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1.

Comparison Table

Comparing high voltage overhead and underground transmission infrastructure (up to 500 kV)

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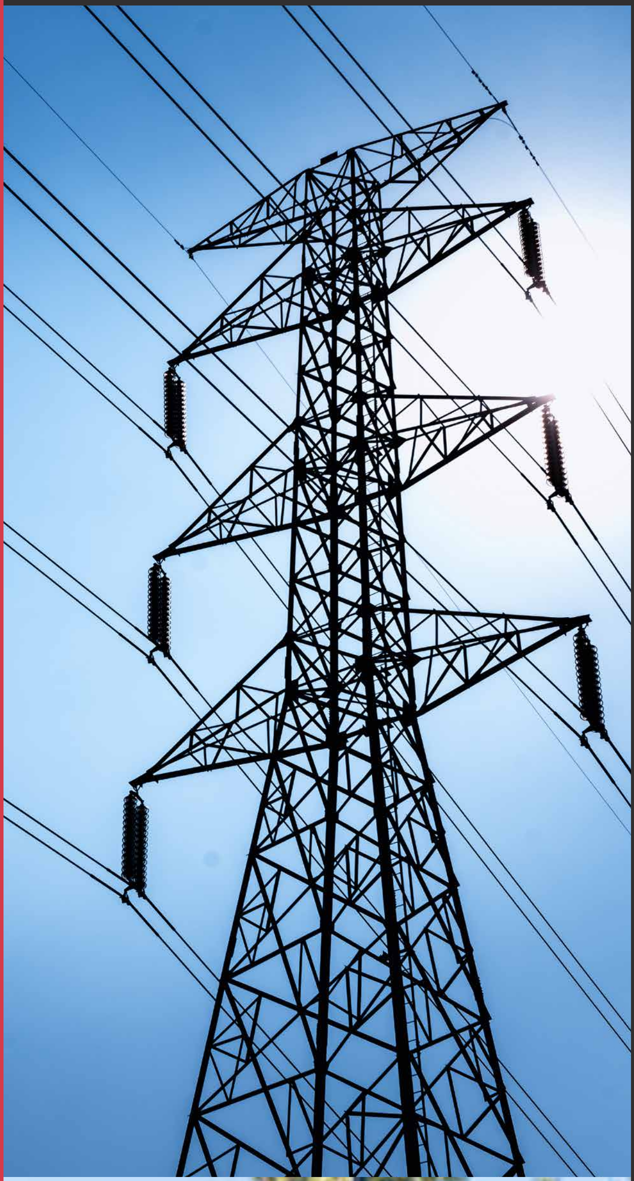

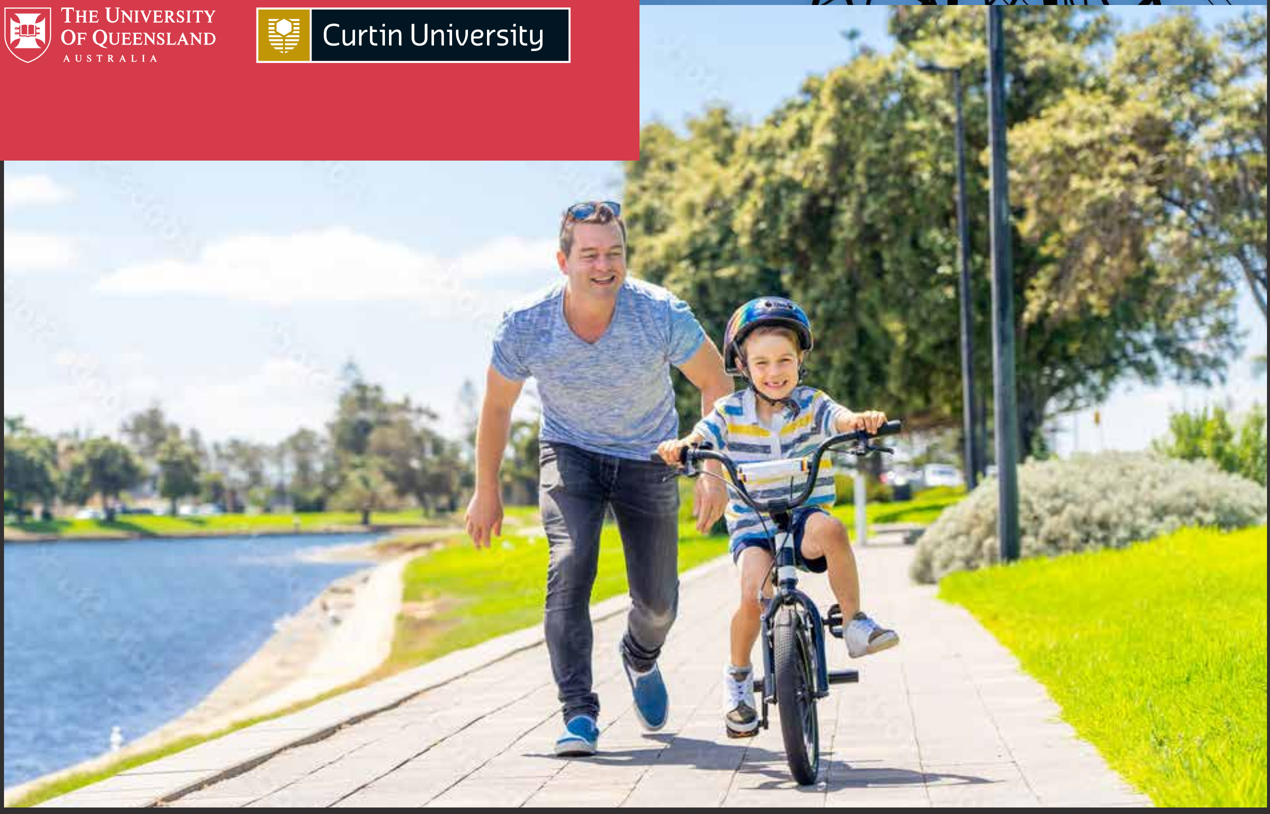

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Abbreviations and Acronyms

Abbreviation	Description
AC	Alternating Current
ACSR	Aluminium conductor steel-reinforced cable (or conductor)
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
AVP	AEMO Victorian Planning
CBA	Cost Benefit Analysis
CIGRE	International Council on Large Energy Systems
DC	Direct Current
EHV	Extra High Voltage—consensus for AC Transmission lines is 345kV and above
EIS	Environmental Impact Assessment
EIR	Environmental Impact Review
EIS	Environmental Impact Statement
ELF	Extremely low frequency
EMF	Electromagnetic Fields
ENA	Electricity Networks Australia
EPR	Ethylene propylene cable
EPRI	Electrical Power Research Institute
GIL	Gas Insulated Line
GC	Gas cable
HDD	Horizontal Directional Drilling
HPOF	High-pressure oil-filled cable

Abbreviation	Description
HTLS	High Temperature Low Sag Conductors
HV	High Voltage
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ISP	AEMO's Integrated System Plan
NEM	National Electricity Market
OH	Overhead
OHTL	Overhead transmission line
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
REZ	Renewable Energy Zone
RIT-T	Regulatory Investment Test—Transmission
ROW	Right of Way (e.g. easement)
SCOF	Self-contained oil-filled cable
SLO	Social Licence to Operate
UG	Underground
UGC	Underground cable
UGTL	Underground transmission line
XLPE	Cross-linked polyethylene

Glossary

Term	Description
Impedance	The impedance in an AC electrical circuit or transmission line are a combination of characteristics which oppose current flow and result in voltage drop or rise and losses in the line. Impedance comprises of two components a) resistive, and b) reactive. The reactive component is a combination of inductance and capacitance.
micro-Teslas (µT)	A measurement unit for magnetic field strength (1µT = 10mG)
milli Gauss (mG)	A measurement unit for magnetic field strength (1µT = 10mG)
Right of Way	The general term used for a corridor secured for a transmission line. An easement provided a legal right of way on a property which may be privately or publicly owned. Transmission lines may also be installed on wider public road corridors.
Trefoil	Trefoil refers to a method of laying and arranging 3 single core cables in a triangular formation to form a 3-phase circuit.

1.

Introduction

This study aims to investigate the benefits and trade-offs between overhead and underground transmission line infrastructure, specifically focusing on issues associated with undergrounding new transmission infrastructure. It seeks to establish a clear and consistent approach to the evaluation of overhead lines and underground cable transmission, including the consideration of community concerns around the need for new transmission infrastructure to connect large renewable energy generation projects. It does this through systematic reviews of the literature as well as incorporating experiences of Transmission Network Service Providers (TNSPs) in Australia and overseas.

The study has a particular focus on 500kV infrastructure which is expected to be the system voltage for high-capacity transmission lines in Australia going forward. A detailed review of HVDC transmission is not within the scope of this study, however an overview of key aspects has been provided.

Historically, transmission networks in Australia developed from the need to transfer large amounts of power from large coal fired power stations, typically co-located near coal reserves, over long distances to major cities and industrial load centres. In contrast, the proposed large scale renewable generation facilities, mainly solar and wind farms, require greater land areas and are largely being located in greenfield areas with little or no existing transmission network infrastructure. These new developments are naturally creating community interest and concerns around a range of potential impacts, including but not limited to: visual amenity; environment; Traditional Owner lands; agricultural land use; and social licence to operate concerns. This has led to questions surrounding when it is appropriate to underground transmission infrastructure and the likely implications of doing so.

Here we provide an overall summary of the findings of the study presented in a table format comparing overhead and underground infrastructure against technical, economic, environmental and social factors.

2.

Comparison Table – HV overhead and underground cable transmission lines

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
		Technical Factors - System Design, Installation and Performance			
1	**Power transfer capacity (typical):**	500kV: AC Single Circuit Quad Bundle ~3000 MW. 330kV: AC Single Circuit ~ 1000 MW. 275kV: AC Single Circuit Twin bundle – 800 to 1000 MW. 132kV: AC Single Circuit Single bundle ~ 200 MW.	500kV AC: 2000MW 330kV AC: 800MW 275kV AC: 800MW 132kV AC: 150MW	+/- 525kV: 2000MW +/1 320kV: 750MW	+/- 525kV: 2000MW +/1 320kV: 750MW
2	**Feasible maximum line route lengths**	Overhead transmission lines can traverse long routes up to 1000km. Overhead lines require less reactive compensation plant (per km) compared to underground cables.	40 to 60km based on critical length (length where cable capacitance equals the rating on cable, typically around 85km for 330 kV and 76km for 500 kV; practical lengths will be around half of these values). Reactive compensation plant such as shunt reactors or static var compensators at termination points are required for underground transmission to counteract the more significant capacitive effects of cables compared to an overhead line.	Feasible route length for comparable power transfers to HVAC lines is currently **up to around 750 to 1000km**. Route lengths greater than 1000km are feasible.	
3	**Conductors, Insulators and Cables**	Typically, aluminium and aluminium with steel core, with 2 conductor bundles at 275/330kV and quad bundles at 500kV. Insulator strings can be glass, porcelain or composite.	XLPE insulated cable is the most common technology. The first installation at 500kV was in 1988, so the technology is now mature.	Conductors similar to HVAC. Longer insulator strings generally required due to higher voltage across insulators compared to 3 phase AC.	XLPE cables similar to HVAC. However cable design provides for insulation subject to greater electrical stresses compared to HVAC.
4	**Reactive compensation equipment requirement**	Reactive compensation is required for longer line routes but is much less than the requirements for an equivalent rated UGTL.	Significant reactive compensation is required for circuit lengths at 50% to 100% of the critical length (around 50km to 70 km for EHV cables).	Not applicable.	Not applicable.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
	Technical Factors - System Design, Installation and Performance				
5	**Power conversion equipment requirement**	Not Applicable.	Not Applicable.	AC/DC power conversion equipment required at each end of the transmission line. This is a major cost factor for HVDC systems.	
6	**Above ground impacts and construction requirements**	Typical lattice tower height and conductor span lengths for double circuit: 500kV : 60 to 80m high, spans 300 to 500 m 330kV : 50 to 60m high, spans 300 to 400 m 275kV : 40 to 50m high, spans 300 to 400 m 132kV : 30 to 40m high, spans 200 to 300 m Alternative pole or aesthetic designs may have lower heights. Aesthetic structures such as steel poles, T-pylons (UK) and lower height structures can be used in specific applications. However, there may be significant trade-offs such as cost, access and maintenance, additional structures and increased easement width.	Transition structures and fenced ground terminations required for connection to OHTL or at terminal substation.	Structure heights depend on DC voltage but will typically be less than the equivalent rated HVAC OHTL Structures will be more compact as less conductors will be needed. HVAC lines can be converted to HVDC application.	Transition structures required for connection to OHTL or at terminal substation.
7	**Below ground impacts and construction requirements**	Tower foundations and earthing conductors.	Depending upon design, voltage and power transfer rating: Cable trenching to lay conduits or cables - typically 1 to 2 m deep. Trench widths varying depending on number of cables and power transfer rating e.g. 500kV : 4 to 5m wide per circuit 330kV : 1.5 to 2m wide per circuit 275kV : 1.5 to 2m wide per circuit 132kV: 1 to 1.5m wide per circuit Horizontal direction drilling or micro-tunnelling required at some locations e.g., under waterway, rail corridors or busy roads. Cable tunnels will generally be required in high density urban areas for EHV cables.	Tower foundations and earthing conductors. Special earthing design required for ground electrodes.	Similar to HVAC UGTL, however trench widths will be less as a lesser number of cables will generally be required for same power transfer capacity.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
8	**Induced voltages**	OHTL's can induce voltages in nearby metallic objects such as fences, rail tracks and pipelines. Earthing and mitigation measures, such as phase conductor arrangements need to be considered in the design of an OHTL to ensure that the hazard is mitigated, and the design complies with standards.	UGTL's can induce voltages in nearby metallic objects such as fences, rail tracks and pipelines, however the earthed metallic screen significantly mitigates the induced voltages. Earthing arrangements of UGTL's that have metallic outer sheaths must also be considered as the induced voltages can cause current flows in the sheath that result in heat losses. Arrangements such as cross-bonding cancel the induced voltages in a 3-phase cable installation.	Induced voltages from HVDC lines into nearby metallic objects are static and tend to be lower than HVAC lines. Both steady state and fault currents in the HVDC line must be considered. Ground potential rise due to discharge currents via earth electrodes in HVDC systems must be considered in the design.	
9	**Vehicle access tracks**	Access tracks required for construction (heavy vehicle) and on-going maintenance (light vehicle). Primary requirement is access to structure location for construction lay down areas and where there is an ongoing requirement for vegetation management along the route.	Apart from where installation is under a formed public road, access tracks along the cable route are normally required for construction and on-going routine inspection and maintenance. The impact will vary depending upon the route, terrain, and installation methods.	Access tracks required for construction (heavy vehicle) and on-going maintenance (light vehicle). Primary requirement is access to structure location for construction lay down areas and where there is an ongoing requirement for vegetation management along the route.	Apart from where installation is under a formed public road, access tracks along the cable route are normally required for construction and on-going routine inspection and maintenance. The impact will vary depending upon the route, terrain, and installation methods.
10	**Future connection capability**	HVAC OHTL's provide the most economic and flexible capability for future connections to the line.	HVAC UGTL's provide economic and flexible capability for future connections to the line. Cost will be greater than OHTL's however with more expensive underground works to extend, joint and terminate cables.	HVDC lines provide the least economic and flexible capability for future connections due to the requirement for additional converter stations. HVDC is more suited to applications for direct power transfer between two distant locations.	
11	**Reliability**	Reliability of performance (typical forced outage rate of 0.5 to 1.0 per 100 km/year). Structural failures (for Australia, failure rate is around 1 in 150,000 per annum). Overhead lines are exposed to severe weather including lightning strikes. Repair time for faults is much shorter duration compared to underground.	For XLPE cables outage rates are typically less than 1 outage/100km/year and lower than equivalent overhead lines. Repair time for underground cable faults is a much longer duration than overhead lines due to excavation, cable jointing and electrical testing work required e.g., up to 4 weeks.	Limited data is available; however, outage rates are expected to be like HVAC OHTLs. The lesser number of conductors in a HVDC line would result is less exposure to faults compared to HVAC.	Limited data is available; however, outage rates are expected to be like HVAC UGTLs. The lesser number of conductors, joints and terminations in a HVDC line would result is less exposure to faults compared to HVAC.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
12	**IElectro Magnetic Fields (EMF)**	Magnetic field levels are maximum under the centreline of the transmission line and decrease less gradually with distance from the line compared to an underground line. Transmission lines are designed to meet industry compliance limits within the corridor. Electric fields are emitted from overhead lines, but lines are designed to be within compliance limits. Magnetic field levels at 40m from overhead transmission line are similar to levels from typical appliances found within a home. The electric fields from transmission lines rated at 330 kV and below will generally produce electric fields less than the reference levels or industry guidelines. Design measures need to address electric fields from 500 kV transmission lines.	Magnetic field levels are above the centreline of the underground transmission line and decrease more rapidly with distance from the line compared to an overhead line. Electric field are contained within a cable with outer earth bonded metallic sheath. EMF levels at 4m from underground transmission line are similar to levels from typical appliances found within a home.	DC magnetic fields are static and subject to higher reference limits (i.e., less onerous) compared to AC. DC electric fields are static and subject to higher reference limits (i.e., less onerous) compared to AC. Design measures to ensure compliance with standard limits are applied.	DC magnetic fields are static and subject to higher reference limits (i.e., less onerous) compared to AC. Design measures to ensure compliance with standard limits are applied. Electric fields are contained within the cable system.
13	**Audible Noise**	Audible noise can occur due to: • corona discharge on the transmission line conductors • dirt or pollution build-up on insulators • wind effects on structure and fittings These effects need to be considered in the design and maintenance measures employed to ensure noise is within compliance limits.	No audible noise from underground cables.	Audible noise – similar to HVAC OHTLs, but is dependent on voltage and size of conductors. Design measures are applied to ensure noise levels are within compliance limits. Audible noise from HVDC converter stations will occur. This needs to be considered in the design and location of converter stations in order to minimise impact.	No audible noise from underground cables. Audible noise from HVDC converter stations will occur. This needs to be considered in the design and location of converter stations in order to minimise impact.
14	**Corridor and easement requirements:**	For double circuit: 500kV AC – 70m wide 330kV AC – 60m wide 275kV AC – 60m wide 132kV AC – 20 to 40m wide Adjoining public roads may form part of a corridor.	For double circuit, rural: 500kV AC – 30 to 40m 330kV AC – 10m to 20m 275kV AC – 10m to 20m 132kV AC – 5m to 10m Urban installation corridor width depends on availability of suitable public road corridors or there is a requirement for a tunnel. Land is also required for underground to overhead transitions.	Corridor widths for HVDC OHTLs of equivalent power transfer ratings are similar to HVAC OHTLs. Buffer zones required for EMF reduction or prudent avoidance would be less.	Corridor widths for HVDC UGTLs of equivalent power transfer rating will be generally less than HVAC UGTLs. This is due to a lesser number of cables and reduced width trench widths required for an installation. Road corridors may be more readily used for cable routes. Land is also required for underground to overhead transitions.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
15	**Lifespan (Typical)**	60 to 80 years.	Greater than 40 years.	60 to 80 years (OHTL) Converters to be considered also.	Greater than 40 years (UGTL cable) Converters to be considered also.
16	**Project timeframes**	e.g. for a 500kV double circuit for 100km route length: Planning and approvals: 3-5 years. Construction: 2 years.	e.g. for a 500kV double circuit for 50km route length: Planning and approvals: 3 years. Construction: 4-6 years.	Construction: 2 years.	Construction: 4 – 6 years.
			Risk Management Aspects		
17	**WH&S – construction**	General construction industry risks. Working at heights risks for erection of towers and conductor stringing. May involve helicopter work. Electrical safety risks – HV switching, testing, live line works.	General construction industry risks. Excavation machinery risks Electrical safety risks – HV switching, testing. Overall risks considered lower for UGTLs compared to OHTLs.	General construction industry risks. Working at heights risks for erection of towers and conductor stringing. May involve helicopter work. Electrical safety risks – HV switching, testing, live line works also at converter stations.	General construction industry risks. Excavation machinery risks. Electrical safety risks – HV switching, testing including converter stations. Overall risks considered lower for UGTLs compared to OHTLs.
18	**Severe weather**	OHTL are exposed to severe weather damage from high winds, flooding, and lightning strikes.	UGTL have limited exposure risk to severe weather. Lightning strikes to the overhead network can cause damage to UGTL.	OHTL are exposed to severe weather damage from high winds, flooding and lightning strikes.	UGTL have limited exposure risk to severe weather. Lightning strikes to the overhead network can cause damage to UGTL lines.
19	**Bushfire risk and exposure**	OHTL can cause bushfires (releasing molten particles from conductor clashing or conductor contact with vegetation or ground). OHTL's may be exposed to bushfire damage risk (high bushfire risk areas).	UGTLs have limited exposure to bushfire damage risks. Above ground equipment including cable terminations at overhead to underground transitions would be exposed.	OHTLs can cause bushfires (releasing molten particles from conductor clashing or conductor contact with vegetation or ground). OHTL's may be exposed to bushfire damage risk (high bushfire risk areas).	UGTLs have limited exposure to bushfire damage risks. Above ground equipment including cable terminations at overhead to underground transitions would be exposed.
20	**Climate change**	Long term climate change effects could increase risks associated with severe weather, wind loads and bushfires on OHTL's. OHTL's line designs will need to consider these impacts which may result in increased project costs.	UGTL's will be less exposed to long term climate change risks. There is exposure to damage in flooding events where erosion of ground can expose cables.	Long term climate change effects could increase risk associated with severe weather, wind loads and bushfires on OHTL's. OHTL's line designs will need consider these impacts which may result in increased project costs.	UGTL's will be less exposed to long term climate change risks. There is exposure to damage in flooding events where erosion of ground can expose cables.
21	**Damage by other parties**	OHTL's may be exposed to malicious and accidental damage. Accidental damage can be by vehicles, construction machinery or aircraft.	UGTL's may be exposed to risk of third-party damage by other excavation machinery including drilling.	OHTL's may be exposed to malicious and accidental damage. Accidental damage can be by vehicles, construction machinery or aircraft.	UGTL's may be exposed to risk of third-party damage by other excavation machinery including drilling.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
22	**Earthquake**	Earthquakes have potential to cause damage to overhead infrastructure. However, repair times will be less than for underground cables.	Earthquakes have potential to cause damage to underground cables, joints, and terminations. Repair time in such situations would be considerably longer than for overhead infrastructure.	Earthquakes have potential to cause damage to overhead infrastructure. However, repair times will be less than for underground cables.	Earthquakes have potential to cause damage to underground cables, joints, and terminations. Repair time in such situations would be considerably longer than for overhead infrastructure.
			Economic Factors		
23	**Capital Investment Costs:** •Planning •Social licence - consultation and engagement. •Design and survey •Approvals •Environmental offsets •Property – easements, right of way, landholder payments •Procurement of plant and materials •Construction (civil, structural, electrical) •Commissioning Indirect costs (overheads)	**Indicative costs** for double circuit OHTL, route 50-100km, including project construction (materials, labour and plant) and excluding property and environmental offsets: 275 kV: \$2M to \$3M per km 500 kV: \$5M to \$6M per km	**Indicative costs** for double circuit UGTL typical 40 km length including project construction (materials, labour and plant) and excluding property and environmental offsets: 275 kV: \$10 M to \$15M per km 500 kV: \$25M to \$30M per km	Project costs were not in the scope of this study. "Break even" distance for HVDC overhead comparted to HVAC overhead is around 600 to 650km for EHV.	
24	**Operating and Maintenance:** •Planned maintenance. •Corrective maintenance •Unplanned maintenance	**Indicative costs:** 0.5 to 1% of capital cost per km per annum for up to 20 years. 1 to 2% of capital cost per km per annum during mid life.	**Indicative costs:** Expenditure per km per annum is typically around 40% of comparative overhead line but can be similar if the patrol specification and frequency of patrols is frequent.	HVDC Transmission lines – Maintenance requirements for overhead and underground line components are expected to be similar to HVAC overhead and underground. However, the additional maintenance requirements associated with AC/DC converter stations would be significant resulting in overall higher lifetime maintenance requirements.	
25	**Operating - Energy Losses**	Cost of losses depend on conductor size selection. Typically, overhead lines losses can be 1.5 to 2.5 times greater than an equivalent underground line.	Cost of losses depend on conductor size selection. Typically, underground cable losses will be less than an equivalent overhead line. Reactive compensation losses need to be considered for longer route lengths (e.g., > 10km).	Losses for HVDC systems can be up to twice that of the equivalent HVAC overhead or underground system due to the additional losses from the AC/ DC converter.	

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
26	**Lifetime Cost:** Net Present Value (NPV) of: •Capital Investment cost. •Operating and Maintenance costs over life •Cost of energy losses with annual load growth factor applied over life. •End of life cost (not significant) Key assumptions included in the NPV calculation are: •Expected asset life span e.g., OHTLs – 60 years, UGTLs – 40 years. Financial discount rate or internal rate of return e.g., 5 to 6%.	275 kV OHTL PV costs at 40 years indicates the following: $3.76 M (Initial cost of $2 M + $1.76 M for maintenance and operating costs (losses and unreliability). It should be noted that 40 years is typically only half the life of an overhead line.	275 kV UGTL PV costs at 40 years indicates the following: $11.1 M (Initial cost of $10 M + $1.0M of maintenance. It should be noted that 40 years is typically only 70% life of underground transmission line. The UGTL to OHTL lifetime cost ratio at 40 years is around 2.9. Lifetime costs have been performed for 275 kV transmission (because parameters for OHTL and UGTL were known). It is expected that the UGTL to OHTL lifetime cost ratio for a 500 kV line at 40 years would be similar to 275 kV transmission.	Not in scope of this study.	
			Environmental Factors		
27	**Overall environmental impacts**	Overall negative impacts on the local biodiversity. The geographical context as well as the local ecosystem influence overall impacts. Transmission line add to the cumulative impacts from all infrastructures and developments in a region.	Likely overall negative impacts on the local biodiversity.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
28	**Barrier effect**	Barrier effect impacts biodiversity negatively. Bird collision and avoidance are the most cited impacts. Flow-on impacts are multiple, including change in migration path and extinction. Potential mitigation measures are through line routing and line markers.	Undergrounding is an effective mitigation measure for the barrier effect.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
29	**Line as resource**	Line as resource is considered positive though with potential negative impacts, particularly on birds. Positive impacts include increased population size and home range. Negative impacts include increased collision, electrocution, predation and invasive species colonisation.	Underground lines cannot act as a resource.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
30	**Habitat loss**	Habitat loss arises mostly from vegetation clearance, particularly in forested area. The most cited impacts are area abandonment and population decline.	Underground line would result in habitat loss from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
31	**Habitat fragmentation**	Habitat fragmentation arises mostly from vegetation clearance and the barrier effect. Negative impact such as altered movement for mammals and amphibians, and reduced bird crossings with increasing voltage.	Underground line would result in habitat fragmentation from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
32	**Edge effect**	Edge effect arises from vegetation clearance and can have positive, neutral or negative impacts on biodiversity. Most intense impacts are in forested areas. Impact on vegetation from change in microclimate and associated species in those communities such as insects, birds, bats and mammals.	Underground line would result in edge effect from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
33	**Habitat conversion**	Habitat conversion arises from vegetation clearance and can overall be positive, particularly in forestry and intense agricultural land. Maintenance in semi-natural grassland can provide significant ecosystems for a variety of species, notably pollinators and open habitat bird species. To be positive, it requires management practices designed for the local context.	Underground line would result in habitat conversion from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
34	**Corridor effect**	Corridor effect arises from the easement providing a connection between areas and can have positive, neutral, and negative impacts. Increased home range for native, non-native, and invasive species. Large carnivores and birds expand their home range, most notably the crow or raven. Limited home range expansion for pollinators. To be positive, it requires management practices designed for the local context.	Underground line would result in habitat conversion from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
35	**EMF**	Potential behavioural, reproductive effects. Some bat species powerline avoidance behaviour is attributed to EMF. EMF affects bees and may pose threat to pollination and colonies survival.	EMF impacts are likely to occur for underground.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
36	**Fire**	Overhead lines can be a source of fire ignition (1.2% of fires in Spain). Bird electrocution can induce fire – mainly distribution lines (2.4% of the 1.2% in Spain).	Undergrounding would mitigate power line induced fires.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
37	**Noise**	Noise arises from construction and maintenance, corona discharge and cable vibration from wind. Noise may alter animal behaviours and interfere with animal communication.	Undergrounding would mitigate corona discharge and wind induced noise.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
38	**Soil degradation, hydrological alterations, air pollution**	Those impacts are mostly associated with the construction and removal phase. Limited data on their impacts in the peer-reviewed literature.	Those impacts would be markedly different and likely more significant for underground cables for the life cycle of the infrastructure.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC underground.
39	**Environmental Assessment Processes**	The Federal Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the State's Queensland Environmental Protection Act 1994 are the key legislative requirements for all projects. Detailed Environmental Impact Assessments (EIAs) and surveys are required to ensure protection of environmental significance including unique plants, animals, habitats and places. Environmental Impact Assessments (EIA) are an essential and critical stakeholder engagement activity forming part of the approval process for all transmission projects.			
		Social Acceptance Factors			
40	**Overall social licence and acceptance**	Context dependent and dynamic. Potentially reduced in host communities because of the perceived burden of the project. Influenced by the factors described in this table.	Context dependent and dynamic. Potentially improved in hosting communities. Influenced by the factors described in this table.	Only one study. Similar to overhead AC.	

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
41	**Aesthetic and visual**	Visual impacts negatively influence acceptance. Expected flow on impacts include diminished: recreational activities, tourism, local commerce, and health stress. Tower design, paint, and landscaping of the corridor may positively influence acceptance.	Undergrounding can positively influence visual impacts, but clearing is required (which is a negative impact).	No data.	
42	**Human health**	EMF concerns' influence on acceptance is neutral to negative. Information provision from independent, trusted sources, and transparency in decision-making process can contribute to mitigating concerns.	Limited data in the literature. An awareness gap was identified for underground EMF effects.	Only one study. No influence on acceptance compared to overhead AC.	
43	**Proximity**	Proximity influence is neutral to negative on acceptance. Concerns relate mostly to EMF and effects on property value. Acceptance does not follow a linear rule with distance from the transmission line.	Similar to OHTL, however acceptable distance appears to be reduced compared to OHTL.	No data	
44	**Familiarity**	Familiarity is linked to proximity of an existing OHTL and may positive influence acceptance.	No data.	No data.	
45	**Property valuation impacts**	Expectation of value loss negatively influences land and home owners' acceptance. Actual property value impact may range from +10% to-30%. Property value loss disappears after 5 to 14 years. Value increase was noticed for landscaped corridors.	Losses are expected to be less that for OHTL though not neutral.	No data.	
46	**Financial compensation**	Geographic boundaries, calculation, and administration of compensation are the subject of contestation mitigated with engagement and participation. Individual compensation for land and Homeowners is expected. Beyond property value loss, it needs to account for attachment to place and community (in the case of resumption) and land use. Community benefits positively influence acceptance. For indigenous communities compensation needs to account for cultural value and reparation of historical wrongs.	No data.	No data.	

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
47	**Environmental impacts**	Environmental impacts negatively influence acceptance. Concerns are focussed on vegetation clearance, habitat and wildlife loss, soil degradation, water and groundwater quality and flow, noise, fire, weed dispersal, waste, national park and conservation areas and impacts on agriculture.	Often seen as a mitigation measure of impact on significant landscape and biospheres, however lack of awareness of UGTL environmental impacts was highlighted.	No data.	
48	**Distributive justice: equity**	If the distribution of benefit and burden is unequal it negatively influences acceptance. This may be mitigated with community benefits and sound environmental measures in place. Capacity to negotiate better outcomes is often unequal between communities. This may be mitigated with capacity building and use of independent experts. Accelerated processes negatively influence acceptance.	Undergrounding might be seen as a mitigation of unequal distribution of burdens.	No data.	
49	**Procedural justice:** **Governance**	Fair and transparent governance influence acceptance positively. Coordination and efficiency in the planning processes between jurisdictions and economic sectors alleviate engagement frustration and fatigue compared to multiple, confusing and, at times, contradictory processes. Participation in national transition planning through to regional transmission line planning may influence positive acceptance. Clear goals and outcomes for all processes, including participation, may contribute to alleviating lack of trust issues.			
50	**Procedural justice: Information**	Quality, contextualised, timely and transparent information about available technologies, risks, trade-offs, and governance positive influences acceptance. Trusted sources and easy access also positively influence acceptance.	Similar to overhead AC An awareness and knowledge gap was identified about EMF and environmental impacts from undergrounding.	Only one study. An awareness and knowledge gap was identified about HVDC. Information provision can be helpful towards improving acceptance.	
51	**Procedural justice:** **Engagement & Participation**	There is a need to have a clear and transparent stakeholder identification process. Engagement is the sum of all interactions between all stakeholders of TLs and can influence acceptance. Participation is an essential component of engagement and requires clear goals and expected outcomes. A goal to solely increasing acceptance tends to negatively influence acceptance. Contextualised knowledge creation and relationship building based on shared understanding, transparently incorporated into project design and construction positively influences acceptance. Participation processes that are inclusive and ensure adequate local representation, provide agency and and account for power imbalances positively influence acceptance. Accountability in the process is key.			
52	**Procedural justice:** **Trust**	High levels of trust in the process and the institution positively influences acceptance. Lack of trust hinders participatory processes and ultimately acceptance. The elements highlighted in this summary are critical to building trust in the proponent and their associated activities.			

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Underground
53	**First Nations' Engagement Principles**	"Engage respectfully; Prioritise clear, accessible and accurate information; Ensure cultural heritage is preserved and protected; Protect Country and environment; Be a good neighbour; Ensure economic benefits are shared; Provide social benefits for Community; Embed land stewardship; Ensure cultural competency; Implement, monitor and report back" Source: https://www.firstnationscleanenergy.org.au/network_guides			

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