal components and undermine tower foundations due to saltwater intrusion and coastal erosion.
- **Surface Water Flooding:** Extreme rainfall or rising river levels can cause waterlogging or erosion around foundations, compromising the structural stability of towers and poles. Designs should incorporate drainage measures, elevated foundations, or other flood-resilient features where required.
- **Changes in Precipitation Patterns:** Increased rainfall or prolonged wet conditions may destabilise soil, leading to landslides or subsidence risks, particularly in clay-rich or unstable ground conditions.
- **Transfer of Renewable Energy:** OHL networks play a critical role in enabling the transfer of renewable energy across regions, supporting decarbonisation efforts and contributing positively to climate change mitigation.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length of the circuit and potential exposure.

6.4.2.4 Visual impact on residential areas

The placing of the OHL will have a permanent impact on nearby residential areas, if in proximity. This impact should be further assessed through visual impact modelling and as part of community engagement process.

- **Visual impact:** The presence of overhead lines can result in a visual change to the surrounding landscape, particularly if they are located close to residential areas (though this is dependent on the route of the circuit). This visual change may affect how communities perceive their local environment, especially from homes with direct views of the infrastructure.

[30] https://spectrum.ieee.org/electric-field-disruption-magnetic-compass-birds-hints-quantum-action

[31] https://prep.enwl.co.uk/globalassets/get-connected/cic/icpsidnos/g81-library/old-pages/installation-and-records/4-overhead-line/cp420-part-1/c-p420-pt-1--ch-15-i7.pdf

A detailed visual impact assessment should be conducted, including modelling from key residential viewpoints. Community engagement should be integrated into this process to identify sensitive locations and where appropriate, incorporate mitigation measures such as route selection, tower design variation or screening vegetation. Long routes may intersect multiple community viewsheds, especially in open landscapes.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length of the circuit and potential exposure to more communities. However, this is largely dependent on the geographical route of the OHL line and proximity to residential areas.

6.4.2.5 Impacts on the neighbouring communities

Once the OHL are in operation, there are several impacts to consider:

- **Electromagnetic Field (EMF) Exposure:** All OHL installations must comply with ICNIRP public exposure limits to ensure health and safety. EMF strength decreases rapidly with distance from the line. For typical high-voltage overhead lines (132–400 kV), EMF levels fall below ICNIRP guideline limits at distances of approximately 5 to 25 metres from the line centreline, depending on voltage, configuration, and current. These distances are normally respected within the designated wayleave or easement corridor. The scientific consensus, supported by ICNIRP and the World Health Organization, confirms that there are no established adverse health effects from EMF exposure where these guideline limits are met. Incorporating clear safety margins and engaging effectively with communities can help reduce concern and ensure the public is well informed.
- **Noise Generation:** AC OHL can generate audible noise due to electromagnetic fields interacting with conductors and other components, as well as electrical arcing or corona discharge (which is when high-voltage distribution lines ionize the surrounding air, creating a bluish glow and a hissing noise).
- **Land/Property Value:** The accumulation of the impact's discussion in the above section, including visual, noise and EMF may influence the land/property value in the nearby communities depending on people's perception of the infrastructure and the proximity of the structures to residential areas, urban centres, schools, recreational facilities, and other amenities.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length of the circuit and potential exposure to more communities. However, this is largely dependent on the geographical route of the OHL line and proximity to residential areas.

6.5 Commercial & supply chain impacts

The unprecedented penetration rate of renewable energy sources on the GB's electricity network, coupled with our increasing need for international transmission interconnection to maintain security of supply and control energy prices, are prompting previously unknown levels of electricity transmission and distribution system development. These GB network development needs are presently reflected around many of the world's electricity supply systems.

The EU hosts many of the global leaders in power system component manufacture including, for example, suppliers of HVDC cables, substation equipment, and transformers. Nevertheless, given the simultaneous circumstances of international growth in equipment demand, global increase in the prices of raw materials such as copper and steel, and multiple major national conflicts, the EU notes, in its 'Communication from the Commission to the European Parliament …', COM(2023) 757 final, dated November 2023 that "… grid project promoters flag long and growing lead times for procuring specific grid components, sometimes of several years even for the most urgent Projects of Common Interest, … because of tight supply of some components or increasing raw material prices."

The same EU document cites several other procurement difficulties, too. These include, firstly, the need to procure secure systems, both in terms of cybersecurity and relating to the weaponisation of supply chain dependencies, and secondly, the need to standardise products, both in order to reduce costs and also the speed of production. A third, and equally vital area attracting their concern for the power industry supply chain is "the lack of skilled workers [which] affects the increasing staffing needs of transmission and distribution system operators, HVDC cable manufacturers and other power system suppliers. This includes the need to acquire further advanced digital and technological skills, such as automation, controlling, big data and advanced analytics, to detect and control network challenges as well as develop the necessary technologies".

At present, these supply chain concerns affect some distribution equipment archetypes more than others, Table 6-4 provides a brief summary of key concerns for each archetype.

Table 6-4: Commercial and supply chain impacts – OHL

OHL	
Towers and foundations	No known concerns, though both lattice steel tower and monopole tower prices are critically dependent upon the supply of steel
Insulators and conductor systems	No known concerns, though conductor system prices are critically dependent upon the supply of aluminium
Sitework	We note the availability of the necessary skills for construction, testing and commissioning will require concerted development effort in the face of an ageing workforce at a time of expanding skills demand.

7 UNDERGROUND CABLES

The use of Underground Cables (UGC) is visually less impactful when compared with the use of OHL. These are likely to be the preferred choice for local residents regardless of economics or the challenges they pose. However, underground cables may have significant environmental, community and socio-economic impacts that should be considered. The summary of the installation methods for 132 kV underground cables discussed in this section is shown in the table below. The methods are based on Standards from the Energy Networks Association (ENA), British Standards (BS EN), and UK Distribution Network Operators (DNOs) such as UK Power Networks, SPEN, and National Grid Distribution.

Table 7-1: Installation Methods for 132 kV UG Cables

Method	Accepted/Suitable	Technical Description
Open Trenching	Yes	The most common method. The cables are laid directly in excavated trenches with thermal backfill, tiles, and protection layers.
Ducted Installation	Yes	Cables are pulled through pre-laid ducts (usually HDPE or concrete) for easier replacement or urban routing.
Mole Ploughing	No	This method is not suitable for 132 kV cables or greater. The method does not give control over depth, spacing, joint access, or protection layers.
Cut and Cover Tunnels	Yes	Reinforced concrete tunnels are built in a trench and backfilled. They are used in urban areas for multi-circuit or critical routes.
Horizontal Directional Drilling (HDD)	Yes	Trenchless method for crossing roads, rivers, or railway lines. They are used only for short sections.

7.1 Trenching for direct burial or ducted installation

In both urban and rural environments, land disruption is greater when excavating the ground/laying underground cables than when erecting overhead line towers. The volume of spoil excavated for the UGC is 14 times more than for an equivalent OHL route. Vegetation has to be cleared along and to the side of trenches to allow for construction and associated access for vehicles. The two main trenching methods are direct burial and ducted installation.

All 132 kV cables should be installed to the following minimum depths, whether they are laid directly or installed in ducts. The minimum distance for footways/grass verges/private property is 900 mm; carriageways (including road crossings) is 900 mm; normal agricultural land (not subject to deep ploughing) is 1050 mm; and agricultural land subject to deep ploughing = 1200 mm.

The Industry Standards, Statutory Regulations and Specifications applicable to the trenching and installation of UGC include (but not limited to): Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002; ENA TS 97-1: Special backfill material for cable installations (Energy Networks Association); ENA TS 12-24: Technical specification for plastic ducts for buried electric cables; ENA TS 09-2: Insulated cables up to 132 kV – design and installation; CDM Regulations 2015; BS EN 61936-1: Power installations exceeding 1 kV AC; and HSG47: HSE guidance for avoiding danger from underground services

7.1.1 Direct burial method

The underground cables are laid directly in the trench and surrounded by sand or thermal backfill for protection and thermal performance. The direct burial of cables is cheaper, faster to install and requires less need for ducts or conduits.

The safety and environmental issues associated with the direct burial method include disruption to traffic, excessive noise, vibration, visual intrusion, dust generation, difficulty in inspecting/maintaining/replacing, high vulnerability to mechanical damage from digging, and limited flexibility for future upgrades.

The direct burial method is appropriate for use in rural or semi-urban areas, long-distance runs, and controlled environments. The buried cables are mostly protected by thermal sand or a screened soil layer, warning tape or concrete slabs above, and cable covers and marker posts.

The trenching design for the burial method has a depth of typically between 1.2 and 1.5 meters (this may vary by Regulations) and a width that is enough for the required spacing between phases (typically 300 – 400 mm). The minimum separation distance from other services is 300 mm.

The layer structure for the direct burial method is described below:

- **Trench Floor:** Compacted soil
- **Bedding Layer:** 100 mm of sieved sand or thermal backfill
- **Cable Placement:** 132 kV XLPE cable directly laid.
- **Cushioning Backfill:** 150 – 300 mm of sand over the cable
- **Protective Layer:** Concrete tiles or cover slabs (optional)
- **Warning Tape:** Placed approximately 300 mm above the cable or 300 mm below the surface.
- **Marker Posts:** At entry/exit points and changes in cable direction
- **Backfill:** Native soil or thermal backfill

NB: Thermal backfill of cement-bound sand is usually used to ensure a known thermal conductivity around the cables to maintain the cable rating (capacity to carry current). The thermal backfill must meet the thermal resistivity specification (typically <1.2 K·m/W).

7.1.2 Ducted installation

The underground cables are pulled through ducts (typically HDPE, PVC, or concrete) and are laid in the trench, often with spare ducts for future use. Ducted installation is appropriate for urban settings, road crossings, high-risk or congested areas.

The ducted installation advantages include better mechanical protection, ease of maintenance, easier cable replacement or upgrades, facilitation of jointing and repairs, and are preferred in urban areas or under roads (road crossings).

On the other hand, the ducted installation comes with the following issues: higher cost, lower heat dissipation (may require derating), and more space and planning are needed in trench design.

The layer structure for ducted installation is described below:

- **Trench Floor:** Compacted base
- **Duct Bedding:** Sand or fine material to surround ducts
- **Conduit/Ducts:** HDPE, PVC, or concrete ducts (single or multi-cell). Must be strong enough to withstand the load and meet the requirements of the relevant specifications, e.g. ENA TS 12-24.
- **Spare Ducts:** Often installed for future use.
- **Encasement:** May be concreted for additional strength (urban or road crossings).

7.1.3 Comparison between direct burial method and ducted installation

Table below shows the comparison between the direct burial method and ducted installation.

Table 7-2: Comparison between the Direct Burial Method and Ducted Installation

Criteria	Direct Burial	Ducted Installation
Cost	✓	×
Installation Speed	✓	×
Maintenance	×	✓
Mechanical Protection	×	✓
Thermal Performance	✓	×
Repairability	×	✓
Heat Dissipation	✓	×
Future Upgrades	×	✓

The design of trenching using direct burial and ducted installation designs are illustrated in Figure 7-1 below.

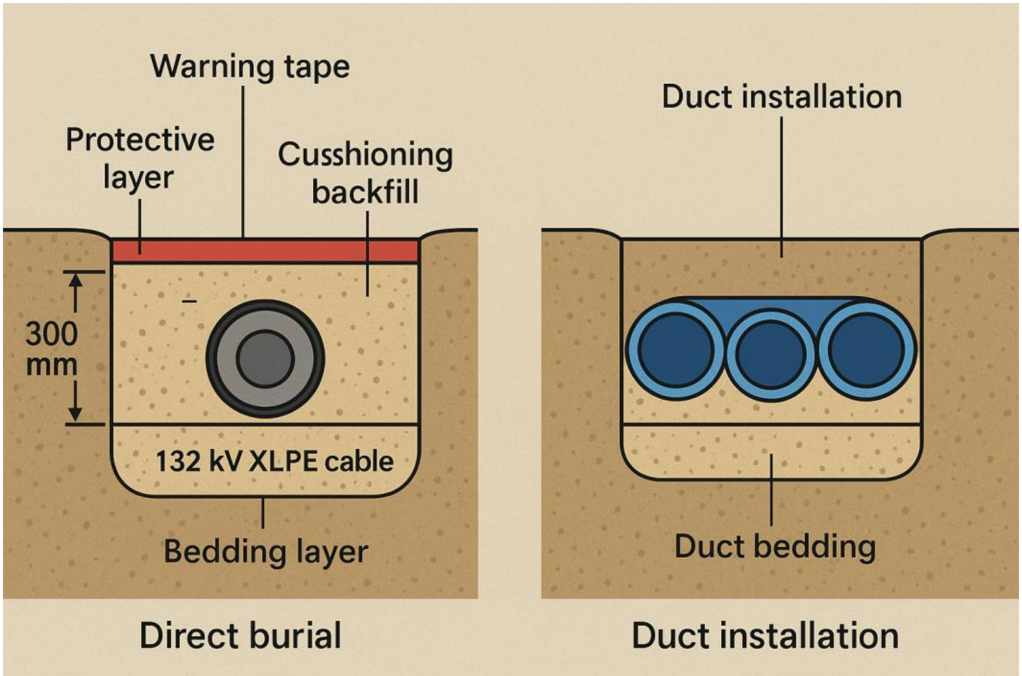


Figure 7-1: Trenching Design for Direct Burial Method and Ducted Installation (note minimum depth is 900mm)

7.2 Mole ploughing

Mole ploughing for underground cables is also called cable ploughing, direct ploughing, or trenchless cable laying. Mole ploughing is a trenchless installation technique used to lay underground cables by slicing a narrow slot through the ground using a plough blade, which simultaneously places the cable at the required depth without needing an open trench.

It is widely used in rural or semi-rural areas and is ideal for long-distance runs, especially for LV, MV, and some HV cables, though it's not suitable for 132 kV due to the size, weight, and protection requirements. Mole ploughing is an efficient trenchless method for cable installation, but it comes with significant limitations when applied to 132 kV cables, especially under the UK conditions.

Mole ploughing is feasible only if approved through detailed thermal/mechanical design, and it is to be used in rural areas, straight-line routes, and temporary or non-primary feeder installations.

Mole Ploughing works include**:** a tractor or tracked vehicle pulls a mole plough fitted with a cable feed, the blade creates a slit while simultaneously placing the cable below ground, the soil naturally recompacts behind the blade while minimising surface disruption, and an optional warning tape or marker tape is fed in just above the cable.

The limitations of mole ploughing for 132 kV Cables in the UK include the following and the summary of the limitations are shown in the Table below:

1. **Cable Size and Rigidity:** The 132 kV cables are large and stiff, often armoured and heavily insulated (e.g., XLPE). Due to this, mole ploughs struggle to handle the large diameters and weight of the cables, especially over long runs or uneven terrain.
2. **Depth Control and Alignment:** The precise depth and spacing between phases (300–400 mm) are harder to maintain. Bend radius constraints of 132 kV cables are strict; mole ploughs may exceed them. No control over bedding layer quality.
3. **Thermal Performance:** Ploughed routes don't allow for thermal backfill (e.g., cement-bound sand or low thermal resistivity material). UK standards often require thermal modelling for 132 kV – direct ploughing limits this.
4. **Mechanical Protection:** No concrete slabs, cable covers, or marker tiles can be placed in a ploughing operation. Makes compliance with DNO specifications and ENA standards difficult.
5. **Ducts and Joint Bays:** Mole ploughing doesn't accommodate pre-laid ducts, joint bays, tiles and link boxes. These are critical for HV cable systems, especially in the UK.
6. **Regulatory Compliance:** UK Distribution Network Operators (DNOs) like UKPN, SSE, or Northern Powergrid typically do not accept ploughing for 132 kV installations unless very specific conditions are met. Most 132 kV installations require trenching, with full protection and thermal validation.

Table 7-3: Summary of Mole Ploughing Limitations for 132 kV Cables

Limitation Criteria	Impact
Cable size	May exceed ploughing limits
Thermal design	Cannot guarantee soil resistivity
Regulatory acceptance	Rarely approved by UK DNOs
Protection standards	Inadequate without trenching
Jointing & access	Not possible with ploughing

N.B.: Mole ploughing is generally not suitable for 132 kV underground cable installations. This is due to stringent technical and regulatory requirements that necessitate precise installation methods to ensure safety, reliability, and compliance with national standards.

DNO Policies and Standards

UK DNOs such as UK Power Networks (UKPN), Electricity North West (ENWL), and Northern Powergrid have established specific guidelines for the installation of 132 kV cables:

- **UKPN**: Their engineering specification mandates that all 132 kV cables be laid on a 75 mm bed of selected sand or cement-bound sand (CBS) and blinded with the same material to a depth of 75 mm above the cable. This ensures adequate thermal performance and mechanical protection.
- **ENWL**: Their policy document, ES400E5, specifies that installations must comply with ENA TS 09-2 standards, which detail requirements for trench dimensions, bedding materials, and protection measures.

- **Northern Powergrid**: Their NSP/002 policy outlines that 132 kV cables should be laid with appropriate bedding and backfill materials, and that trench configurations must be designed to accommodate the specific thermal and mechanical requirements of high-voltage cables.

The above-mentioned policies and standards emphasise the necessity for controlled trench environments, precise cable placement, and the use of specific backfill materials to manage thermal resistivity and mechanical protection in conditions that are challenging to achieve with mole ploughing techniques.

Advantages of mole ploughing include fast and efficient over long distances, minimal disruption to the environment or land use, lower labour and excavation costs, and ideal for remote or agricultural areas.

Best use cases for mole ploughing include rural grid reinforcement, wind or solar farm connections to substations, and long-straight cable routes with minimal crossings.

In conclusion, while mole ploughing offers advantages in terms of speed and reduced surface disruption, it falls short of meeting the stringent requirements for 132 kV cable installations in the UK. The lack of control over trench conditions, bedding materials, and protective measures makes it unsuitable for such high-voltage applications (132 kV and above). DNOs mandate installation methods that ensure precise cable placement, adequate thermal management, and robust mechanical protection to maintain the integrity and reliability of the power network.

7.3 Cut and cover tunnels

The Cut and Cover Tunnels are a method of installing underground structures, such as cable tunnels for 132 kV cables, where a trench is excavated, the tunnel is constructed in place, and then the trench is backfilled. The method involves open excavation to the desired depth, building of a reinforced concrete tunnel within the trench, installation of cable trays and supports, pulling and termination of cables, backfilling of the structure and surface/road restoration. This technique is widely used in urban environments (such as cities, near substations, railways, parks, etc.) where open trenching or deep bored tunnels are not feasible or cost-effective.

Open-cut trenching allows for precise control over cable placement, bedding, and backfill materials. It also facilitates the installation of protective coverings and warning tapes.

The applicable standards for Cut and Cover Tunnels include ENA TS 09-2: Insulated cables for rated voltages up to 132 kV - Installation and testing practices; ENA TS 97-1: Civil engineering design and construction of cable tunnels and ducts; and BS EN 61936-1: Power installations exceeding 1 kV AC – Common rules.

The typical design features and criteria for Cut and Cover Tunnels are shown in the Table below:

Table 7-4: Typical Design Features & Criteria for Cut and Cover Tunnels

Features/Requirements	Technical Description
Tunnel Size	Typically, 1.5–3.0 m wide and 2.0–3.0 m high (for personnel access)
Reinforced Concrete	A minimum internal clear dimension typically ≥2.0 m (height & width)
Cable Support	Galvanised steel cable ladders or cleats and minimum clearance between phases is typically ≥200 mm. Consideration should be given to induced voltages and EMF
Long-Term Structural Integrity	Accounting for soil pressure, groundwater, and live loads (e.g., road traffic above)
Cable Trays/Racks	Mounted on walls or ceiling; allow 3-phase spacing and separation
Ventilation	Natural or forced air circulation to reduce heat buildup
Thermal Considerations	Thermal modelling using IEC 60287 to calculate ampacity and the use of low thermal resistivity bedding around cables or ducts

Fire Protection	Fire-retardant coatings or panels, passive fire barriers, fire & smoke detection systems, and fire escape routes
Drainage	Channels, pumps or sumps to manage water ingress
Access Shafts	Every 300-500 m or at joint bays for inspection and maintenance
Security	Lockable access points and CCTV in sensitive urban areas
EMC/EMF	Routing and layout should be designed to minimise EMF exposure in public areas
Health and Safety	Compliance with CDM Regulations 2015 and confined space entry standards

Cut and Cover Tunnels offer a blend of technical robustness and environmental advantages for 132 kV underground power cables, especially in dense urban or sensitive zones.

The following are the environmental and technical benefits of the Cut and Cover Tunnels method:

1. **Reduced Urban Congestion and Surface Disruption:** It avoids major surface disruptions during maintenance. Once installed and backfilled, there is no repeated road digging for maintenance or upgrades. It is ideal for urban environments, reducing noise, dust, and traffic impacts long-term.
2. **Lower Visual Impact:** It replaces OHL with underground infrastructure, preserving landscape aesthetics that are important in heritage areas, parks, or residential zones.
3. **Controlled Waste Management:** Construction involves planned excavation and reusable material options (e.g., recycled concrete). There is better control over runoff, contaminated soil, and emissions compared to deep-bore tunnelling.
4. **Habitat and Land Use Preservation:** It avoids the long-term footprint of above-ground substations or towers. After backfilling, the land above can be restored to green space, roads, or paths.
5. **Multi-Circuit Capacity:** Cut-and-cover tunnels can host multiple circuits, future-proof the route and reduce the need for duplicate trenches. It allows bundling of multiple HV cables in an organised space.
6. **Ease of Access for Maintenance:** It enables easy access for repairs or upgrades via cable tunnels. Tunnels can also be designed with personnel access, allowing safe inspection, testing, or cable replacement without new excavation.
7. **Thermal Management:** It facilitates thermal modelling and active ventilation to control temperature rise, essentially for 132 kV circuits under continuous load. Tunnels can also be designed with forced ventilation or heat-resistant ducts.
8. **Mechanical and Enhanced Cable Protection:** Cables are fully enclosed in reinforced concrete, protected from mechanical damage, flooding, and third-party interference.
9. **Integration with Other Utilities:** Coordinated infrastructure (e.g., fibre, water, gas) can be routed through shared sections, reducing utility clashes.

7.4 Horizontal directional drilling

Horizontal Directional Drilling (HDD) is a trenchless installation method used in the UK for 132 kV underground cable routes but only in specific and short-span applications. It offers clear benefits for crossings under roads, rivers, railways, or environmentally sensitive areas but also has strict technical constraints at this voltage level.

HDD is used in areas where open-cut trenching is impractical, such as under rivers or existing infrastructure. HDD allows for the installation of ducts or cables with minimal surface disruption.

HDD is accepted for 132 kV cables in the UK for instances such as River crossings - to avoid aquatic habitats or navigable waterways; Railway/Highway crossings – to prevent major surface disruption; Protected habitats/urban areas - to avoid tree roots, heritage zones, or dense utilities; Sensitive environment zones – to avoid excavation in protected or difficult areas; and Short-span urban sections – to bypass dense utility corridors or heritage zones.

The applicable standards for HDD include ENA TS 97-1: Civil works for cable systems; BS EN 12889 – Trenchless construction and testing of drains and sewers; CDM Regulations 2015; and HSG47: Avoiding underground service strikes.

The technical specifications and considerations for HDD at 132 kV are described in the Table below:

Table 7-5: Technical Specifications and Considerations for HDD at 132 kV

Factor	Technical Specifications and Considerations
Duct Size	Minimum inner diameter of 160–200 mm per phase duct (usually HDPE)
Number of Ducts	Typically, three single-phase ducts, or a triangular trefoil duct bundle
Thermal Design	Must assess soil thermal resistivity, duct spacing, and ampacity impacts
Pulling Forces	Cable manufacturer's limits (e.g., maximum pulling tension of 30-100 kN per conductor dependant on cable manufacturer)
Cable Types	Must be XLPE insulated, robust outer sheathing (e.g., MDPE/HDPE)
Route Geometry	Avoid excessive curvature; the minimum bend radius should be 20 x Cable Outer Diameter (OD)
Entry/Exit Pits	Require temporary excavations to support duct access and cable jointing

HDD can be used for 132 kV underground cable installations in the UK but it presents several technical limitations and challenges that must be carefully addressed. While it's valuable for trenchless crossings (such as rivers, roads, railways), it is not suitable for long routes longer than 300 m, where joint bays cannot be constructed at both ends, in high thermal load corridors with no cooling strategy, and high-complexity installations (e.g. congested urban ducts) where precise alignment is critical.

The technical limitations and challenges of the HDD method are described below:

1. **Cooling Issues:** Poor heat dissipation unless ducts are spaced or thermally backfilled.
2. **Damage Risk:** Cable sheath may be damaged during pull if not properly lubricated.
3. **Limited Visual Access:** No inspection access unless ducts are pulled back.
4. **Length Constraints:** Maximum pull distances are typically limited to 200–300 m, due to mechanical strain and thermal limits on the cable. Longer HDD routes require intermediate joint bays, which cannot be located underground.
5. **Bend Radius Limits:** Requires large curvature (minimum ~20 x Cable OD) to avoid damaging the conductor, insulation, or sheath. This limits routing flexibility.
6. **Thermal Dissipation:** HDD ducts are surrounded by compacted or native soil with unknown or poor thermal properties, risking cable overheating unless thoroughly modelled and mitigated.
7. **Duct Heating:** Multiple ducts in close proximity can cause thermal derating unless spacing or thermal backfill is managed.
8. **Cable Jointing:** Cable joints cannot be made within ducts or in the HDD bore. This mandates joint bays at entry and exit points, which increases the civil scope.
9. **Unknown Subsurface Conditions:** Drilling through mixed or rocky ground can lead to tool deviation, collapse, or damage to ducts. Pre-drilling surveys (e.g., GPR, boreholes) are essential.
10. **Duct Collapse or Deformation:** In unstable or wet soils, ducts may collapse or shift before cable pulling unless supported or reinforced.
11. **Cable Pulling Tension:** Cable manufacturers specify maximum pulling force (E.g., 30 kN by Prysmian cables to 100 kN by Sudkabel). Friction in curved ducts can cause tension overrun, risking damage.

12. **Lubrication Required:** High friction during pulling demands the use of approved cable lubricants (e.g., bentonite slurry, cable gel), which must be compatible with the sheath.

The engineering challenges associated with the HDD method and their mitigations and solutions are described in Table 7-6 below:

Table 7.6: Engineering Challenges associated with the HDD Method and their Mitigations / Solutions

Challenge	Solution / Mitigation
Poor Soil Thermal Resistivity	Conduct detailed thermal modelling (IEC 60287) and consider thermal grout or enhanced ducts
Cable Tension during Pull	Use pulling calculations, capstans, or intermediate winches
Curvature too sharp	Design shallow arc transitions with HDD profile modelling
No Space to Joint Bays	Limit HDD to non-jointed spans or relocate joints to accessible locations
Subsurface Interference	Conduct utility surveys and use steerable drill heads to avoid clashes

7.5 Archetype description

Figure 7-2: HV cable section

Underground cables make up approximately 5% of the existing system in England and Wales[32]. This is typical of the proportion of UGC to OHL equipment in electricity networks worldwide, though this proportion is increasing gradually in Europe, driven by urbanisation trends and potential land value impacts of overhead alternatives.

The National Policy Statements EN-1 and EN-5 require that Nationally Significant Infrastructure Projects (NSIPs) demonstrate that they are efficient and economical. In Wales, this would be a Development of National Significance (DNS). The DNS process is administered by Planning and Environment Decisions Wales (PEDW) on behalf of the Welsh Ministers.

For this reason, most underground cable is installed in non-industrial urban areas, where installing and OHL is much less practicable. However, examples of other situations where underground cables have been installed in preference to OHL include passing through nationally designated landscape areas, where they preserve important views from intrusion by OHL. To achieve this objective, underground cables will often be used in short sections of a composite circuit that principally comprises an overhead line.

UGC are very heavy and cannot be tightly coiled, so they are delivered to the site on large drums in lengths of up to a maximum of around 1,000 m, though sometimes less than this. The cable systems thus comprise of two main components – the cable sections themselves and their joints. The joints along the underground cable route that connect lengths of cable together will be buried in joint bays. These can take the form of an above-ground joint testing kiosk, manhole cover or signpost for an easy dig pit. Meanwhile, the cable's terminating connectors in substations are necessarily above ground.

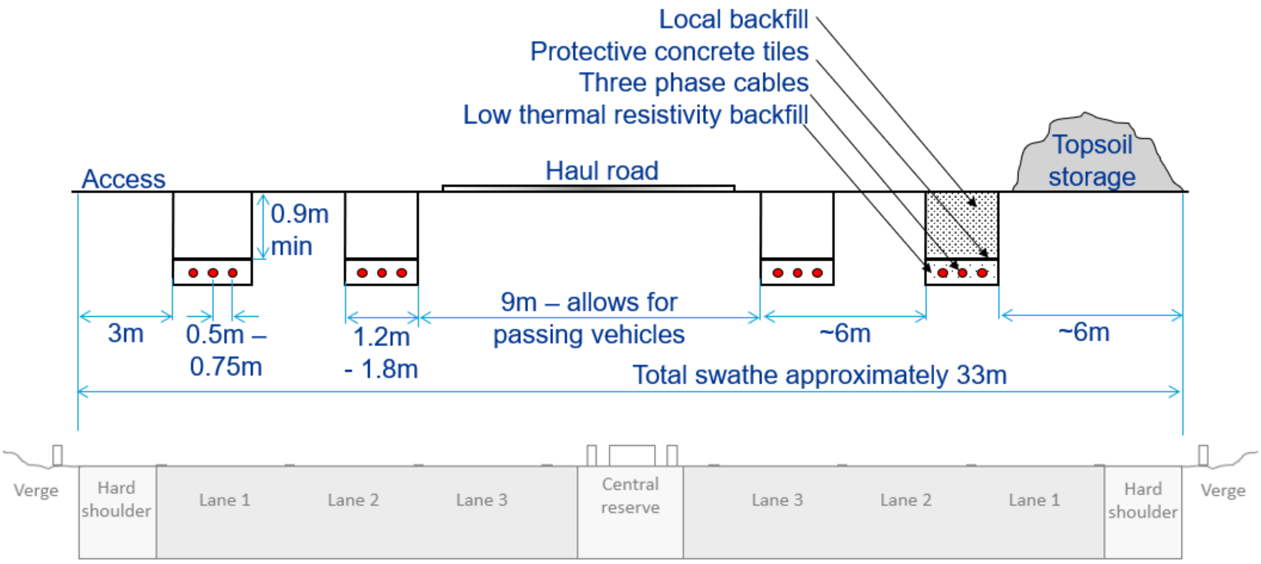
As illustrated in Figure 7-2 above, an underground cable consists of a central electrical conductor, which is either copper or aluminium, surrounded by insulating material and sheaths of protective metal and plastic. The purpose of the insulating material is to ensure that, although the conductor is operating at a very high voltage and the outside of the cable remains safely earthed.

32 Electricity Ten Year Statement (ETYS) 2022: Appendix B – System Technical Data

Modern cable uses cross-linked polyethylene (XLPE) insulated cable in preference to the older oil impregnated paper insulated cable which is less environmentally friendly.

High voltage underground cables may be installed in many ways, depending upon the environment they are passing through; they can be pulled into ducts, laid in surface troughs, cleated to the sides of deep bore tunnels or more commonly and the cheapest UGC option, directly buried in the ground. Direct burial requires trenches approximately 1.2 m deep with a width that varies between about 0.5 m and 3 m per circuit, depending on the burial formation and the number of cables per circuit. A thermally stable backfill of cement-bound sand is used to ensure a known thermal conductivity around the cables, to avoid the cable overheating.

This direct burial approach is illustrated Figure 7-3 below. This layout is an example of a high-capacity installation, two circuits, each with 2 cables per phase. The reason for laying three phase cables fairly close to each other in a single trench is to minimise electrical imbalance for the system operators, and to minimise magnetic field strengths around the cables. However, the reason why the cables are often spaced apart from each other within the trench and the reason why the trenches are spaced well apart from each other, is to allow heat from the cables to dissipate without their temperatures rising to damaging levels. For high-capacity cable routes, for example, 2 cables per phase (12 cables total), this need for heat dissipation results in a construction swathe width of around 33 m, this is almost the same width as a 3-lane motorway. To match the capacity of modern OHL conductors, the increase in the number of UGC conductors can easily require a 60m swathe. Once the construction project has been completed, the land can be reinstated for the original above-ground rural and agricultural uses so long as the ground immediately above and around the buried cables is not disturbed. To ensure that the cables stay safe and do not pose any risk during their operational lives, activities such as building, excavation, tree-growing, and fence post insertion are permanently discouraged within the swathe contained between the outermost cables, that is, for the 2-cable-per-phase example, a swathe width of around 25 m.



Note 1: A double circuit, 2-cables-per-phase, underground transmission cable construction swathe cross section – 2 trenches per circuit, 4 trenches total. Intermediate dimensions are approximate, varying with application

Note 2: For comparison, the cross-section of 3-lane motorways in Great Britain (33m wide including hard shoulders) is shown here on a similar scale

Figure 7-3: Example dimensions of an underground cable construction swathe cross-section

Lower capacity circuits may require only 1 cable per phase and a construction swathe width of around 12 m narrower than that depicted in the graphic, whilst higher capacities may even require 3 or 4 cables per phase and a correspondingly greater swathe width For high capacity cable circuits, the construction swathe for joint bays is 5-8 m wide and 10-15 m long, and for topsoil storage height (topsoil) limit is 1.5-2 m and 3-5 m width (a standard construction swathe of 14-20 m in total for higher capacity circuits).

A cable construction swathe would be granted to a network company in the form of an easement, permitting the company access for the specific purpose of installing the cable. The width of the easement would be a function of the number of circuits, the number of cables installed per circuit and the required work areas. Whilst the following graphic depicts a typical 2-cables-per-phase construction swathe width along most of the circuit length, the swathe width is often greater at joint bays to allow space for the jointing process to take place.

Whilst the focus of this section is to provide information on AC cable systems in onshore networks, it should be noted, for completeness, that offshore AC transmission can sometimes also be an option – however, see Section 6.1.3 for further information about limitations to cable route lengths.

7.5.1 Circuit capacity

The transmission capacity of a 132kV underground cable circuit depends on the cross-sectional area and type of its conductors and upon the number of cables that comprise each of the three phases. From DNVs analysis of 500, 132 kV circuits across 3 distribution networks, a 132 kV distribution circuit's pre-fault continuous summer rating design capacity can range from 35 MVA to 250 MVA, with 50% of the circuits analysed being between 60 and 105 MVA. Generally, the rating of underground cable sections used in composite overhead line circuits would match the rating of the overhead line circuit, and for high power transfer requirements, multiple cables per phase may be installed to achieve the desired transmission capacity.

The limiting factor, in terms of underground cable transmission capacity, is the permissible cable temperature, for example or 90°C. Since copper has a lower electrical resistance than aluminium, for a given conductor temperature, copper can pass a higher current than aluminium. As an approximation, a copper conductor can transmit 30% - 40% more power than the equivalent sized aluminium cable core. The choice of using multiple aluminium cables or fewer copper cables is largely dependent on the market prices of the metals at the time that they need to be purchased for the cable's manufacture.

The continuous current rating of a cable will be 'derated' by a factor based on the environment that encapsulates the cable. The derating factor considers the thermal properties of the cable core's surroundings, such as the cable insulation, the burial backfill, ducts (and duct fill material) and the ambient conditions above the surface of the ground. The formation of the cables in the ground, whether bundled together in a trefoil formation, or equally spaced apart in a flat formation, can also make over 10% difference to the cable rating, because of the heating effect of each core on the adjacent cables but also the reduction in dielectric losses associated with running cables in trefoil.

Whilst larger than commonly used, a 2500 mm² copper cable is rated at 1,460 A when buried. Operating at 132 kV, this gives the maximum capacity of a single burred three phase circuit of 334 MVA. For transport and manageability, it is generally seen that a 1200 mm² would be used, this has a capacity of 225 MVA.

7.5.2 Lifespan

The expected lifespan of an underground cable is over 40 years although this can depend on the operational utilisation of the cable; for instance, routinely operating a cable close to its maximum permissible rated load for long periods which can significantly shorten its expected lifespan. Cable life can also be affected by external factors that the cable has been exposed to which could cause it to degrade over time, for instance UV light (particularly at cable terminations), chemicals, and excessive flexing or mechanical action.

It is not practicable to refurbish or upgrade underground cable conductors in the way that can be achieved for OHL. However, since underground cables are mostly protected from corrosive and mechanical stresses relating to weather conditions there is the expectation that modern cable designs, with life extension reviews and sample visual inspections, have the potential to reach 60 or 80 years of satisfactory service-life without needing to be disturbed.

7.5.3 Limitations

UGC will usually require a larger cross-sectional area that an equivalently rated OHL. This is due to increased thermal resistance of the surrounding medium. OHLs are able to dissipate heat much more efficiently then UGC and therefore can afford to have a smaller CSA which leads to slightly higher resistance. The main limiting factor of OHLs is the sag of the line and therefore the distance between towers. The main limiting factor of UGCs is temperature rise and heat dissipation.

High voltage cable capacitances still cause significant losses, so cable circuits with light average loads can be less efficient than equivalent OHL. The longer the cable circuit, the greater are these losses, therefore, there are practical limits to cable circuit length before compensators should be added to the circuit. DNVs analysis of existing 132 kV circuits indicates that the median cable length is 25% less than the median OHL.

Another limitation of underground cables (that is shared to a lesser extent by OHL) is that their currents set up magnetic fields that can induce voltages in nearby insulated metallic structures such as pipelines, especially where these lie in parallel with the cables over significant distances. Magnetic fields diminish rapidly with distance from the power cables; nevertheless, close, parallel metallic structures can suffer safety and corrosion issues, in which case cable designers have recourse to various technical solutions that can reduce the effects of the magnetic fields.

7.5.4 Future scalability for long-term planning

Underground cable systems are a mature and versatile transmission technology, being equally applicable to both the main distribution networks and to specific network user connection applications. Once installed, underground cable circuits have limited potential for future development, as their capacities are controlled by their conductor cross-sectional areas, and their geographical routes are dependent upon successful negotiations with landowners.

However, underground cable circuits can accommodate the evolving demands of the system by supporting power overloads for short periods of time, and by allowing instantaneous changes in power flow levels and direction. In this way they can at least start to accommodate regional long-term variations in supply and demand, within their capacity limits, offering some potential support for future system development.

7.6 AC underground cable costs

Compared with the bare wire conductors of OHL, underground cable manufacture processes are far more complex and use far more materials. They are also heavier and less flexible than overhead line conductors, so their transport to site is more complex, too, even though they are delivered in much shorter lengths than overhead line conductors. Once the cables are delivered to site, there is far more groundwork to be performed, and over a wider working swathe, and there are many more conductor joints to be made than for OHL. For all these reasons, underground cable costs tend to be higher than for an overhead line option.

Another possible reason for higher costs of long underground cables can be the need for reactive compensators, to reduce the effects of the cable capacitances on the rest of the network. These compensators look and sound like grid transformers and they would normally be placed at either end of the cable route. The length of cable circuit that would require these separate reactive compensators depends upon the capability of the nearby network to provide reactive compensation to the circuit. Typically, a cable of 2km+ would most likely require installation of shunt reactors.

Installation method would also have a significant impact on the capital costs, with direct burial methods such as trenching and ducting being more economical options in comparison to tunnelling.

Other capital costs to keep in mind include those of environmental assessment and impact mitigation, public consultation and public inquiry, and consents and wayleaves. Meanwhile, the most significant operational cost of underground cables relates to lifetime losses.

7.7 Deliverability and operability

As with OHL, the deliverability and operability of any proposed new underground cable are key aspects for its ability to satisfy its required in-service date. In this Section we consider first the deliverability of new underground cables, and then secondly their operability.

Underground cable technology is mature, although new cable developments – especially improvements in electrical insulation technology – are introduced incrementally from time to time. Apart from the current manufacturing capacity pressures that we anticipate will reduce the capacity of UK cable producers increases, the challenges of acquiring the technology for a new cable route are well understood and solved. As with OHL, therefore, the main unknown regarding deliverability is thus the question of whether, and when, planning consent would be granted, so this is the subject of our next subsection.

Underground cable operation is also well understood, and its technical challenges mostly solved, so the other three subsections here address some of the operating characteristics and benefits that are specific to underground cables.

7.7.1 Planning consents

Unlike OHL, underground cables may be classed as 'permitted development' in certain circumstances where there is little environmental impact, under the Town and Country Planning (General Permitted Development) (Scotland) Order 1992 (as amended), (England) Order 1995 as amended by the2015 and 2025 Orders, and (Wales) Order 1995 as amended by Order 2019. Such developments may automatically be granted planning permission, by statutory order, and do not require submission of a planning application to the local planning authority.

Although less likely at distribution level due to the scale of singular projects, (EN-1) Mar-2023[33] indicates that, where "*[an underground cable proposal]* … is considered to be nationally significant, there is a power under section 35 of the Planning Act 2008 ... for the Secretary of State, on request, to give a direction that a development should be treated as a Nationally Significant Infrastructure Project, for which development consent is required". So, if this situation were to occur for a proposed underground cable, then as for OHL, the planning process would after all require the proposed cable installation project to apply for a Development Consent Order (DCO) to the Planning Inspectorate, with a final decision taken by the Secretary of State.

In Wales, if planning consent is required it would be the decision of the Local Planning Authority. The Welsh Government prefers undergrounding new electricity circuits, especially in scenic or sensitive areas. Planning policy in Wales supports this where feasible but takes a balanced view and considers what is practical in each specific situation, considering among other aspects the costs and environmental impacts. In June 2024, the Senedd narrowly voted against making undergrounding mandatory, despite rising public and political pressure.

The November 2023 version of the National Planning Statement EN-5[34], is applicable to overhead transmission lines of 132 kV and above in addition to all cables underground, of any voltage. This NSP starts with the presumption that new transmission will comprise OHL as stated in 2.9.20 but this presumption is reversed where proposed developments cross designated landscape including National Park or Areas of Outstanding National Beauty. In paragraph 2.9.14 it is also stated that where the nature or proposed route of an overhead line will likely result in particularly significant landscape and visual impacts, the applicant should demonstrate that they have given due consideration to the costs and benefits of feasible alternatives to the overhead line. This could include underground cables and the feasibility e.g. in cost, engineering or environmental terms of these.

The consenting process for underground cables does not have to address the long-term visual impacts issue normally associated with OHL, however the cable installation process itself would still comprise a very significant visual impact for the duration of the construction work. In rural environments, the construction process also requires greater assessment of the disturbance to wildlife and habitat, archaeological, significant construction traffic to include earth movers and land use impacts and the time taken to agree ways to mitigate or avoid these effects may jeopardise achievement of a transmission network required in-service date. Page 8 of National Grid Electricity Transmission's paper 'Undergrounding high voltage electricity transmission lines – The technical issues'[35] shows an example underground cable construction swathe. The paper highlights the increased volume of spoil that is required to be excavated, that being 'some 14 times more than for an equivalent overhead line' and the clearance of vegetation along the route. It is also highlighted that concrete cable jointing bays, of a width greater than the trench itself are required every 500-1000 m. In the case of buried underground cables on agricultural land certain ploughing operations must be avoided and no trees or hedges can be permitted along the route of the buried cable[36].

As a separate exercise, to permit the construction, operation and maintenance of underground cables, suitable rights over land (wayleaves or easements) are needed from every owner or other party holding a relevant interest in the land crossed by a proposed major electrical infrastructure project. Often these will be granted to the DNO voluntarily following negotiation but if this cannot be achieved, the DNO can apply to the appropriate body (Government Office) for any necessary authority.

[33] https://assets.publishing.service.gov.uk/media/65bbfbdc709fe1000f637052/overarching-nps-for-energy-en1.pdf

[34] https://www.gov.uk/government/publications/national-policy-statement-for-electricity-networks-infrastructure-en-5/national-policy-statement-for-electricity-networks-infrastructure-en-5

[35] https://www.nationalgrid.com/sites/default/files/documents/39111-Undergrounding_high_voltage_electricity_transmission_lines_The_technical_issues_INT.pdf

[36] https://www.energynetworks.org/assets/images/Resource%20library/Environment%20Briefing%2002%20-%20Transporting%20Electricity.pdf?1695859306

7.7.2 Reliability, availability, maintainability

Reliability: Underground distribution cables are buried about a metre underground, normally within specially stabilised backfill and beneath sets of concrete tiles and warning tape, so it is very unusual for third party physical disturbance or damage to cause unplanned outages and reduce their reliability. Ground subsidence could damage an underground cable, as could an unattenuated lightning strike or switching surge at the end of a cable, however these latter risks are normally avoided by installing lightning protection equipment at the cable ends. Once commissioned, therefore, underground cables have a good track record for highly reliable operation.

Up to 2015 the quantity of 132 kV XLPE cable in service was 6,356 km[37]. Between 2006 and 2015, the failure rate of XLPE cable in that voltage range was 0.108 faults per 100-circuit-km-year. This means that for every 100 km of the cable in this voltage range, there are on average 0.108 faults per year.

Availability: High reliability tends to deliver high availability, too, however the significant difference between underground cables and OHL is that, because the cables are buried, if a cable fault should occur (a rare event), it can take much longer to locate the fault, and it can take much longer to repair the fault, once located. Although fault locators are becoming increasingly sophisticated, because cables are buried and not easily accessible, the entire fault-finding and repair process can easily take several weeks, during which time the cable circuit would be unavailable for operational service. Analysis of fault repair times for XLPE 110 kV to 219 kV UGC, shows that the average outage is 33.9 days[38]. This includes the time from the initial fault to the restoration of the circuit.

Maintainability: Being buried, underground cables are protected from the forces of the weather and from most third-party interference, so the cables themselves are largely maintenance free. However, it is important that the cable circuit's environment is maintained and, in particular, that the cable joint earthing systems operate effectively throughout its operational life so two key maintenance tasks are, firstly, the periodic patrol of the cable swathe to ensure that the cable circuit is not in danger of being disturbed, and secondly, tests of each of the cable joint sheath earthing arrangements along the route to ensure that they remain healthy and are not degraded by corrosion. Whilst the patrols can be undertaken during cable circuit operation, the sheath tests require the circuit to be taken out of service which, depending upon circuit length and the number of test teams, might take 1 to 3 days per year on average, still amounting to an availability of over 99%. Another consideration is the cables resilience to water given the likelihood of the cable sitting below the water table, especially at times of flooding. In addition, the chemical makeup of the ground and any potential contamination should be factored in when specifying cable insulation types, although most modern insulation designs account for a wide range of surrounding environments.

As with OHL, a useful property of underground cable systems is their ability to withstand overloads for short periods of time before they reach their safe temperature limits. This is a valuable characteristic because, during emergency conditions such as during an unplanned outage, it allows the system operator time to reconfigure the network and return power flows to normal levels without damaging the equipment or disconnecting customers. Allowable overload periods can vary from 30 minutes to tens of hours, depending upon the circumstances, before the cable reaches its safe temperature limit and the load must be reduced again. In fact, by applying these cable circuit dynamic ratings carefully, it is possible to effectively gain significant additional transmission capacity on a routine basis, up to 30% in some cases, depending on factors such as the cable type, the cable laying configuration, its immediately previous load levels and the weather. To facilitate this approach, most modern high-voltage cables include optical fibres for monitoring their temperatures and this allows the system operator a greater degree of certainty that the cable is not reaching damaging temperatures during such operation

7.7.3 System restoration capability

The process of system restoration needs simple distribution connections that require minimum controls, absorb minimum amounts of energy, do not require supplies to be available at both ends of the connection and are immediately available for service. Underground cables meet most of these criteria and thus are fairly well suited to transferring restoration power across the distribution system to help network and generation operators to restart the national power supply.

[37] Cigre. UPDATE OF SERVICE EXPERIENCE OF HV UNDERGROUND AND SUBMARINE CABLE SYSTEMS – Table 10d. Sep 2020.
[38] Cigre. UPDATE OF SERVICE EXPERIENCE OF HV UNDERGROUND AND SUBMARINE CABLE SYSTEMS – Table 17a. Sep 2020.

A downside to using underground cables for system restoration is that the significant charging currents required by long underground cables before any useful power is transmitted (over 20 times more than that required by an equivalent capacity overhead line) makes system restoration with them more complex than with OHL.

In saying that underground cables are well suited in this situation, the reader should nevertheless understand that, like OHL, underground cables are passive network components that do not provide any restoration energy themselves; in this role they simply facilitate the transfer of power from restoration energy sources to other, larger generators needing startup power.

7.8 Environmental impacts

This chapter summarises the most prominent environmental impacts to be considered during the manufacturing and construction phase and operation phase for this archetype:

- 2 km distance single circuit UGC
- 100 km distance UG Cables – two circuits

The underground cable installation assessed in this report is a direct current (DC) transmission system because alternating current (AC) is not technically suitable for long-distance transmission. Over distances like 100 km, AC cables suffer from high reactive power losses and capacitive charging, making them inefficient and unstable. DC transmission avoids these issues and ensures efficient, reliable power delivery over extended underground routes.

The impacts outlined below will largely be dependent on the route of the transmission line, therefore some may or may not be applicable and level of impact will be determined through the route. However, for theoretical purposes the below impacts could be assumed for any similar UGC project. Detailed impacts and mitigation measures can be found in Appendix B.

A summary of applicability for the above archetype is provided in the table below:

Table 7-6 Summary Table: Applicability of Environmental Impacts

Impact Category	2 km UGC (Single Circuit)	100 km DC UGC (Double Circuit)	Notes / Clarifications
Resource Use (Materials & Waste)	Moderate (plastic sheath, steel, aluminium)	High (large cable volume, trenching materials)	100 km route requires significantly more cable, conduit, and backfill.
Energy Use (Construction & Transport)	Low (shorter works, fewer deliveries)	High (extended duration and material movement)	Driven by construction machinery and haulage needs.
Pollution Potential (Air, Water)	Low to moderate (localised)	High (multiple access sites)	Includes dust, machinery emissions, and minor watercourse risks.
Soil Impacts (Compaction, Erosion, Excavation)	Moderate (limited length)	High (cumulative across long route)	Trenching and stockpiling soil can alter local hydrology and compact soils.
Groundwater Interaction	Localised risk	High (especially near high water tables)	Proper sheath design and drainage planning are required.
Ecological Impact (Habitats & Species)	Moderate	High	Risk increases with route length and ecological sensitivity of land crossed.
Visual Impact	Minimal (mostly below ground)	Low to moderate (more joint bays, access points, potential tree removal)	Surface infrastructure (e.g., sealing ends) may have a localised impact.
Noise and Dust (Construction Phase)	Localised and short-term	Prolonged and cumulative	Heavier and longer construction may affect larger community areas.
Site Access During Construction	Temporary, narrow footprint	Extensive (access tracks along full route)	Temporary roads may be needed parallel to cable trench.
Site Access During Operation	Periodic (dependent on O&M)	Periodic (multiple joint bays and markers)	Access for inspections or fault response is more frequent over 100 km.
Climate Resilience (Extreme Weather, Flooding)	Moderate (limited above-ground exposure)	Moderate (depends on drainage and waterlogging)	Sensitive to water ingress, temperature, and insulation properties.

Cumulative Impacts	Low	High	Repeated land-use and biodiversity impacts over long linear route.

7.8.1 During the Construction Phase

7.8.1.1 Resource efficiency & waste

The following should be considered during the construction phase of underground cable systems:

- **Material Usage**: Underground cable installations require a range of materials including cables, conduits, joint bays, and backfill materials. Material demand increases with route length and can contribute to resource depletion and emissions from production and transport.
- **Energy Consumption**: Construction activities such as trenching, directional drilling and cable laying are energy intensive. Emissions result from the use of heavy machinery, transport vehicles, and site infrastructure. The overall energy footprint is proportionally higher for longer routes.
- **Waste Generation:** Construction activities generate waste including excavated soil, cable offcuts, packaging, and surplus materials. Excavated soil is typically the largest waste stream and should be prioritised for reuse where feasible. Most packaging and cable drums are now reused or recycled in line with industry practices.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher as the 100km route requires significantly more cable volume/ trenching materials and energy use through extended duration of construction.

7.8.1.2 Pollution prevention

The following should be considered for pollution prevention:

- **Soil and Groundwater Risks:** Excavation and drilling can alter soil structure and expose shallow groundwater. There is a risk of localised contamination from fuel or oil spills. Pollution prevention measures and spill contingency plans should be implemented to manage these risks.

The impact of a 2km Single Circuit is expected to be lower to moderate, in comparison to the 100km Double Circuit, where the impact is expected to be higher as the 100km route will require more access sites and will accumulate more impacts due to longer route.

7.8.1.3 Impacts on biodiversity

The following should be considered during the construction phase:

- **Habitat Loss and Fragmentation (Excavation Activities):** The trenching required for installing underground cables can lead to temporary loss and fragmentation of habitats, particularly where the route crosses vegetated or semi-natural areas. These effects are typically limited to the construction phase and are usually reversible if appropriate reinstatement is carried out.
- **Disturbance of Ecological Processes**: While underground cable installation is unlikely to significantly disrupt wider ecosystem functions, localised and short-term effects may occur in sensitive habitats — for example, soil disturbance may temporarily affect plant regeneration, microhabitats, or hydrological patterns. These impacts are generally confined to the construction period and can be mitigated through appropriate site management and restoration.
- **Disturbance to Wildlife (Soil Disturbance):** Construction activities can disturb the soil, potentially affecting the viability of plant species and disrupting soil-dwelling organisms. Additionally, clearing vegetation along the cable route can result in the direct loss of plant species, including trees, and understory vegetation. This can impact the food sources, shelter, and nesting habitats of various wildlife species.
- **Disruption of Wildlife (Movement)**: Construction activities and the presence of underground cables can disrupt the movement patterns of wildlife, including terrestrial and arboreal species. This can lead to isolation of populations and limit their access to essential resources or breeding grounds.
- **Watercourse and Wetland Impacts:** Works near or across wetlands and rivers can alter hydrological function and degrade associated habitats.
- **Invasive Species Spread:** Ground disturbance and vehicle movement may increase the risk of introducing or spreading invasive non-native species (INNS), which can outcompete native flora and fauna.

- **Barrier Effect:** Underground cable installations may act as barriers for small mammals, reptiles, or amphibians that cannot easily move through or beneath the infrastructure, depending on the depth of the installation. This can impact population dynamics.
- **Cumulative Ecological Impact:** For longer routes (e.g. 100 km underground cables), the cumulative impact of trenching, vegetation clearance, and temporary access routes can be significant, particularly where multiple ecosystems are traversed. Even with narrow working corridors, the aggregated footprint can lead to widespread habitat fragmentation and increased edge effects.

The impact of a 2km Single Circuit is expected to be moderate, in comparison to the 100km Double Circuit, where the impact is expected to be higher as the 100km route as risks increase with route length and ecological sensitivity but largely dependent on the geographical route and surrounding areas. The use of directional drilling can minimise disturbance in sensitive areas such as watercourses or woodland edges by reducing surface-level interference, however, directional drilling can only be used in certain circumstances and over limited distances.

7.8.1.4 Impacts of excess noise and dust

The following impacts should be considered:

- **Air Quality:** Dust generated from excavation and the use of construction machinery can temporarily affect local air quality. Emissions may include both airborne particulates from earthworks and exhaust emissions from generators, excavators, cranes, and delivery vehicles. Dust may also settle on nearby vegetation, soil, and water surfaces, with the potential for minor, short-term effects on local ecosystems and communities if not effectively managed. These emissions form part of the overall construction-related impacts discussed in the climate change section below.
- **Noise Pollution:** Construction activities can generate significant noise levels, potentially impacting nearby communities. Construction activities, including excavation, foundation work, and material handling, can create noise, particularly during the assembly and erection of overhead line structures. Proper planning, use of noise-reducing equipment, and adherence to noise regulations can help mitigate noise pollution.
- **Traffic and Transportation:** Increased traffic and transportation associated with the delivery of construction materials, equipment, and personnel to the construction site can contribute to noise generation.

The impact of a 2km Single Circuit is expected to be localised and temporary, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the extended construction window.

7.8.1.5 Accessibility to site

The following impacts should be considered:

- **Construction Area - Road Closures/ Traffic Disruptions:** The construction activities associated with underground cable installations may result in restricted access to certain areas close to the site. For example, depending on the location and extent of the construction activities, temporary road closures, lane restrictions, or traffic diversions may be required. This can impact local transportation routes and accessibility for nearby communities.
- **Construction Site Infrastructure:** The construction phase may involve the establishment of temporary infrastructure, such as site offices, storage areas, or construction laydown yards. These temporary facilities will occupy space and potentially affect access to surrounding areas. A work-road in parallel with the underground cables is also required to accommodate vehicles for site deliveries, ground works and installation activities.
- **Material Transportation:** Transporting construction materials, equipment, and machinery to the site can temporarily impact access routes, especially if the project requires large deliveries or specialised vehicles.

The impact of a 2km Single Circuit is expected to be localised and limited, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length and access road network.

7.8.1.6 Land use and community impacts

It is important to understand the current land use on the length of the underground cable and the presence of any natural habitats or cultural heritage sites. This should be undertaken during the environmental impact phase of the pre-construction period. The main impacts to be considered:

- **Land Use Disruptions:** The installation of underground cables involves construction activities that can disrupt local communities, including noise, dust, traffic congestion, and restricted access to certain areas during the construction phase.

Underground cables require extensive trenching or, alternatively, directional drilling to lay the cables. This process can disrupt land use and temporarily impact areas where the cables are being installed and can potentially disturb archaeological sites, including buried artifacts, features, or structures. Additionally, construction activities can cause soil disturbance, which may result in the disruption or destruction of archaeological layers and deposits.

- **Right-of-Way Requirements:** Underground cables may require a dedicated right-of-way, which can involve land acquisition or easement agreements with landowners.
- **Interfacing with Multiple Land Uses:** Longer cable sections are more likely to intersect diverse land uses, such as agricultural, urban fringe, and conservation areas. The design must account for context-specific mitigation at multiple points along the route.
- **Employment and Economy:** The construction phase can provide employment opportunities and contribute to the local economy through job creation, supply chain involvement, and ancillary services.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length of the circuit and potential exposure to more communities. However, this is largely dependent on the geographical route of the UGC line.

7.8.2 During the Operational Phase

7.8.2.1 Impacts on biodiversity

During the operation phase, the following impacts should be considered:

- **Cable Access Points:** Vegetation clearance around these access points may be required to ensure proper access and maintenance, which can affect local vegetation and small-scale wildlife habitat. Though, typically hedges are replanted following construction over the UGC.
- **Indirect Impacts:** The operation of underground cable systems is connected to energy generation sources, which may have indirect impacts on biodiversity through associated infrastructure, such as power plants or renewable energy installations.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit, where the impact is expected to be higher due to the longer route, thus needing to consider cumulative impact.

7.8.2.2 Accessibility to site

During the operation phase, the following impacts should be considered:

- **Cable Access Points:** Access points, such as manholes or cable pits, may be present along the cable route but not necessarily so. These access points may require covers or markers to indicate their presence, which can be located within public spaces or private properties.
- **Maintenance and Repair:** Access may be required to perform maintenance, inspections, or repairs on the underground cable system. This may involve temporary disruptions or limited access to certain areas while work is being carried out.

The impact of a 2km Single Circuit is expected to be localised and limited, in comparison to the 100km Double Circuit, where the impact is expected to be higher due the length and access road network.

7.8.2.3 Climate change impacts

The operational performance of underground cable systems can also be influenced by climate change:

- **Increased Temperature and Heatwaves:** Elevated soil temperatures can reduce the cable's current-carrying capacity and increase electrical losses. Appropriate cable sizing and thermal management can help mitigate these effects.
- **Surface Water Flooding:** Prolonged or intense rainfall can saturate soils, increasing the risk of water ingress into ducts, joint bays, or sealing end compounds, which may compromise cable insulation or performance.
- **Changes in Precipitation Patterns:** Altered rainfall patterns can affect soil stability along the cable route, particularly at access points, joint bays, or transition compounds, increasing maintenance requirements or fault risk.
- **Sea-Level Rise and Coastal Flooding (where applicable):** Coastal sections of UGC may be exposed to rising groundwater levels, saltwater intrusion, or erosion, potentially affecting cable protection or long-term reliability.
- **Transfer of Renewable Energy:** UGC infrastructure enables the reliable, long-distance transfer of renewable electricity, supporting grid decarbonisation and reducing broader greenhouse gas emissions.

The impact of both a 2km Single and a 100km Double Circuit is expected to be moderate but limited to the geographical route.

7.8.2.4 Visual impact on residential areas

During the operation phase, the visual impact of underground cables is minimal in comparison to OHL. However, the following impacts should be considered:

- **Swathe Management:** Depending on the location, there may be periodic vegetation management activities, such sapling removal and clearing, to ensure the integrity and accessibility of the underground cables. These activities may have temporary visual impacts.

The visual impact of UGC is typically minimal for both the 2km and 100km circuit.

7.8.2.5 Impacts on neighbouring communities

During the operation phase, the following impacts should be considered:

- **EMF Impact:** The community should be informed of the potential EMF impact from the underground cable, which should be considered during the design phase and may impact both humans and biodiversity, however with strategic planning may have no impact at all. EMF levels are highest directly above the cable route but decrease rapidly with distance. For typical high-voltage underground cables (e.g., 132 kV and above), EMF levels fall below international public health guidelines within approximately 1 to 2 metres from the cable alignment. With appropriate cable design, burial depth, and spacing, EMF exposure can be minimised to levels considered negligible for both humans and biodiversity. There are no established adverse health effects from underground cable EMF exposure where international guidelines are met.

The impact of a 2km Single Circuit is expected to be lower, in comparison to the 100km Double Circuit due to longer coverage. However, the exact levels depend on factors such as the type of cable, current flow and laying formation of the cables.

7.9 Commercial & supply chain impacts

Table 7-7 below provides a general discussion of some aspects of the supply chain to the electricity supply industry for underground cables.

Table 7-7: Commercial and supply chain impacts – AC underground cables

AC underground cables	
Cable systems	Raw materials for the conductors, insulators and the cable external protection are all managed by the OEMs. The metals, in particular, will be bought ahead of manufacturing requirements, to attempt to minimise costs as the commodity prices vary. With a number of suppliers, including Prysmian, Nexans, NKT, Sumitomo, Hellenic, LS Cable and Taihan, competition should be healthy, Current indications are that lead times are driven by manufacturing capacity and not availability of materials. This manufacturing capacity is a global constraint, with manufacturers presently expanding production capacity. Current orders are expected to deliver in 2031 - 2032, depending on specific length and technical requirements of the cables.
Reactive compensation	Reactive compensation, most frequently provided by shunt reactors, is required for any significant length of HVAC underground cable installed on a distribution network, Shunt reactors are heavily dependent upon copper and, depending upon their design, upon grain orientated steel. Historically, there has been only a limited number of suppliers, worldwide, which may become an increasing issue if the proportion of distribution built is installed underground rather than overhead.
Sitework	We note the availability of the necessary skills for construction, testing and commissioning will require concerted development effort in the face of an ageing workforce at a time of expanding skills demand.

8 COMPOSITE CIRCUITS

While any individual circuit may predominantly be of a single type, OHL or UGC, there will often be situations where a hybrid of the two is preferred. This could be for a variety of reasons including crossing obstacles, through environmentally sensitive areas or, where sections of a predominantly rural route lead into an urban environment. Through these areas it is preferable to have short sections of UGC or OHL where required before returning to the alternative method to continue the circuit route. DNVs analysis of existing 132 kV circuits illustrated that the median hybrid circuit was approximately 6% shorter than the median OHL and 25% longer than the median UGC.

8.1 Crossing obstacles

As part of the research for this report, DNV have studied a sample of 500, 132 kV circuits in Great Britain across three Distribution Network Operators (DNOs). DNV used publicly available sources for their information such as the individual DNO open data sites and the Open Infrastructure Map[39]. This study identified the lengths of each circuit as well as identifying whether it was and OHL, UGC or Hybrid type and what significant features or obstacles the circuit encountered on the route. These obstructions were noted along with whether a OHL or UGC was used to pass the obstacle.

Of the 500 circuits studied, 110 were identified as composite type. From DNVs study, 39% of the Hybrid cables went under dwellings and urban centres (towns, cities etc.). This demonstrates the primary use-case for UGC is to avoid densely populated areas. This is to prevent accidental damage to OHL which has an increased likelihood in the proximity of population centres and to decrease the visual impact on an already cluttered skyline.

36% of hybrid cables were noted to enter one or both connecting substation underground. This is to reduce cable density near substations where space overhead may be limited. This does leave almost two thirds of hybrid circuits entering substations in OHL. This is preferable for cost purposes as it makes reconductoring and maintenance simpler. 11% of hybrid circuits utilised UGC to cross existing transmission lines. This is to avoid a conflict with the high voltage line.

15% of hybrid circuits used OHL to cross lakes or rivers. It is often impractical to cross a large body of water with a UGC as the cable required is significantly more complex and expensive while also being more liable to wear and damage from boats and corrosion. One circuit was noted to cross under a river. This was noted to be a short crossing but demonstrates that is it possible and practical in certain circumstances.

Nearly all hybrid cables crossed farmland and fields. A mix of both OHL and UGC was used for this with a preference for OHL but this was not significant. Both types of circuit could be used for crossing natural sites and vast fields. UGC in these areas may require digging a trench trough the terrain which may damage the landscape, but OHL provide a permanent visual obstruction. In farmers' fields UGC risk being damaged by farm equipment and may prohibit crop growth around the area of their burial. See the sections 6 and 7 for more information about OHL and UGC respectively.

8.2 Transition

Of the 110 composite circuits studied, 77 converted from UGC to OHL (or vice versa) once, 29 converted twice, three converted three times and only one converted four times. Each time the circuit changes from OHL to UGC (or vice versa) a Sealing End Compound (SEC) is required to be constructed. This compound needs to accommodate both the overhead line terminal tower, which is usually larger than normal towers, and the cable sealing ends that take the high voltage overhead line connections below ground. A cable sealing end - a rigid insulator stack, usually three – four metres long, mounted vertically on a steel structure that is two – three metres tall. The end of the underground cable is threaded up through this insulator stack and terminated at the top. From this point the overhead line connections are taken up on to the overhead line tower.

For each SEC, the environmental, community, and cost impacts need to be studied. The higher capacity double circuit OHL would require twelve cables for the underground section of the route. To provide enough space for these, the SEC can become as large as a small substation. At the opposite end of the underground section, a second, similar transition SEC would be required to connect the underground cables back up to the next section of overhead line route.

[39] https://openinframap.org/

9 ENVIRONMENTAL IMPACTS COMPARISON TABLE

Impact Category	2 km UGC (Single Circuit)	100 km DC UGC (Double Circuit)	Notes	2 km Single Circuit (Wooden Pole)	100 km Double Circuit (Steel Tower)	Notes
Resource Use (Materials & Waste)	Moderate (plastic sheath, steel, aluminium)	High (large cable volume, trenching materials)	100 km route requires significantly more cable, conduit, and backfill.	Moderate (wood, small-scale aluminium conductors)	High (steel, concrete, large-scale conductors)	Steel towers and larger spans require more resource-intensive materials.
Energy Use (Construction & Transport)	Low (shorter works, fewer deliveries)	High (extended duration and material movement)	Driven by construction machinery and haulage needs.	Low (short distance, fewer deliveries)	High (due to volume and route length)	Driven by material transport, equipment, and duration of installation.
Pollution Potential (Air, Water)	Low to moderate (localised)	High (multiple access sites)	Includes dust, machinery emissions, and minor watercourse risks.	Low	Moderate	Includes dust, machinery emissions.
Soil Impacts (Compaction, Erosion, Excavation)	Moderate (limited length)	High (cumulative across long route)	Trenching and stockpiling soil can alter local hydrology and compact soils.	Localised, minimal	Higher than wooden poles due to cumulative impact	Soil erosion, compaction, and sediment runoff more significant over long routes.
Groundwater Interaction	Localised risk	High (especially near high water tables)	Proper sheath design and drainage planning are required.	Low	Moderate	Especially relevant if works are near shallow water tables or wetlands.
Ecological Impact (Habitats & Species)	Moderate	High	Risk increases with route length and ecological sensitivity of land crossed.	Minor (localised vegetation clearance)	High (cumulative across long route)	Longer route increases ecological risk and disturbance area.
Visual Impact	Minimal (mostly below ground)	Low to moderate (more joint bays, access points, potential tree removal)	Surface infrastructure (e.g., sealing ends) may have a localised impact.	Moderate (lower profile, small scale)	High (tall towers, multiple viewpoints affected)	Visibility more widespread in open landscapes.
Noise and Dust (Construction Phase)	Localised and short-term	Prolonged and cumulative	Heavier and longer construction may affect larger community areas.	Localised and temporary	Higher due to extended construction window	Use of heavy machinery and transport over a larger area.
Site Access During Construction	Temporary, narrow footprint	Extensive (access tracks along full route)	Temporary roads may be needed parallel to cable trench.	Temporary and limited	Extensive, including access road network	Access planning critical to reduce footprint.

Impact Category	2 km UGC (Single Circuit)	100 km DC UGC (Double Circuit)	Notes	2 km Single Circuit (Wooden Pole)	100 km Double Circuit (Steel Tower)	Notes
Site Access During Operation	Periodic (dependent on O&M)	Periodic (multiple joint bays and markers)	Access for inspections or fault response is more frequent over 100 km.	Periodic (for inspection and repairs)	Frequent (vegetation clearance, inspections, patrolling)	Maintenance and vegetation management needed regularly.
Climate Resilience (Extreme Weather, Flooding)	Moderate (limited above-ground exposure)	Moderate (depends on drainage and waterlogging)	Sensitive to water ingress, temperature, and insulation properties.	Low sensitivity	High sensitivity	Frequency of extreme weather events increases the risk to tall structures exposed to wind loading, corrosion, thermal expansion.
Cumulative Impacts	Low	High	Repeated land-use and biodiversity impacts over long linear route.	Low	High	Includes repeated ecosystem crossings, and landscape effects.

10 APPENDIX A: GLOSSARY

Item	Definition
Alternating current (AC)	Electricity transmission in which the voltage varies in a sinusoidal fashion, resulting in a current flow that periodically reverses direction. In Great Britain the direction is reversed 50 times each second, which is known as a frequency of 50 Hz.
Capacitor (also referred to as a condenser)	A multi-purpose device that can store electrical charge in the form of an electric field. It is used, for example, for power factor correction in (inductive) AC circuits. Capacitors are used to buffer electricity (smooth out peaks) and to guard against momentary voltage losses in circuits (when changing batteries, for example).
Capital expenditure (CAPEX)	Funds used by a company to purchase or upgrade assets such electricity transmission equipment, control systems, and the land on which these are installed
Committee for Climate Change (CCC)	An independent, statutory body with the aim to advise the UK and devolved governments on emissions targets and to report to Parliament on progress made in reducing greenhouse gas emissions.
Composite circuit	A transmission circuit that comprises a mix of overhead line and underground cable. Every transition between overhead line and underground cable requires a sealing end compound.
Conductor	A material or structure that is designed to carry electric current, typically made of metals with good electrical conductivity such as copper or aluminium.
Development Consent Order (DCO)	A Development Consent Order is the means of obtaining permission for developments categorised as Nationally Significant Infrastructure Projects.
Distribution Network Operator (DNO)	A Distribution Network Operator owns and operates the electricity distribution assets in Great Britain. There networks are divided into regions.
Development of National Significance (DNS)	A Development of National Significance (DNS) is a large infrastructure project that are considered crucial for the due to their scale and impact. The Planning (Wales) Act 2015 introduced the DNS process, where such applications are submitted to the Planning and Environment Decisions Wales rather than local planning authorities.
Double circuit	A double circuit transmission line has two independent circuits on the same structure with each circuit made up of three sets of conductors.
Electromagnetic field (EMF)	Electromagnetic fields are a combination of invisible electric and magnetic fields of force. They are generated by natural phenomena like the Earth's magnetic field but also by human activities, mainly through the use of electricity. Nowadays, they represent one of the most common and fastest growing environmental issues.
Environmental Health and Safety (EHS)	Environment, health and safety is the set that studies and implements the practical aspects of protecting the environment and maintaining health and safety at occupation.

Environmental impact assessment (EIA)	A process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse.
Flashover	A flashover is an electrical short-circuit (often between a high-voltage conductor and the ground, or something connected to the ground) that results in a very high-energy spark that can cause danger to property, people and animals.
GB transmission network owners (GB TOs)	A collective term used to describe the three electricity transmission asset owners within Great Britain, namely National Grid Electricity Transmission, Scottish and Southern Electricity Networks Transmission and SP Transmission plc.
Habitat Regulations Assessment (HRA)	A process that competent authorities must undertake to consider whether a proposed development plan or program is likely to have significant effects on a European site designated for its nature conservation interest.
HVAC	High-voltage alternating current (HVAC) – a method of transmitting electrical power with voltages above 110kV that (in Great Britain) alternate at 50Hz.
National Electricity System Operator (NESO)	The NESO is the electricity system operator for Great Britain. The control room moves electricity around the country second by second to ensure that the right amount of electricity is where it's needed, when it's needed – always keeping supply and demand in perfect balance.
Horizontal Directional Drillings (HDD)	Horizontal Directional Drilling is a construction technique whereby a tunnel is bored under a waterway or other designated area, and a pipeline or other utility is pulled through the drilled underground tunnel.
Institution of Engineering and Technology (IET)	The Institution of Engineering and Technology (IET) is a multidisciplinary professional engineering institution. [IET - Institution of Engineering and Technology (theiet.org)](theiet.org)
Inductive reactor	Inductive reactors can perform more than one function on a transmission network but, in the context of this document, they are a source of 'reactive compensation', (see glossary entry) providing electric currents that counteract the effects of cable charging currents on the power network. For this function they are normally connected at the ends of the cable although, in the case of a long cable circuit, they may also be connected at an intermediate location part- way along the circuit.
International Finance Cooperation (IFC) Performance Standards	The Performance Standards provide guidance on how to identify risks and impacts and are designed to help avoid, mitigate and manage risks and impacts as a way of doing business in a more sustainable way.
kilovolts (kV)	kilovolts, 1,000 Volts
kilowatt (kW)	kilowatt, 1,000 Watts
kilowatt-hour (kWh)	kilowatt-hour, the energy delivered by 1 kW over the course of 1 hour

Megavolt ampere (MVA)	Megavolt ampere; 1,000,000 volt ampere, a measure of reactive power.
Megawatt (MW)	Megawatt, 1,000 kW.
MWh	Megawatt-hour, the energy delivered by 1 MW over the course of 1 hour
National Grid Electricity Transmission (NGET)	Transmission owner in England and Wales.
Nationally Significant Infrastructure Project (NSIP)	Nationally Significant Infrastructure Projects are large scale developments (relating to energy, transport, water, or waste) which require a type of consent known as “development consent”.
Office of National Statistics (ONS)	The Office for National Statistics is the executive office of the UK Statistics Authority, which reports directly to the UK Parliament.
Operational expenditure (OPEX)	The ongoing costs for running a product, business, or system throughout its operational life.
Overhead line (OHL)	Electrical conductors, supported by steel towers (pylons), that transmit power from power stations, via high voltage substations, to consumers. (Refer to Section 5)
Reactive compensation	The automatic adjustments to voltages and currents in an AC power system that help to maintain its voltages, currents and stability within acceptable limits. The compensation may be provided intrinsically, by passive components such as capacitors and reactors, or through the automatic controllers of active components such as static var compensators, generators, and VSC HVDC links.
Reactive power	The frequency-related loss of useful power in an AC system resulting from the unavoidable production of electric and magnetic fields during the transmission of electricity. Reactive power is measured in Volt-Amps-Reactive (VAR) and is significant because it must be continuously provided to control the voltages and currents on the AC transmission network.
Reliability, availability, maintainability (RAM)	Reliability, Availability, and Maintainability (RAM) are design attributes of a system or an asset. Reliability is the probability of zero failures over a defined time interval. Availability is the percentage of time a system is considered ready to use when required. Maintainability is a measure of the ease with which a system can be restored to operational status following a failure.
Restoration services (black start)	The services providing stand-alone energy (from sources such as, for example, diesel generators, batteries, renewable generators, if available) so that, in the (rare) event of a total shutdown of the national electricity transmission system, key generating site operations may be restored so that they, in turn, can enable general electricity supplies to be re-established. An important element of system restoration is a set of transmission circuits that can, themselves transmit the restoring supplies without, themselves, absorbing much of the supplies through losses. Restoration services used to be termed ‘black start’.

SEC	Sealing end compounds (SEC) safely accommodate the high-voltage connections between underground cables and OHL. A SEC is always required at every overhead line / underground cable interface on composite circuits.
Short circuit	An electric contact between parts of an electric circuit, which causes a very high current, increases in temperature and potentially fire, if the circuit is not properly protected. This can occur if two live wires come into contact with each other, perhaps because of worn insulation. The term is also used when defining the safe operating conditions for electrical devices. If a device is said to have a short-circuit resilience of 400 amps (A), that means that it can be subjected to up to 400 A before it will shut itself down.
Strategic environmental assessment (SEA)	A process by which public bodies and private companies operating in a public character, such as utility companies, are required to assess, consult on, and monitor the likely impacts their plans, programs and strategies will have on the environment.
Switchgear	The term used to describe components of a substation that can be used to carry out switching activities. This can include but is not limited to, isolators/disconnectors and circuit breakers.
UGC	Underground cables (UGC) can be used as an alternative to OHL for the provision of electrical power. (Refer to Section 6)

11 APPENDIX B: ENVIRONMENTAL AND COMMUNITY IMPACT

This Appendix sets out the potential environmental impacts that may occur, and the potential mitigation measures, during both the construction and operational phases. The impacts and mitigation listed are not exhaustive and will be dependent on the characteristics and locations of specific projects.

11.1 Overhead line: Environmental impact

11.1.1 Summary of environmental impacts during construction of OHL

Potential impacts source:	Mitigation measures:
Resource efficiency & waste	
• **Raw Materials Consumption:** The construction of overhead line conductors, insulators and support structures requires significant amounts of materials (including steel, aluminium, concrete, wood and porcelain or glass, as well as other raw materials), which can lead to resource depletion and environmental impacts associated with material extraction, manufacturing, and transportation. These materials are also used in road access works, tower foundations, and temporary construction platforms. • **Waste Generation:** Waste will be generated from packaging, surplus construction materials, and earthworks. Soils represent a major construction waste stream and should be prioritised for reuse where suitable. Packaging and conductor drums are frequently recycled or reused by suppliers. **Energy Consumption:** Energy-intensive activities, such as manufacturing components, transportation of materials and equipment, and installation processes contribute to energy consumption and greenhouse gas emissions, especially where these activities are supported by non-renewable energy sources.	**Resource Efficiency:** • Optimise material use by selecting sustainable and recyclable materials, promoting the use of recycled or reclaimed materials, and implementing efficient design practices to reduce material waste. • Consider the life cycle assessment of materials to identify environmentally preferable options. • Implement responsible sourcing practices and prioritise suppliers with sustainable manufacturing processes. • The steel and aluminium used for towers and conductors should be assessed for responsible sourcing, considering the environmental and social impacts of mining and refining activities. • For wooden pole installations, ensure the wood is sustainably harvested from certified sources (e.g., FSC-certified forests), to prevent contributing to deforestation and biodiversity loss. • Where possible, a traceability and sustainability assessment should be conducted on key material suppliers, especially for large-scale projects involving international procurement. **Waste Management:** • Use dedicated waste bins in certain locations around the construction site, so as no open storage of domestic solid waste would be allowed. The contractor should regularly transfer waste, or subcontract a waste collector, to the nearest authorised waste disposal. • Recyclables, such as plastics, woods and metals, should be separately collected for reuse in other sites by the contractors or sold to recycling dealers. • It is recommended to develop a waste management plan for the size, including hazardous and non-hazardous waste storage and collection. **Energy Efficiency:** • Improve energy efficiency during construction activities by optimising construction schedules and logistics to minimise transportation distances, adopting energy-efficient equipment and machinery, and utilising renewable energy sources where feasible. • Promote the use of energy management systems to monitor and reduce energy consumption on construction sites.
Pollution prevention	
• **Soil and Groundwater Pollution:** Soil disturbance from excavation and tower construction can cause erosion or alter soil structure. Accidental spills of fuel or lubricants from machinery can pose contamination risks. While these risks are typically localised, appropriate spill response measures, containment systems, and contingency planning should be implemented to minimise environmental harm.	**Soil Management:** • Excess soil is being used for other purposes (if applicable); either land levelling or in other nearby properties or be transferred to a landfill to be used for daily cover of waste in coordination with the landfill staff.

	• Arrange for delivering any waste oils to an authorised company for appropriate disposal. Waste oils should be adequately labelled and stored in designated locations of the construction site until being collected. • Spill kits should be available throughout the site. Workers shall be trained in spill prevention and handling.
Impact on biodiversity	

• **Habitat Loss and Fragmentation**: Vegetation clearance during construction can lead to direct loss of habitats. The linear nature of OHL infrastructure can fragment landscapes, hindering wildlife movement and reducing ecological connectivity.
  ○ **Disturbance of Ecological Processes:** Construction activities may disrupt natural ecological processes, such as seed dispersal, pollination, and nutrient cycling, which are important for the maintenance of local biodiversity.
• **Disturbance to Wildlife:** Noise, vibration, lighting, and human activity during construction can disturb fauna, potentially displacing species or affecting breeding behaviour. Additionally, Earthworks and vegetation removal can cause erosion, increasing sediment input into watercourses, which may negatively impact aquatic habitats.
  ○ **Nesting Site Disturbance**: Vegetation clearance could remove nesting habitat or disturb active nests.
• **Watercourse and Wetland Impacts:** Works near or across wetlands and rivers can alter hydrological function and degrade associated habitats.
• **Invasive Species Spread:** Ground disturbance and vehicle movement may increase the risk of introducing or spreading invasive non-native species (INNS), which can outcompete native flora and fauna.
• **Collision Risk:** Birds may collide with unmarked overhead wires, especially during poor visibility or migratory periods.
	Studies & Management Plans:
	• Implement measures to minimise habitat loss and fragmentation, such as conducting pre-construction surveys to identify sensitive habitats and species and avoiding or minimising impacts on critical habitats. Consider re-vegetation or habitat restoration programs to compensate for any habitat loss, promoting connectivity between fragmented habitats where feasible.
	• Conduct pre-construction surveys to identify sensitive species and their breeding or nesting periods. Schedule construction activities to minimise disturbance during critical periods, such as breeding or nesting seasons. Establish buffer zones around sensitive areas to minimise disruption. Implement best practices for minimising noise, using visual barriers, and reducing vibration levels to minimise disturbance to wildlife.
	• Develop and implement invasive species management plans to prevent the spread of invasive species during construction. Conduct surveys to identify and remove invasive species before construction commences. Implement appropriate measures to prevent the introduction and establishment of invasive species during restoration and revegetation activities.
	Erosion & Sediment Control:
	• Implement erosion and sediment control measures, such as sediment barriers, sediment ponds, or erosion control blankets, to prevent or minimise soil erosion and sediment runoff. Properly manage construction site runoff to prevent contamination of nearby water bodies. Implement erosion and sediment control plans consistent with local regulations and best management practices.
	• Comply with regulations and guidelines regarding the protection of water bodies and wetlands. Implement appropriate measures, such as using sediment barriers, temporary bridging, or elevated platforms, to minimise direct impacts on water bodies. Avoid or minimise disturbance to sensitive aquatic habitats and species.
	Reducing Impact on Birds:
	• Implement measures to minimise the risk of bird collisions, such as using bird diverters or markers on the OHL to increase their visibility. Install bird flight diverters and perch deterrents near the lines to reduce the chances of bird collisions. Monitor bird behaviour and mortality during construction to assess and mitigate collision risks.
	• Install bird guards, nesting prevention devices, or insulating materials on the equipment to prevent birds from perching or nesting in hazardous areas. Regularly inspect and maintain the equipment to ensure its integrity and effectiveness in mitigating electrocution risks.
	• Conduct nesting surveys prior to construction to identify active nests and breeding sites. Implement measures to avoid or relocate active nests, ensuring that appropriate timing and methods are used to minimise disturbance. Provide alternative nesting structures or nearby suitable habitats to compensate for any loss of nesting sites.

Impact of excess noise and dust	
• **Air Quality:** Dust generation from excavation or construction machinery can contribute to air pollution. Air emissions expected during the construction of the project may include both airborne dust resulting from earthworks and exhaust emissions from construction machinery such as power generators, excavators, cranes and delivery vehicles. Dust particles in the air can cause reduced breathing air quality and can settle on vegetation, soil, and water bodies, leading to potential harm to ecosystems and nearby communities. Excess dust will also contribute to the overall emissions generated as part of the project which is highlighted as part of the climate change impact section below. • **Noise Pollution:** Construction activities can generate significant noise levels, potentially impacting nearby communities. Construction activities, including excavation, foundation work, and material handling, can create noise, particularly during the assembly and erection of overhead line structures. Proper planning, use of noise-reducing equipment, and adherence to noise regulations can help mitigate noise pollution. • **Traffic and Transportation:** Increased traffic and transportation associated with the delivery of construction materials, equipment, and personnel to the construction site can contribute to noise generation.	**Noise Mitigation:** • Implement measures to minimise noise emissions, such as using noise barriers or enclosures around noisy equipment, selecting quieter equipment where feasible, and adhering to noise control guidelines and regulations. • Schedule noisy activities during daytime hours and consider the proximity of noise-sensitive areas, such as residential areas or educational institutions. • Employ construction practices that reduce noise, such as using advanced construction techniques and equipment that minimise noise emissions. Implement noise control measures, such as the use of acoustic barriers, soundproof enclosures, or damping materials around construction sites. • Communicate with nearby residents or businesses to inform them of construction activities and potential noise impacts. • Develop and implement traffic management plans to minimise noise from construction-related vehicles. Use designated routes and consider scheduling deliveries during off-peak hours to reduce the impact on nearby communities. Utilise noise-reducing technologies, such as low-noise vehicles or vehicle routing systems, where feasible. **Dust Control Measures:** • Water Spraying: Implement water spraying techniques to suppress dust emissions during activities such as excavation, material handling, and site preparation. • Dust Screens and Barriers: Use physical barriers or screens to prevent dust from spreading to adjacent areas or sensitive receptors. • Soil Stabilisation: Implement erosion control measures such as covering exposed soil with mulch, geotextiles, or stabilising agents to minimise dust generation.
Accessibility to site	
• **Construction access:** The construction activities associated with overhead line installations may result in restricted access to certain areas close to the site. For example, depending on the location and extent of the construction activities, temporary road closures, lane restrictions, or traffic diversions may be required. This can impact local transportation routes and accessibility for nearby communities. • **Construction Site Infrastructure:** The construction phase may involve the establishment of temporary infrastructure, such as site offices, storage areas, or construction laydown yards. These temporary facilities will occupy space and potentially affect access to surrounding areas. • **Material Transportation:** Transporting construction materials, equipment, and machinery to the site can temporarily impact access routes, especially if the project requires large deliveries or specialised vehicles.	**Construction access:** • Design and construct access routes that can accommodate construction vehicles and equipment, ensuring appropriate width, stability, and load-bearing capacity. • Implement erosion control measures to minimise the environmental impact during construction. • Coordinate with local authorities to ensure compliance with any road permits or restrictions. • Establish traffic management plans to minimise disruption to local communities and ensure safe access. **Public Safety and Security:** • Install appropriate signage, barriers, or fencing to discourage unauthorised access to dangerous areas and ensure public safety. • Implement security measures, such as surveillance cameras or alarms, to deter vandalism, theft, or unauthorised entry into distribution line infrastructure.

11.1.2 Summary of environmental impacts during operation of OHL

<table>
<tr><th>Potential impacts source:</th><th>Mitigation measures:</th></tr>
<tr><td colspan="2">Impact on biodiversity</td></tr>
<tr><td>

Collisions: Birds in flight may collide with power lines, especially during low visibility conditions or when the lines are not clearly visible.
Nesting: Birds may build nests on or near distribution structures, putting them in close proximity to live electrical equipment.
Electromagnetic fields: There is some evidence to suggest that there some adverse impacts on birds and species from EMF, specifically around, behavioural effects, magnetic field sensitivity, health effects and species variability.

</td><td>
Avian markers and deterrents:
Adding visual markers, such as bird flight diverters or reflective devices, can increase the visibility of power lines to birds and reduce collision risk. These markers can help birds perceive the presence of the lines and avoid them.
Insulation and separation:
Retrofitting distribution infrastructure with insulating materials or using bird flight-safe designs can minimise the risk of electrocution when birds come into contact with the lines or structures.
Nest management:
Conducting thorough surveys and monitoring of distribution line routes to identify active nests and implementing nest relocation or construction of alternative nesting platforms can reduce the risk of nest failures or destruction during maintenance activities.
Strategic line routing:
When planning new distribution lines, avoiding sensitive bird habitats and important migratory routes can help minimise the impact on bird populations.
Research and technology development:
Continued research into bird behaviour, flight patterns, and the effectiveness of different mitigation measures can inform the development of more bird-friendly distribution line designs and operational practices.
Electromagnetic fields (EMFs):
As the research into this subject is not yet definitive, it is advised to apply avian protection measures (such as bird flight diverters) and continue monitoring the research undertaken within this field.
</td></tr>
<tr><td colspan="2">Climate change impact</td></tr>
</table>

- **Extreme Weather Events**: Increased frequency and severity of storms, high winds, and lightning events may damage towers, poles, and conductors.
- **Increased Temperature and Heatwaves:** Higher ambient temperatures can increase electrical resistance in conductors, resulting in greater transmission losses. Refer to Section 4.2 for further details on losses.
- **Sea-Level Rise and Coastal Erosion (if located near the coast):** Rising sea levels can corrode metal components and undermine tower foundations due to saltwater intrusion and coastal erosion.
- **Surface Water Flooding:** Extreme rainfall or rising river levels can cause waterlogging or erosion around foundations, compromising the structural stability of towers and poles. Designs should incorporate drainage measures, elevated foundations, or other flood-resilient features where required.
- **Changes in Precipitation Patterns:** Increased rainfall or prolonged wet conditions may destabilise soil, leading to landslides or subsidence risks, particularly in clay-rich or unstable ground conditions.
- **Transfer of Renewable Energy:** OHL networks play a critical role in enabling the transfer of renewable energy across regions, supporting decarbonisation efforts and contributing positively to climate change mitigation.

Climate-resilient design and engineering:

- Incorporating climate change considerations into the design and engineering of distribution infrastructure can improve its ability to withstand future climate conditions. This includes accounting for factors like increased temperatures, changes in precipitation patterns, and sea-level rise in the planning and construction phases.

- **Life Cycle Assessment**: It is important to consider the full life cycle of the overhead line, including its manufacturing, installation, operation, maintenance, and eventual decommissioning, to assess the overall climate change impact.

Enhanced monitoring and early warning systems:

- Deploying advanced monitoring technologies, such as sensors and weather forecasting systems, can help detect potential risks and provide early warnings. Real-time monitoring allows for timely responses and proactive measures to prevent or mitigate damage to distribution lines.

Vegetation management:

- Regular maintenance of vegetation around distribution lines is essential to minimise the risk of damage caused by falling trees, branches, or debris during storms or high winds. Clearing vegetation in a controlled and planned manner reduces the chances of outages and potential fire hazards.

Surface water management:

- To mitigate this, OHL routes should avoid flood-prone zones where feasible, and design should incorporate raised foundations, drainage ditches, or permeable ground materials where flood risk cannot be avoided.

Fire prevention:

- Fire prevention plans including, firebreaks, vegetation clearance regimes, emergency equipment access and fire suppression resources should be in place during construction.

11.2 Overhead line: Community impact

11.2.1 Summary of community impacts during construction of OHL

Potential impacts source:	Mitigation measures:
Land use and community impacts	
• **Land Use Disruptions:** Construction activities may require temporary land use changes, including access roads, construction staging areas, and storage of construction materials. These changes can disrupt existing land uses and activities in the area. Dust and noise impacts may also be significant on nearby communities as well as increased traffic inflow due to transportation of materials. Additionally, Construction activities associated with OHL, such as excavation for foundations or installation of support structures, can disturb archaeological sites of cultural significance. • **Employment and Economy:** The construction phase can provide employment opportunities and contribute to the local economy through job creation, supply chain involvement, and ancillary services.	**Community Engagement:** • Implement design considerations that minimise visual impacts, such as selecting appropriate tower and pole designs that blend with the surrounding landscape. Consider landscaping and vegetation screening to help visually integrate the OHL into the environment. Engage with the community and local stakeholders to address concerns and seek input on design aspects where feasible. • Develop comprehensive construction plans that minimise disruption to existing land uses. Coordinate with local authorities and stakeholders to identify suitable locations for temporary facilities and minimise conflicts with other land uses. Communicate with the community and affected stakeholders to provide information about construction plans, timing, and potential impacts. • Establish a proactive and transparent communication strategy to engage with the community and stakeholders. Provide timely and accurate information about construction plans, timelines, and potential impacts. Address community concerns, solicit feedback, and involve stakeholders in decision-making processes where feasible. Implement mechanisms for addressing and resolving complaints or issues raised by the community. **Archaeological Studies:** • Conduct thorough archaeological surveys and assessments prior to construction to identify and protect any significant archaeological sites. Implement appropriate mitigation measures, such as archaeological monitoring, salvage excavations, or rerouting of the OHL to avoid impacting sensitive cultural heritage sites.

11.2.2 Summary of community impacts during operation of OHLs

Potential impacts source:	Mitigation measures:
Visual impact	
• **Visual impact:** The presence of overhead lines can result in a lasting visual change to the surrounding landscape, particularly where they pass near or through residential areas. This visual change may affect how communities perceive their local environment, especially from homes with direct views of the infrastructure.	• A detailed visual impact assessment should be conducted, including modelling from key residential viewpoints. Community engagement should be integrated into this process to identify sensitive locations and, where appropriate, incorporate mitigation measures such as route selection, tower design variation, or screening vegetation. Long routes may intersect multiple community viewsheds, especially in open landscapes.
Impacts on neighbouring communities	
• **Electromagnetic Field (EMF) Exposure:** All OHL installations must comply with ICNIRP public exposure limits to ensure health and safety. EMF strength decreases rapidly with distance from the line. For typical high-voltage overhead lines (132–400 kV), EMF levels fall below ICNIRP guideline limits at distances of approximately 5 to 25 metres from the line centreline, depending on voltage, configuration, and current. These distances are normally respected within the designated wayleave or easement corridor. The scientific consensus, supported by ICNIRP and the World Health Organization, confirms that there are no established adverse health effects from EMF exposure where these guideline limits are met. Incorporating clear safety margins and engaging effectively with communities can help reduce concern and ensure the public is well informed. • **Noise Generation:** AC OHL can generate audible noise due to electromagnetic fields interacting with conductors and other components, as well as electrical arcing or corona discharge (which is when high-voltage distribution lines ionize the surrounding air, creating a bluish glow and a hissing noise). • **Land/Property Value:** The accumulation of the impact's discussion in the above section, including visual, noise and EMF may influence the land/property value in the nearby communities depending on people's perception of the infrastructure and the proximity of the structures to residential areas, urban centres, schools, recreational facilities, and other amenities.	**Safety and education programs:** • Providing information on safety precautions, such as maintaining a safe distance and avoiding unauthorised access to distribution infrastructure, can promote community safety. **Noise Management:** • Implement measures to reduce noise generation, such as using low-noise design principles, optimal conductor configuration, and insulation materials. • Apply noise barriers or enclosures around substations or equipment to attenuate noise propagation. • Conduct regular maintenance and inspections to identify and repair any sources of excessive noise. • Conduct noise modelling studies to assess the noise propagation patterns and identify areas where noise levels may exceed acceptable limits. • Implement noise mitigation measures such as vegetation buffers, noise barriers, or retrofitting noise-damping materials on existing structures to reduce noise propagation.

11.3 Underground cable: Environmental impact

11.3.1 Summary of environmental impacts during construction of underground cables

Potential impacts source:	Mitigation measures:
Resource efficiency & waste	
Resource Efficiency: • **Material Usage:** Underground cable installations require a range of materials including cables, conduits, joint bays, and backfill materials. Material demand increases with route length and can contribute to resource depletion and emissions from production and transport. • **Energy Consumption**: Construction activities such as trenching, directional drilling, and cable laying are energy intensive. Emissions result from the use of heavy machinery, transport vehicles, and site infrastructure. The overall energy footprint is proportionally higher for longer routes. • **Waste Generation:** Construction activities generate waste including excavated soil, cable offcuts, packaging, and surplus materials. Excavated soil is typically the largest waste stream and should be prioritised for reuse where feasible. Most packaging and cable drums are now reused or recycled in line with industry practices.	**Resource Efficiency:** • Optimise material use by selecting sustainable and recyclable materials, promoting the use of recycled or reclaimed materials, and implementing efficient design practices to reduce material waste. • Consider the life cycle assessment of materials to identify environmentally preferable options. • Implement responsible sourcing practices and prioritise suppliers with sustainable manufacturing processes. **Energy Efficiency:** • Improve energy efficiency during construction activities by optimising construction schedules and logistics to minimise transportation distances, adopting energy-efficient equipment and machinery, and utilising renewable energy sources where feasible. • Promote the use of energy management systems to monitor and reduce energy consumption on construction sites. **Waste Management:** • Waste Minimisation: Promote waste minimisation through efficient material use, recycling, and waste management practices. Encourage the use of recycled or reclaimed materials wherever feasible. • Construction Waste Recycling: Establish procedures for sorting, recycling, and appropriate disposal of construction waste materials, such as excess cables, packaging materials, and debris.
Pollution prevention	
• **Soil and Groundwater Risks:** Excavation and drilling can alter soil structure and expose shallow groundwater. There is a risk of localised contamination from fuel or oil spills. Pollution prevention measures and spill contingency plans should be implemented to manage these risks.	**Erosion and Sediment Control:** • Erosion Prevention: Implement erosion control measures, such as sediment barriers, silt fences, or erosion control blankets, to minimise soil erosion and sediment runoff during construction activities. • Stormwater Management: Develop and implement stormwater management plans to capture and treat runoff water, reducing the potential for pollution and protecting nearby water bodies. **Spill Prevention and Response:** • Spill Prevention: Develop spill prevention plans and provide training to construction personnel on proper handling, storage, and transport of construction materials to minimise the risk of spills. • Spill Response: Establish spill response protocols and ensure that appropriate spill response equipment, such as containment booms and absorbent materials, are readily available on-site
Impact on biodiversity	

• **Habitat Loss and Fragmentation (Excavation Activities):** The trenching required for installing underground cables can result in the loss and fragmentation of habitats, especially if the project traverses areas with existing vegetation or natural habitats. However, the use of directional drilling may cause minimal disturbance due to the limited area of interference. ◦ **Disturbance of Ecological Processes**: Construction activities may disrupt natural ecological processes, such as seed dispersal, pollination, and nutrient cycling, which are important for the maintenance of local biodiversity. • **Disturbance to Wildlife (Soil Disturbance):** Construction activities can disturb the soil, potentially affecting the viability of plant species and disrupting soil-dwelling organisms. Additionally, Clearing vegetation along the cable route can result in the direct loss of plant species, including trees, and understory vegetation. This can impact the food sources, shelter, and nesting habitats of various wildlife species. • **Disruption of Wildlife (Movement)**: Construction activities and the presence of underground cables can disrupt the movement patterns of wildlife, including terrestrial and arboreal species. This can lead to isolation of populations and limit their access to essential resources or breeding grounds. • **Watercourse and Wetland Impacts:** Works near or across wetlands and rivers can alter hydrological function and degrade associated habitats. • **Invasive Species Spread:** Ground disturbance and vehicle movement may increase the risk of introducing or spreading invasive non-native species (INNS), which can outcompete native flora and fauna. • **Barrier Effect:** Underground cable installations may act as barriers for small mammals, reptiles, or amphibians that cannot easily move through or beneath the infrastructure, depending on the depth of the installation. This can impact population dynamics. • **Cumulative Ecological Impact:** For longer routes (e.g. 100 km underground cables), the cumulative impact of trenching, vegetation clearance, and temporary access routes can be significant, particularly where multiple ecosystems are traversed. Even with narrow working corridors, the aggregated footprint can lead to widespread habitat fragmentation and increased edge effects.	**Habitat Conservation and Restoration:** • Habitat Assessment: Conduct thorough ecological assessments prior to construction to identify important habitats, endangered species, or ecologically sensitive areas along the cable route. • Habitat Restoration: Develop and implement habitat restoration plans to mitigate habitat loss. This may involve replanting native vegetation, establishing wildlife corridors, or creating new habitat areas. **Wildlife Protection:** • Wildlife Surveys: Conduct wildlife surveys to identify the presence of protected or endangered species. This information can inform the development of appropriate mitigation measures. • Timing Restrictions: Schedule construction activities to avoid critical periods for breeding, nesting, or hibernation of sensitive wildlife species. • Wildlife Passages: Install wildlife passages or underpasses where feasible to facilitate the movement of wildlife across the underground cable infrastructure. **Soil Stabilisation:** • Implement erosion control measures to help protect soil health and preserve the viability of plant species and soil-dwelling organisms. **Environmental Monitoring:** • Incorporate adaptive management approaches to address unforeseen biodiversity impacts during construction and make necessary adjustments to mitigate these impacts effectively.

Impact of excess noise and dust	
• **Air Quality:** Dust generation from excavation or construction machinery can contribute to air pollution. Air emissions expected during the construction of the project may include both airborne dust resulting from earthworks and exhaust emissions from construction machinery such as power generators, excavators, cranes and delivery vehicles. Dust particles in the air can cause reduced breathing air quality and can settle on vegetation, soil, and water bodies, leading to potential harm to ecosystems and nearby communities. Excess dust will also contribute to the overall emissions generated as part of the project which is highlighted as part of the climate change impact section below. • **Noise Pollution:** Construction activities can generate significant noise levels, potentially impacting nearby communities. Construction activities, including excavation, foundation work, and material handling, can create noise, particularly during the assembly and erection of overhead line structures. Proper planning, use of noise-reducing equipment, and adherence to noise regulations can help mitigate noise pollution. • **Traffic and Transportation:** Increased traffic and transportation associated with the delivery of construction materials, equipment, and personnel to the construction site can contribute to noise generation.	**Dust Suppression:** • Use water sprays, dust screens, or other appropriate dust suppression techniques to minimise airborne dust emissions during construction activities. **Noise Mitigation:** • Implement noise mitigation measures, such as using noise barriers or scheduling noisy activities during less sensitive times, to minimise noise impacts on nearby communities.
Accessibility to site	
• **Construction Area - Road Closures/ Traffic Disruptions:** The construction activities associated with underground cable installations may result in restricted access to certain areas close to the site. For example, depending on the location and extent of the construction activities, temporary road closures, lane restrictions, or traffic diversions may be required. This can impact local transportation routes and accessibility for nearby communities. • **Construction Site Infrastructure:** The construction phase may involve the establishment of temporary infrastructure, such as site offices, storage areas, or construction laydown yards. These temporary facilities will occupy space and potentially affect access to surrounding areas. A work-road in parallel with the underground cables is also required to accommodate vehicles for site deliveries, ground works and installation activities. • **Material Transportation:** Transporting construction materials, equipment, and machinery to the site can temporarily impact access routes, especially if the project requires large deliveries or specialised vehicles.	**Traffic Management:** • Traffic Control Plans: Develop and implement traffic management plans to minimise congestion and ensure safe access for both construction vehicles and local traffic. This may involve using designated routes, scheduling deliveries during off-peak hours, or providing alternative access routes when necessary. • Communication and Notifications: Provide timely and clear communication to affected stakeholders, such as local residents, businesses, and emergency services, about road closures, traffic diversions, and alternative access routes. **Construction Site Layout:** • Optimise the layout of the construction site to maintain adequate access for vehicles, pedestrians, and emergency services. Consider the placement of temporary infrastructure and the arrangement of equipment to minimise access restrictions. **Stakeholder Engagement:** • Engage with local communities, businesses, and relevant stakeholders to understand their concerns, preferences, and specific accessibility needs. Incorporate their feedback into the project planning and implementation to ensure their needs are considered. **Signage and Safety Measures:** • Clear Signage: Install clear and visible signage to provide directions, information, and warnings regarding access changes, detours, or potential hazards. • Safety Measures: Implement appropriate safety measures, such as pedestrian walkways, temporary barriers, or lighting, to ensure the safety of pedestrians and maintain accessibility in and around the construction area

11.3.2 Summary of environmental impacts during operation of underground cables

Potential impacts source:	Mitigation measures:
Impact on biodiversity	
• **Cable Access Points:** Vegetation clearance around these access points may be required to ensure proper access and maintenance, which can affect local vegetation and small-scale wildlife habitat. Though, typically trees are replanted following construction over the UGC. • **Indirect Impacts:** The operation of underground cable systems is connected to energy generation sources, which may have indirect impacts on biodiversity through associated infrastructure, such as power plants or renewable energy installations.	**Vegetation Management:** • Habitat Restoration: Implement habitat restoration initiatives in areas surrounding substations or access points, if feasible, to compensate for any vegetation clearance during installation or maintenance. • Native Planting: Promote the use of native vegetation and landscaping practices in and around substations and access points to provide habitat and support local biodiversity. **Wildlife Protection:** • Protected Species Surveys: Conduct surveys and assessments to identify the presence of protected or sensitive species in the vicinity of substations or access points. Implement measures to protect these species and their habitats during operation and maintenance activities. • Wildlife-friendly Practices: Incorporate wildlife-friendly design features, such as nesting boxes or wildlife corridors, into the design and management of substations and access points, where appropriate. **Environmental Monitoring and Reporting:** • Implement robust environmental management systems to monitor and report any potential impacts on biodiversity during the operation phase. This includes regular inspections and assessments to ensure compliance with applicable regulations and best practices.
Accessibility to site	
• **Cable Access Points:** Access points, such as manholes or cable pits, may be present along the cable route but not necessarily so. These access points may require covers or markers to indicate their presence, which can be located within public spaces or private properties. • **Maintenance and Repair:** Access may be required to perform maintenance, inspections, or repairs on the underground cable system. This may involve temporary disruptions or limited access to certain areas while work is being carried out.	**Stakeholder Communication:** • Foster positive communication and collaboration with stakeholders and provide clear and timely information to affected stakeholders, such as property owners, tenants, and local communities, about access restrictions, maintenance schedules, or any temporary disruptions that may occur. **Maintenance Planning:** • Plan maintenance and repair activities in a way that minimises disruptions to access and considers the needs of the surrounding area. This may involve coordinating with local authorities, businesses, and residents to minimise inconveniences. **Safety and Security:** • Signage and Barriers: Use appropriate signage, barriers, or safety measures to clearly indicate restricted areas or hazards associated with substations or access points. • Security Measures: Implement security measures around substations or access points to prevent unauthorised access and ensure public safety.
Climate change impact	
• **Increased Temperature and Heatwaves:** Elevated soil temperatures can reduce the cable's current-carrying capacity and increase electrical losses. Appropriate cable sizing and thermal management can help mitigate these effects. • **Surface Water Flooding:** Prolonged or intense rainfall can saturate soils, increasing the risk of water ingress into ducts, joint bays, or sealing end compounds, which may compromise cable insulation or performance.	**Renewable Energy:** • Where feasible, utilise renewable energy sources to power construction activities. This can include using solar panels, wind turbines, or grid-connected renewable energy. **Sustainable Material Selection:** • Low-Carbon Materials: Choose construction materials with lower carbon footprints, such as those made from recycled or sustainable sources. This can help reduce emissions associated with material production.

Potential impacts source:	Mitigation measures:
• **Changes in Precipitation Patterns:** Altered rainfall patterns can affect soil stability along the cable route, particularly at access points, joint bays, or transition compounds, increasing maintenance requirements or fault risk. • **Sea-Level Rise and Coastal Flooding (where applicable):** Coastal sections of UGC may be exposed to rising groundwater levels, saltwater intrusion, or erosion, potentially affecting cable protection or long-term reliability. • **Transfer of Renewable Energy:** UGC infrastructure enables the reliable, long-distance transfer of renewable electricity, supporting grid decarbonisation and reducing broader greenhouse gas emissions.	• Local Sourcing: Prioritise locally sourced materials to minimise transportation distances and associated carbon emissions. **Carbon Offsetting:** • Consider participating in carbon offset programs by investing in projects that reduce greenhouse gas emissions or enhance carbon sequestration. This can help mitigate the construction-related emissions that cannot be avoided. **Environmental Management Systems:** • Implement robust environmental management systems that include monitoring and reporting mechanisms to track energy consumption, greenhouse gas emissions, and other climate-related impacts during construction. This can help identify areas for improvement and facilitate ongoing reduction efforts.

11.4 Underground cable: Community Impact

11.4.1 Summary of community impacts during construction of underground cables

Potential impacts source:	Mitigation measures:
Land use and community impacts	
• **Land Use Disruptions:** The installation of underground cables involves construction activities that can disrupt local communities, including noise, dust, traffic congestion, and restricted access to certain areas during the construction phase. Underground cables require extensive trenching or, alternatively, directional drilling to lay the cables. This process can disrupt land use and temporarily impact areas where the cables are being installed and can potentially disturb archaeological sites, including buried artifacts, features, or structures. Additionally, construction activities can cause soil disturbance, which may result in the disruption or destruction of archaeological layers and deposits. • **Right-of-Way Requirements:** Underground cables may require a dedicated right-of-way, which can involve land acquisition or easement agreements with landowners. • **Interfacing with Multiple Land Uses:** Longer cable sections are more likely to intersect diverse land uses, such as agricultural, urban fringe, and conservation areas. The design must account for context-specific mitigation at multiple points along the route. • **Employment and Economy:** The construction phase can provide employment opportunities and contribute to the local economy through job creation, supply chain involvement, and ancillary services.	**Strategic Planning** • Strategic Route Planning: Conduct thorough studies and assessments to identify the most suitable route for underground cables, considering existing land use, environmental sensitivities, and community preferences. This can help minimise impacts on important land uses, such as agriculture or ecologically sensitive areas. • Co-location with Existing Infrastructure: Explore opportunities to co-locate underground cables with existing infrastructure corridors, such as roadways or utility corridors, to minimise the need for additional land acquisition or disruption. • Compact Design: Optimise cable designs and trenching techniques to minimise the spatial requirements of underground cables, allowing for more efficient land use and reducing the impact on surrounding areas. • Consideration of Landowners and Community Needs: Engage in open dialogue with landowners and affected communities to understand their concerns, consider alternative route options, and develop mitigation strategies that address their specific needs. **Archaeological Surveys and Assessments:** • Prior Assessment: Conduct thorough archaeological surveys and assessments to identify any known or potential archaeological sites along the proposed route of the underground cables. • Site Avoidance/ Modification: Adjust the cable route, where feasible, to avoid known or high-potential archaeological sites. If avoidance is not possible, consider modifying construction techniques or implementing additional archaeological investigations and monitoring to minimise impacts on sensitive areas. • On-site Monitoring: Assign and train personnel to monitor construction activities during trenching or drilling to identify and document any archaeological remains encountered. This allows for prompt mitigation measures to be implemented if necessary. • Salvage Excavations: If significant archaeological remains are discovered, undertake salvage excavations and archaeological mitigation measures to record and preserve the cultural heritage before construction proceeds. **Collaboration with Heritage Authorities:** • Engage with relevant heritage authorities, archaeological experts, and local communities to seek their input, expertise, and recommendations throughout the planning and construction phases.

11.4.2 Summary of community impacts during operation of underground cables

<table>
<tr><th>Potential impacts source:</th><th>Mitigation measures:</th></tr>
<tr><td colspan="2">Visual impact</td></tr>
<tr><td>Swathe Management: Depending on the location, there may be periodic vegetation management activities, such as tree trimming or clearing around access points, to ensure the integrity and accessibility of the underground cables. These activities may have temporary visual impacts.</td><td>Screening and Visual Integration:
Implement appropriate landscaping strategies, such as the planting of trees, shrubs, or other vegetation, to visually integrate infrastructure elements, such as substations or surface installations, into the surrounding environment.
Community Engagement:
Engage with local communities and stakeholders to communicate the visual design considerations and any potential impacts. Seek their input and address concerns to the extent possible, considering their preferences for visual integration or mitigation measures.
Environmental Planning and Design:
Develop and adhere to design guidelines or standards that aim to minimise visual impacts during the installation and operation of underground cable systems. This can include considerations for equipment placement, surface installations, and landscaping.</td></tr>
<tr><td colspan="2">Impact on neighbouring communities</td></tr>
<tr><td>EMF Impact: The community should be informed of the potential EMF impact from the underground cable, which should be considered during the design phase and may impact both humans and biodiversity, however with strategic planning may have no impact at all. EMF levels are highest directly above the cable route but decrease rapidly with distance. For typical high-voltage underground cables (e.g., 132 kV and above), EMF levels fall below international public health guidelines within approximately 1 to 2 metres from the cable alignment. With appropriate cable design, burial depth, and spacing, EMF exposure can be minimised to levels considered negligible for both humans and biodiversity. There are no established adverse health effects from underground cable EMF exposure where international guidelines are met.</td><td>Community Engagement:
Engage with local stakeholders, community groups, and residents through regular consultations, public meetings, or workshops to address concerns, gather feedback, and ensure community involvement.
Safety and Security:
Implement appropriate safety measures around substations, access points, or any visible infrastructure to ensure the safety and well-being of the community. Maintain necessary security measures around substations or access points to prevent unauthorised access and protect the integrity of the underground cable system.</td></tr>
</table>

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.