Submission No 13

INQUIRY INTO FEASIBILITY OF UNDERGROUNDING THE TRANSMISSION INFRASTRUCTURE FOR RENEWABLE ENERGY PROJECTS

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Date Received: 8 November 2023

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8 November 2023

Ms Cate Faehrmann, MLC
Committee Chair
Parliament of New South Wales
Sydney

Dear Ms Faehrmann,

Re: Select Committee Inquiry into the Feasibility of Undergrounding the Transmission Infrastructure for Renewable Energy Projects.

On behalf of Curtin University I am pleased to provide a copy of our "Summary Report: Comparing high voltage overhead and underground transmission infrastructure (up to 500kV)" and accompanying Comparison Table. These documents summarise the findings of an independent systematic literature review of high voltage overhead and underground transmission infrastructure.

The work was funded by Powerlink Queensland who, based on the experience of transmission network service providers (TNSP) in other states across Australia and internationally, wanted to establish a clear and consistent approach to the consideration of undergrounding of transmission infrastructure. To do this effectively, Powerlink Queensland commissioned The University of Queensland and Curtin University to undertake a research project to investigate the benefits and trade-offs between overhead and underground transmission infrastructure.

These two documents are complemented by more detailed reports provided separately in Chapters 2 to 7, which cover technical, economic, environmental and social considerations in more detail along with a range of Australian and international case studies. Chapter 8 summarises the findings of focus group discussions undertaken with members of the Queensland general public in August 2023 where we presented the findings of the review to ascertain their responses to the information. We are currently undertaking additional engagement with representatives from First Nations Prescribed Body Corporations in Queensland and hope to publish the findings from this collaboration at a subsequent date.

Please note these documents will not be made public until after the 16th of November at https://research.curtin.edu.au/ciet/engagement/publications/powerlink-report/. However, we are providing these documents confidentially in advance of that date in line with your submission closing date. We do hope the Select Committee finds the information helpful in your Inquiry.

Kind regards

Professor Peta Ashworth OAM
Director, Curtin Institute for Energy Transition
Curtin University
Bentley, WA 6012

SEPTEMBER 2023

Summary Report

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

Gary Madigan, Colin Lee, Audrey Cetois, Anupam Dixit, Xin Zhong, Andrew Knight, Sarah Rohl, Nasrin Aghamohammadi, Tapan Saha, Fran Ackermann and Peta Ashworth

Foreword

This report summarises the findings of an independent systematic literature review of high voltage overhead and underground transmission infrastructure, which was undertaken by The University of Queensland and Curtin University.

This is the summary report for the study which is complemented by more detailed reports provided separately in Chapters 1 to 8 which cover the themes and cases studies in more detail.

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

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Acknowledgements

We would like to acknowledge the contributions of:

Susantha Wanniarachchi

For his help in seeking copyright for the images included in the document

Sheree Stokell

For her help in identifying the key literature for the environment section of this report

Members of Powerlink's Customer Panel

Who guided us through the research design elements of the project

Report Reviewers

Who generously gave up their time to provide much needed feedback on the report and chapters

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

Executive Summary

Background

Decarbonisation of Australia's energy system through electrification via renewable energy sources is a key pillar of the transition to a climate-friendly economy. Without grid expansion, either with new or upgraded transmission lines, decarbonisation and a successful transition is at risk. However, the challenges of grid expansion are not limited to the techno-economic ones. Experience from around the world shows that transmission lines tend to be less accepted than most other energy infrastructures, with public opposition leading to significant project delays. This is also being experienced here in Australia. Successful navigation of such challenges requires a systemic approach to the problem. Recognising there is a complex interplay between the economic, environment, and technical constraints that impact society's response and ultimate acceptance. This in turn requires strong leadership to move the agenda forward with significant attention to the procedural and distributive justice considerations of such projects. Informed by a systematic literature review we summarise the main trade-offs between overhead and underground transmission line infrastructure by considering the technical, economic, environmental and social and cultural factors.

This research project to assemble the literature and case studies was undertaken between February and July, 2023. However, there is additional and ongoing engagement with a range of different groups to understand the various publics' responses to the information, including First Nations People and farmers. The considerable developments in relation to social licence, community engagement and opposition that have occurred in more recent months are not detailed in this report. For example, the findings from the NSW Parliamentary Inquiry, and the draft determination and rule change for enhancing community engagement in transmission building, proposed by the Australian Energy Market Commission (AEMC) are not detailed in this review. We also note that a further Inquiry by a Select Committee in NSW was announced in September. Finally, the Australian Energy Infrastructure Commissioner is also undertaking a review to "enhance community support and ensure that electricity transmission and renewable energy developments deliver for communities, landholders and Traditional Owners".

Technical Considerations

For years, HVAC overhead transmission lines have been the most common form of transmission line infrastructure, providing the lowest cost system for connecting multiple generators and ensuring bulk supply of electricity to customer load centres. They are designed to meet high-performance standards for safety and reliability with proven technologies for structures, conductors, and insulators that with good maintenance practices have a long service life of between 60 to 80 years.

Alternatively, when traversing high-density urban areas where there is already congestion of overhead lines, or in areas of environmental sensitivity or natural beauty, HVAC underground transmission cables have been used. However their application is limited to much shorter route lengths, for example around 50km for 500kV. This is due to the significant charging currents associated with the highly capacitive characteristics required for longer HVAC underground cables. To counteract the resulting energy losses caused by this phenomenon, expensive reactive power compensation plant (e.g. shunt reactors) are required. Usually made from polyethylene (XLPE), the cables are expected to have a service life of around 40 to 50 years.

High Voltage Direct Current (HVDC) (overhead or underground) transmission is an alternative to the HVAC system. Its main advantages are that it provides for:

(a) High power transfer power over very long distances with lower line losses compared to HVAC.
(b) Interconnection of asynchronous AC grids, for example between two regions or countries.
(c) More compact line infrastructure "foot-print" requiring narrower land corridors due to fewer conductors or cables compared to the equivalent rated HVAC overhead or underground line.
(d) Long offshore or on-shore cable connections where the route length exceeds the feasible or critical route length for a HVAC transmission cable of equivalent power transfer capability

The main disadvantages of HVDC is the requirement for large and expensive AC/DC converter stations at terminal connection points to the main HVAC transmission grid. For example the converter stations for the Suedlink project will occupy around 7 hectares [1]. Noise levels from the equipment at converter stations can also be a significant environmental issue [2]. The requirement for large and expensive converter stations tends to limit application of HVDC to point to point connections.

Until now, HVDC has been used extensively for inter-regional transmission connectors and offshore and onshore renewable zone interconnections in more highly populated regions (i.e. Europe, America, and Asia). In Australia, there are only three examples - Basslink submarine cable; Directlink (Northern NSW); and Murraylink (Vic to SA) - constituting a small component of Australia's transmission grid.

Economic Considerations

Multiple studies by government bodies, Transmission Network Service Providers (TNSPs), industry organisations, and other stakeholders compare the cost of overhead versus underground cable transmission. Based on published literature, including the Parsons Brinkerhoff UK report [3] (often referred to by the industry for its methodology for evaluating lifetime costs) and the Australian Energy Market Operator (AEMO) [4], the comparative ratios are generally in the range of 3 to 20 depending upon type of construction, route length and other project specific factors. However, Parsons Brinkerhoff note the complexities of undertaking economic analysis stating *"Cost ratios are volatile, ... Use of financial cost comparisons, rather than cost ratios, are thus recommended when making investment decisions."*

A detailed review of HVDC transmission costing and economic factors was not within the scope of this study. However, based on data from Acaroğlu et al [5], ABB [6], Amplitude Consultants [7], and the AEMO Transmission Cost Database, the break-even cost point for HVDC overhead transmission is at a route length of around 600km to 700km when compared to an equivalent of a 500kV HVAC line. The cost ratio of HVDC underground to HVAC overhead was reported as 3.3 for a 1500MW, 1000km case study [5].

However, the economic feasibility of HVDC compared to HVAC, ultimately depends on project-specific factors such as route length and constraints. Regulatory investment test requirements also need to be satisfied and these highlighted costs only relate to the technical costs and do not encompass access to land and costs of gaining a social licence, for example.

Environmental Considerations

While the overall environmental impacts of transmission lines are likely to be negative, the extent to which their impact is felt is context dependent. Principally, habitat loss, fragmentation, and the alteration of environmentally sensitive areas are key negative outcomes of the construction of transmission infrastructure on the natural environment. The clearing of vegetation for easements is likely to have a significant impact on wildlife habitats as well as cause changes in the microclimate by restricting the growth of plants and trees, with secondary impacts on some species including insects, birds, and other mammals. Transmission lines constructed in highly sensitive natural environments including watercourses, wetlands, and national parks, would see these impacts amplified.

Overhead lines are likely to create a barrier effect, where biodiversity is negatively impacted by changes in bird migration patterns because of collision and avoidance of the transmission lines, whereas the use of underground transmission can somewhat mitigate this impact. In contrast, underground transmission may cause soil degradation and hydrological alterations throughout the lifetime of underground lines, whereas initial data indicates that these impacts are less significant in overhead lines being restricted largely to the construction phase and mitigated through carefully designed construction and restoration methods. Bushfires have in a few instances (2 out of 32 noted in the NSW 2019 Inquiry) been started by transmission lines, and also cause damage to both overhead and underground lines.

The generation of electromagnetic fields and noise from transmission lines, particularly overhead lines, has the potential to disrupt not only local nearby communities but also the behaviour and health of some species including bats and other pollinators. Knowledge of the extent of these impacts is less developed but is an important factor to consider given the significant role these species play in an area's overall biodiversity and environmental stability.

Beyond the direct effect of transmission lines on the natural environment, projects must also consider how their construction is likely to impact the archaeological and cultural heritage of the surrounding area. More work in this area will provide a valuable perspective and understanding of other dimensions of environmental impacts.

To minimise the environmental impacts from any transmission project there are strict legislative requirements in place at both Federal and State levels. The Federal Environment Protection and Biodiversity Conservation Act 1999[1] and the Queensland Environmental Protection Act 1994[2] are the main legislative requirements that govern transmission project developments. These require detailed assessment and surveys and a typical time frame to complete such processes is around two years.

Social and Cultural Considerations

The literature review identified a range of factors that influence acceptance – a necessary part of acquiring a social licence. Factors such as aesthetics, human health

1 Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)(www.dcceew.gov.au/environment/epbc)
2 Environmental Protection Act 1994 - Queensland Legislation - Queensland Government (www.legislation.qld.gov.au/view/html/inforce/current/act-1994-062)

and some safety considerations generally see underground performing better than overhead for public acceptance. Augmented with environmental and economic concerns, along with trust in the developer and concerns around procedural and distributive justice reflect the systemic and complex nature of the decision space.

The distribution of benefit and burden is at the heart of distributive justice considerations. Local host individuals and communities bear the major burdens and risks of projects, while benefits are often realised far away in cities or even globally when it comes to emissions reduction. To overcome the likely negative reaction to projects, compensation has played an important factor in positively influencing local host acceptance, along with an expectation that neighbours are included in discussions of compensation to ensure fairness in how the process is perceived.

However, experience has shown the public's response is never solely about the financial incentives. If the process of engagement is not seen as respectful and fair, then it is unlikely any amount of compensation will guarantee the project will progress. Individuals' values also strongly influence attitudes towards a project and ultimately its acceptance. These attitudes might relate to strength of their attachment to the place in which they live, place and social identity along with the timeliness of the process that was used to engage, and availability of information.

Open, regular, and transparent project processes that involve two-way dialogue, significantly help to build trust in project developers. This was evidenced in the current Australian transmission projects where *the speed of delivery and the need to build a lot* has caused concerns for many stakeholders. Multiple developments (e.g. renewables plus transmission) occurring at the same time can lead to cumulative impacts and create additional burdens on communities. Transparent and fair processes need to include all stakeholders, ensuring any power imbalances are addressed. This should also include appropriate place-based engagement and collaboration with Traditional Custodians.

Findings Case Studies – Australia and beyond

Many of the considerations arising from the systematic literature review are vividly illustrated in the current Australian 500kV projects and international cases. Understanding both the historical and current context of project locations, along with engaging early and reflexively, and allowing communities time to engage to understand the trade-offs between options – all help to build fair processes. Impacts on land use, archaeological sites, farming practices, property values, tourism and increased traffic on local roads were all common issues emerging from the case studies.

The need for adequate compensation beyond the host community and the undergrounding of some sections, in response to stakeholder concerns, also helped to build greater acceptance for projects internationally. In the case of the UK and Denmark, the use of aesthetic overhead transmission line structures - more compact with a lower height compared to traditional steel lattice towers for the same system voltage – led to successful project outcomes. However, the downside of these structures is the greater width of the structures resulting in larger easement requirements and land-use restrictions.

Conclusion

While the urgent need to decarbonise our energy system is a global issue, unless directly impacted by a project, the Australian public's understanding of the need for new transmission infrastructure remains low. This is despite the fact, that such investment will ultimately be reflected in state capital borrowings and individual electricity bills. Therefore, to ensure fairness and understanding in the investment and trade-offs required for such a transition, there is a need for increased, easy to understand information and engagement on the topic.

Key considerations include, why there is a need to build more transmission infrastructure, and how it differs to distribution networks. What the differences are between HVAC and HVDC and the trade-offs that emerge when considering either overhead and underground infrastructure. This must include the combination of factors that arise, beyond the techno-economic considerations, to highlight the complex decision space that is required when choosing a final route.

While there is no one size fits all for final route selection, transparent, collaborative constraint mapping, undertaken between projects developers and communities can help to build trust in the process and more successfully lead to the identification of a preferred route option. However, this is only if distributive and procedural fairness considerations have been central to the process. Given the delays that have occurred both in Australia and beyond, there is a need for strong leadership that, where necessary, can make the tough decisions, if necessary, for the resumption of land and to clearly articulate the trade-offs that led to the final decision.

1. Introduction

1.1 Background

The Australian federal government has committed to reducing its greenhouse gas emissions by 43% below 2005 levels by 2030. This target is set under the Paris Agreement, a global effort to combat climate change. As one of the measures supporting this commitment an additional target has been set to reach 82% renewable energy generation by 2030. This includes a range of initiatives to promote the deployment of renewable energy sources including solar, wind, and hydroelectric power.

State Governments accordingly have established plans and strategies to support and, in many cases, exceed the national targets. For example, the *Queensland Energy and Jobs Plan (2022)* set a target of 70% renewable energy generation by 2032. An essential component of this plan is to establish a "SuperGrid" to provide a new backbone transmission network that will connect more renewable energy and storage sites across the state. The other states and territories, which operate in Australia's National Electricity Market (NEM): New South Wales, Victoria, South Australia, ACT and Tasmania, have similar plans for expanding the transmission networks to connect projects in renewable energy zones (REZs).

Transmission line infrastructure in Australia and overseas is predominantly overhead construction. Based on 2015 data collected by Geoscience Australia [8], only about 0.9% of the transmission line circuit route of 220kV or greater is underground in Australia. This is generally consistent with data reported internationally by CIGRE [9] of about 0.5% for lines in the 315 to 500kV range being underground. This has mainly been attributed to technical limitations and the significant cost of undergrounding compared to the construction of overhead transmission lines. The capital cost of underground compared to overhead transmission infrastructure is generally reported by many TNSP's[3] to be in the order of 5 to 10 or even higher, depending on project specific factors.

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 concerns around a range of potential impacts, including but not limited to: visual amenity; environmental impacts; cultural heritage considerations; Traditional Owner rights; agricultural land use; and social licence to operate.

While national and state regulatory frameworks seek to ensure these concerns are addressed in the planning phase of new infrastructure projects, there has been a marked increase in public opposition to proposed transmission projects in Australia. This has not only resulted in significant delays to projects, along with increasing project costs as a result of the delays, it has also caused significant negative impacts on landholders' and other local communities' overall wellbeing. Different groups have invested much time and effort in opposition to transmission projects proposed for their local communities, seeking answers around the trade-offs between overhead and underground transmission infrastructure. With the urgent need to decarbonise and increasing timeframes for the processes and approvals the situation is becoming critical.

1.2 About this Review

This review aims to investigate the benefits and trade-offs between overhead and underground transmission line infrastructure, specifically focusing on issues associated with under-grounding 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.

[3] Underground-construction-summary-November-2021.pdf (www.westernrenewableslink.com.au)
HumeLink: Connecting Wagga Wagga, Bannaby and Maragle | Transgrid (www.transgrid.com.au/projects-innovation/humelink#Resources)
Electricity Transmission Costing Study (www.theiet.org)

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.

To ensure a comprehensive and independent analysis, the research project began with a three hour collaborative, co-design workshop with key agricultural, resources, community, and customer representatives from Powerlink's Customer Panel to help to set the guidelines for this review to accurately identify the knowledge gaps. In total there were seven participants from the Customer Panel, two representatives from Powerlink and four of the technical experts from the research team. Chief Investigators, Ashworth and Ackermann, guided the workshop process. Participants were asked to identify what they saw as *"The top 3 issues and opportunities relating to either overhead (O) or underground (U) cables"?* Eight different themes emerged from the workshop and to prioritise these, participants were asked to rate each theme on a scale from 0 (lowest priority) to 10 (highest priority). Reflected in Table 1, the first column shows the number of supporting statements that emerged in each theme, while the following columns, provide the mean and standard deviation of combined scores, illustrating the priority and degree of consensus across each of the themes.

Social licence and impacts on landholders and communities received the highest average score and the highest degree of consensus. *Ensuring new transmission has minimal environmental impact* was the next highest priority followed by *Community consultation and engagement*. Both of the latter are key constructs and considerations for achieving a social licence to operate. This reinforces the importance of the social and cultural aspects in achieving new transmission upgrades regardless of whether they are overhead or underground.

Table 1. Key themes emerging from the workshop with relative priority ranking

Theme	No. of Supporting Statements	Mean	SD (Degree of consensus)
Social licence and impacts on landholders and communities	33	8.9	1.1
Minimising environmental impact	34	7.6	2.2
Community consultation and engagement	35	7.5	1.4
First Nations engagement and benefits, FPIC	12	7.2	2.5
Corridor selection and securing land access	11	7.2	1.6
Whole of life cost	10	6.7	2.9
Speed of delivery and need to build a lot	13	6.5	1.7
Building a smarter more resilient grid	6	6.0	3.5

Subject matter experts were engaged to undertake a peer review of the research. This inclusive approach aimed to address a broad range of issues and instil confidence in the report conclusions. The study first used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology to document the latest peer reviewed literature on the technical, economic, environmental, and societal considerations for the use of overhead and underground transmission infrastructure. This PRISMA review was supplemented by purposeful study of the latest CIGRE and EPRI reference books and reports, along with other grey literature and case study material, to ensure the findings were comprehensive. It was considered essential to adopt a life-cycle approach (from planning phase to end of life) to compare the trade-offs between overhead and underground transmission infrastructure. The findings are currently being shared with different representatives from the general public and their responses documented in the separate report (Focus Group Findings). Additional engagement with First Nations People, farmers and other stakeholders is ongoing and will be documented and shared subsequent to this report.

It is worth noting, the literature review and case studies for this research project were undertaken between February and July, 2023. The considerable developments in relation to social licence considerations, community engagement and opposition that have occurred in more recent months are not detailed in this report. For example, the findings from the NSW Parliamentary Inquiry, and the draft determination and rule change for enhancing community engagement in transmission building, proposed by the Australian Energy Market Commission (AEMC) are not detailed in this review. Although we note that a further Inquiry by a Select Committee in NSW was announced in September. Finally, we note that the Australian Energy Infrastructure Commissioner is also undertaking a review to “enhance community support and ensure that electricity transmission and renewable energy developments deliver for communities, landholders and Traditional Owners”. The findings from this scientific review are complementary, in highlighting the trade-offs across the technical, economic, social, cultural and environmental for transmission infrastructure.

2.

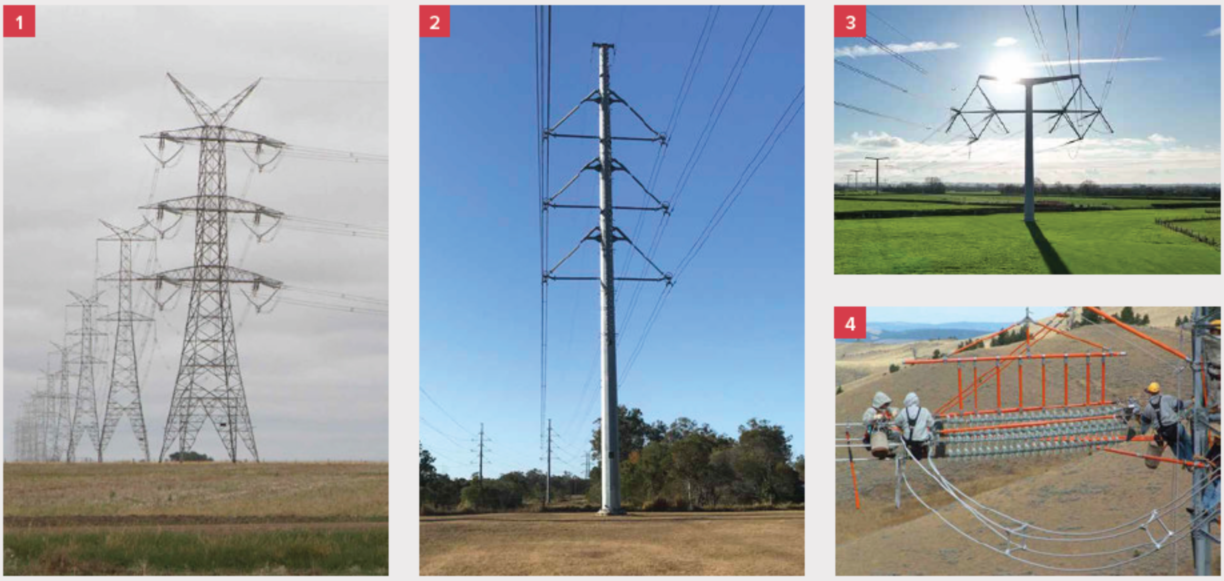
Technical Aspects

2.1 HVAC Overhead Transmission Lines

High voltage alternating current (HVAC) overhead line technology has been the dominant form of transmission infrastructure worldwide since the early twentieth century. This is because it has provided the most cost-effective and technically feasible system for constructing, operating, and maintaining a grid that meets high standards of safety and reliability. Overhead transmission lines have a service life of around 60 to 80 years with appropriate maintenance.

Examples of HVAC overhead transmission infrastructure are shown in *Figure 1*. The design and main components of a HVAC transmission line are described as follows:

- Transmission lines can be constructed as either a **single** or **double circuit lines**. Each circuit will comprise of a 3-phase set of insulators and conductors.
- The most common and cost-effective **tower structure** is the steel lattice construction type. The structures are constructed using prefabricated galvanised steel components which are assembled on-site and mounted on concrete **foundations** or footings.
- **Structure heights** vary from around 30m for 132kV lines up to around 70m for 500kV lines.
- There are two main types of tower constructions by function: (1) **Suspension towers** –with vertical insulator strings supporting conductors with no change in direction of the line, and (2) **Tension towers** – with horizontal insulator strings in both directions of the line from the tower. Tension towers are placed at the ends of long sections of conductors or at change in directions of the line. Tension towers need to have higher strength steel construction and concrete foundations to support the higher tensile loads.
- **Cross arms** are the sections that extend outward from the main structure and support the insulator strings for each circuit.
- **Insulators** support the conductors from the cross arms and ensure that the conductors are electrically isolated from earth including the steel work. Insulators are manufactured as either individual porcelain or glass discs which can be assembled into a string or alternatively a single composite material string. The length of the insulator string increases with system voltage.
- **Conductors** – are normally aluminium alloy or Aluminium conductor steel-reinforced cable (ACSR) which are lightweight and strong and can be strung at high tensions to minimise conductor sags. To increase the power transfer rating of a line **bundled conductors** held together with **spacers** are used. For example, 275kV lines are often designed with 2 conductors per phase. Quad bundled conductor is common for 500kV lines.
- Conductor **span lengths** between structures varies in the range of 200m to 600m depending on environmental, topography and line design requirements.
- **Earth wires** at the top of the structure shield and protect the line against lightning and voltage surges. Fibre optic cables can be integrated into special types of earth wires – Optical Ground Wire (**OPGW**) to provide a telecommunication channel.
- **Vibration dampers** can be attached to the conductors to reduce the effects of vibration fatigue caused by wind.
- **Corona rings** at the ends of insulator strings help provide a smooth surface to mitigate against an electrical phenomenon called corona discharge which can cause noise and electrical losses.



1. 500kV double circuit tension tower and suspension towers (Marcus Wong)
2. 275kV double circuit compact steel pole
3. 400kV T-Pylon structures (National Grid UK)
4. Live insulator change-out (North-Western Energy UK)

Figure 1. Examples of Overhead Transmission Infrastructure

Long overhead transmission lines require reactive compensation plant in the form of shunt reactors or Static Var Compensators (SVCs). The purpose of this equipment is to improve efficiency of power transfer and limit temporary overvoltage that occurs when a line is energised or switched out of service. The reactive compensation plant is usually installed at the line's terminal substations. Underground transmission cables also require reactive compensation, but the requirement can be much greater compared to overhead lines (refer section *2.2 HVAC Underground Transmission Cable*)

The design of a transmission line is a specialised engineering activity which provides an optimal solution for a route to meet functional requirements of power transfer, voltage, rating, and reliability performance based on many input parameters including technical and safety standards and environmental conditions such as ambient temperature, solar radiation, maximum wind loadings, lightning flash density, and ground conditions.

One of the fundamental requirements for overhead transmission lines is a land corridor which is normally secured by an **easement**. The easement width varies depending on the system voltage and other design requirements. An easement provides for construction and maintenance access, and vegetation clearing. Easements will have restrictions on certain activities or objects within an easement (mainly for safety reasons) but may allow some activities subject to conditions including grazing, agriculture, and certain types or size of vegetation. **Typical easement widths** vary from about 30m for 132kV lines to around 70m for a double circuit 500kV line.

Overhead transmission lines can be designed with more **aesthetic or compact structure**s. These include compact steel pole structures (see 275kv pole in *Figure 1*) or painted structures to better blend in with the local environment. Architecturally designed structures (e.g. T-pylons in *Figure 1*) can also be used. However, there are trade-offs in terms of additional cost, maintenance requirements and wider easements (where the structures are lower height with wider cross-arms).

Third party assets such as telecommunication facilities including antennas and repeaters can be co-located on transmission towers. Other non-metallic utility services including fibre optic telecommunication cables can also be installed on the transmission structures. These third party facilities are seen as providing additional potential benefits to communities.

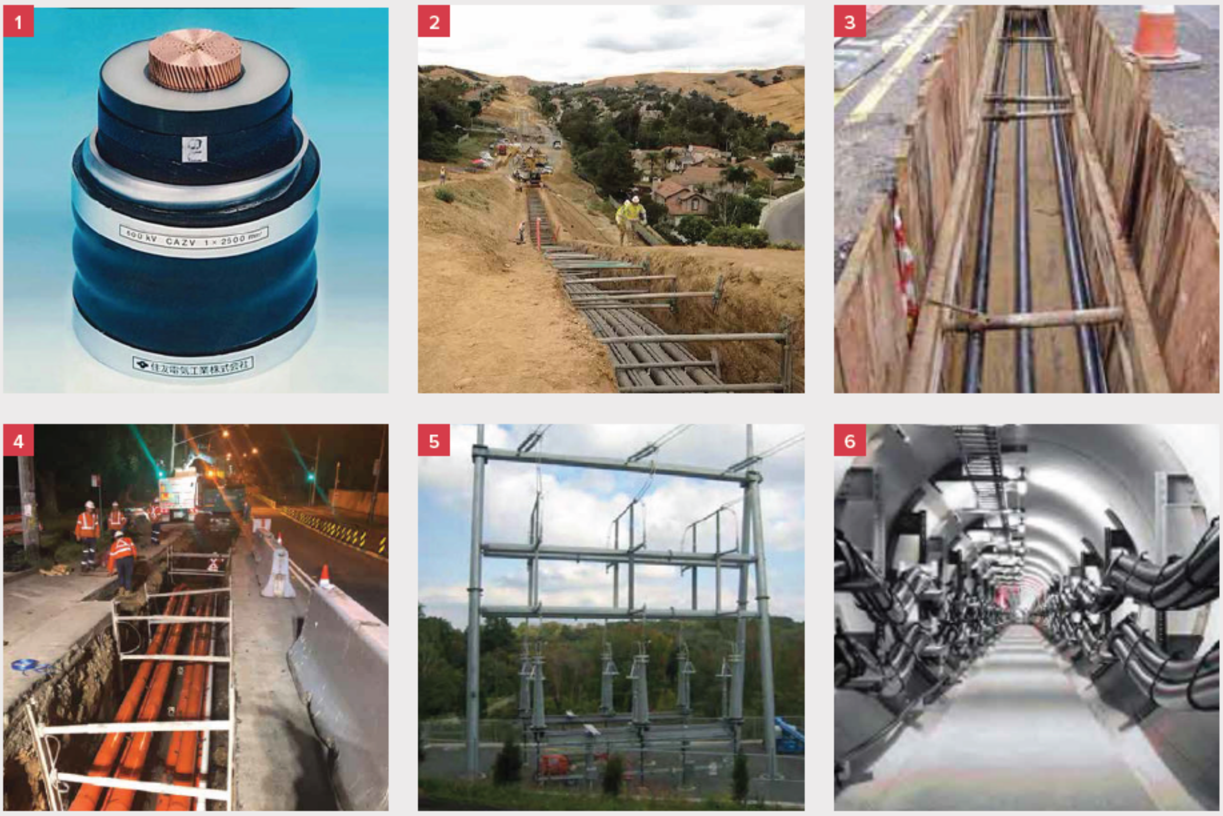
Metallic services or structures running parallel to a transmission line may be subject to induced voltages and currents which are a safety hazard and can also cause corrosion. In these situations, the design needs to be assessed for compliance with technical and safety standards.

2.2 HVAC Underground Cable Transmission

HVAC underground cable transmission infrastructure has primarily been used for short route sections where transmission lines need to traverse high density urban areas, areas where there is already a congestion of overhead lines or areas with environmental sensitivity or natural beauty. Typical underground cable transmission infrastructure is shown in *Figure 2*.

Cross linked polyethylene (XLPE) insulated cables is now the most common type of cable used in HV transmission, and was first widely used in the early 1980's (*Figure 2*). Each cable is one of a 3 phase set, and multiple 3 phase sets may be required to form a circuit depending on the power transfer requirement. The **conductors** used on underground transmission cables are predominantly copper because of the higher conductivity of copper compared to aluminium and its small cross-section required for the equivalent rating. For 500kV transmission cables, copper cross sectional areas of up to 2500mm^2 are common. These larger conductors result in less line losses compared to overhead lines. The cables can be designed to have integrated fibre optics which can be used for real time temperature sensing, with the benefit of increased power transfer capability.

A **technical limitation** with HVAC transmission cables is that feasible route lengths are relatively short compared to overhead lines, for example, of around 50km for 500kV. This is due to the significant charging currents and voltages associated with the highly capacitive HVAC cables. To counteract the resulting energy losses caused by this phenomenon, expensive reactive power compensation plant (e.g. shunt reactors) is required. XLPE cables are expected to have a service life of around 40 to 50 years.



1. 500kV XLPE cable (Sumitomo Electric)
2. 500kV cable installation (Southern Californian Edison)
3. 400kV direct buried cable (National Grid UK)
4. 330kV cable duct installation (Transgrid)
5. Overhead to underground transition station (Public Service Commission of Winconsin)
6. Cable tunnel installation (CIGRE 2017)

Figure 2. Examples of Underground Transmission Cable Infrastructure

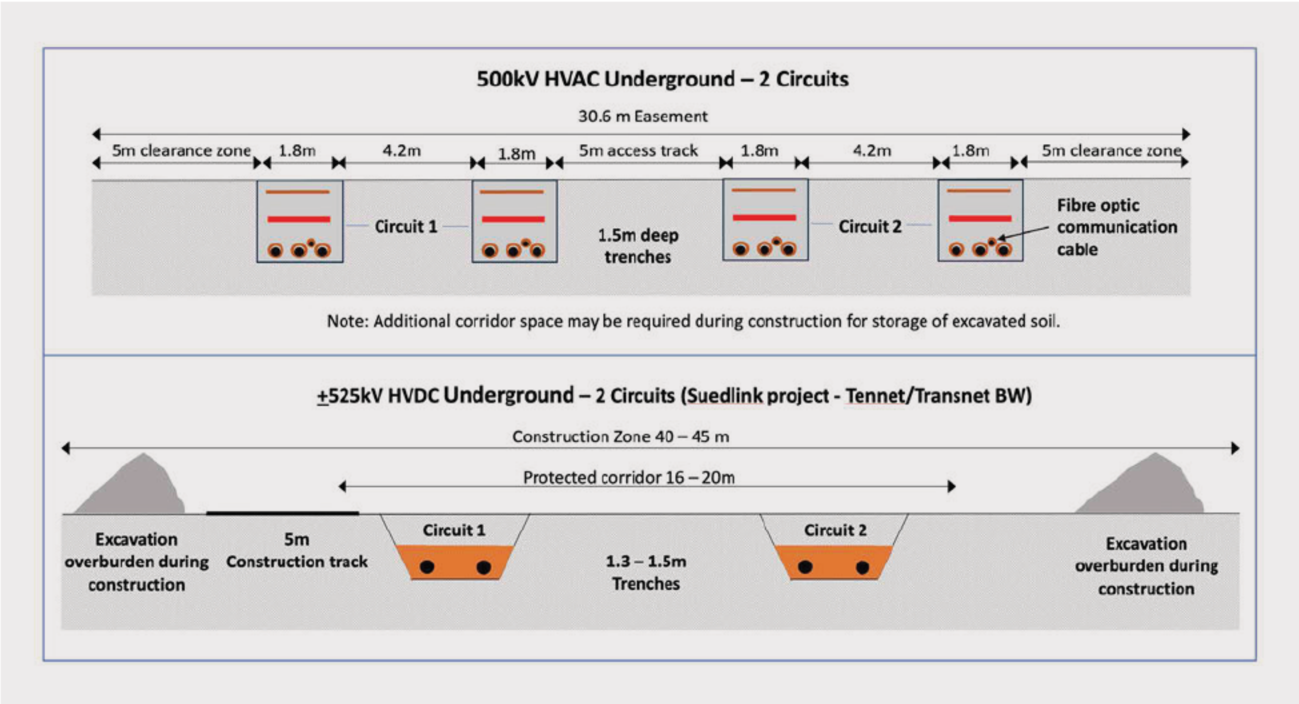


Figure 3. Examples of 2x2500MW 500kV HVAC and 2x2000MW +/-525kV HVDC underground cable installations

Cable installation methods are also shown in *Figure 2*. Transmission cables are normally installed in **buried conduits or ducts** in trenches around 1.2m to 1.5m deep. Duct installation provides more flexibility during construction as it minimises the duration of when trenches are left open which can be a safety issue and cause inconvenience to local communities. Cables are pulled into the ducts in lengths that vary between around 500m up to 1000m depending on the route constraints. Each section of cable must be jointed to the next section using specially designed joints and installed by highly trained specialist tradespersons. A lower cost method of installation is the **direct buried** method. Cables are laid directly in an open trench which is back-filled upon completion. Cable trenches, whether with duct or direct buried cable, need to be backfilled with special stabilised material which has low thermal resistivity compared to normal soil to optimise power transfer ratings.

Typical trench layout and configuration for a 500kV HVAC double circuit underground transmission line is shown in *Figure 3*.

It is common for telecommunication cables including fibre optic cables to be installed in a transmission cable trench. The fibre optic cable can provide distributed temperature sensing of the cable and provide telecommunication services, such as operational protection and control systems associated with the transmission line. Similar to overhead transmission, in some cases, there may be opportunity for **third party assets** - telecommunication cables to also be installed, thereby providing additional community benefits. “However there are often trade-off’s for co-located third party assets due to safety and operational limitations in safely accessing the assets for maintenance.”

A section of underground cable which forms part of a hybrid transmission line requires a **transition station** at either end of the underground section. Cable terminations are connected to the overhead line at these stations. A typical overhead to underground transmission transition station is also shown in *Figure 2*.

In high density city centres or areas with other constraints limiting excavation, specially designed cable tunnel installations may be required [10] (see example in *Figure 2*).

2.3 HVDC Transmission

High voltage direct current (HVDC) transmission is an alternative technology to HVAC overhead and underground systems for high power transfer over very long distances. HVDC transmission can be either overhead or underground cable. The main advantages of HVDC are that it provides for:

(a) High transfer power capability over long distances with lower line losses compared to HVAC.
(b) Interconnections between asynchronous AC grids or grids operating at different frequencies, for example between two regions or countries;
(c) Long offshore or onshore cable connections where the route length exceeds the feasible or critical route length for a HVAC transmission cable of equivalent power transfer capability; and
(d) More compact infrastructure "foot-print" requiring narrower land corridors – this is due to less conductors or cables compared to the equivalent rated HVAC overhead or underground line.

An example of HVDC underground installation configuration compared an equivalent HVAC underground line is shown in *Figure 3*.

The main disadvantages of HVDC transmission are:

(a) Requirements for large and expensive AC/DC converter stations at terminal connection points to the main HVAC grid. For example the converter stations for the Suedlink project will occupy around 7 hectares [1];
(b) Additional system losses from converter stations;
(c) Limited capability for intermediate connections along a transmission route. Although multi-terminal HVDC transmission schemes are an option, the requirement for any additional converter stations along a transmission route, tends to limit the economic feasibility of intermediate connections;
(d) Noise levels from the equipment at converter stations can be an environmental issue [2]; and
(e) Additional measures to mitigate increased corrosion risk with DC systems.

There are two main types of converter technologies used for HVDC-transmission:

- Line-commutated converters (LCC) based on thyristors; and
- Voltage source converters (VSC) based on transistors.

VSC-based converters have become the most used technology in recent years, particularly for applications such as offshore wind farm connections and grid interconnections. LCC technology is mainly used for very high power transmission with ultra-high DC voltages (800 kV and above) and overhead DC lines [11].

In Australia, only a relatively small component of the transmission grid is HVDC. This includes: (1) Basslink submarine cable connecting the Tasmanian and mainland grids; (2) Directlink (Northern NSW); and (3) Murraylink (Vic to SA). In other parts of the world, such as Europe, America, and Asia, HVDC has been used extensively for inter-regional transmission connectors, and offshore / onshore renewable zone interconnections. The transmission grid serving the Australian eastern states and territories is characterised as one of the longest in the world with generation and bulk supply to customers dispersed along the grid. As a result, the drivers for long point to point inter-regional connectors which become more economic for HVDC have been minimal. This is in contrast to countries with much higher population, energy generation load densities.

2.4 Electromagnetic Fields (EMF)

Electromagnetic fields (EMF) is the term used to describe the combination of electric and magnetic fields that are generated by electrically energised or charged objects, including power lines, cables, appliances, and electronic devices. These fields are present everywhere in our environment, including the Earth's natural magnetic field. There is much information available on EMF from many sources. Scientific research on the health effects of EMF from powerlines has occurred since the 1970s when concerns were first raised.

The electricity transmission and distribution industry in Australia has continued to monitor the scientific research, advice and guidelines from national and international organisations including Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), International Commission on Non-Ionizing Radiation Protection (ICNIRP), and the World Health

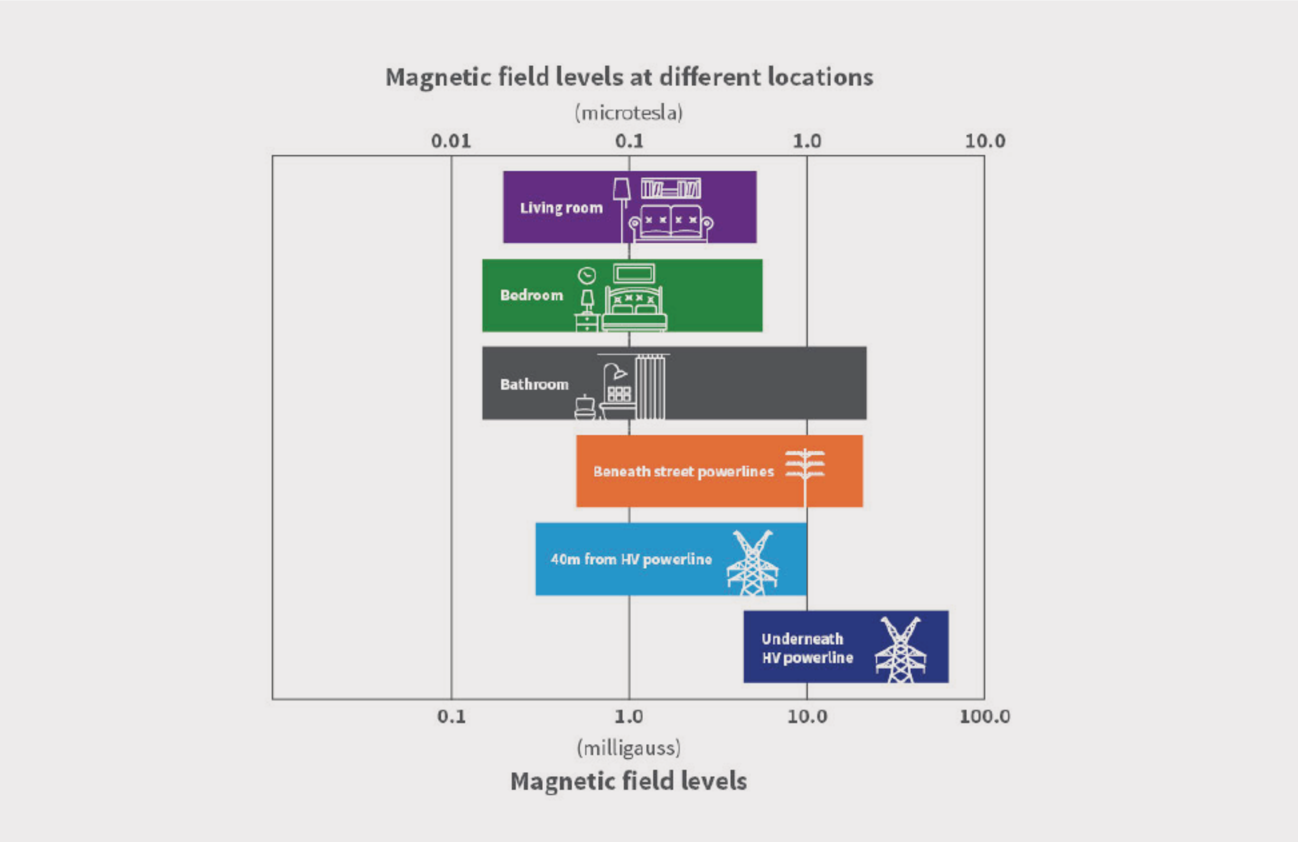


Figure 4. Comparison of Magnetic Fields from Household Appliances and Power Lines (ARPANSA[4])

Organisation (WHO).

ARPANSA provides advice on its website[5] that:

"The scientific evidence does not establish that exposure to extremely low frequency (ELF) EMF found around the home, the office or near powerlines and other electrical sources is a hazard to human health".

ARPANSA provides a comparison of magnetic fields from typical household appliances and transmission and distribution lines in *Figure 4*.

Australian TNSPs broadly adopt the approaches recommended by Electricity Networks Australia (ENA) as outlined in their handbook [12]. This includes adopting the prudent avoidance approach, also known as the precautionary principle, which is a guiding principle used in the management and mitigation of EMF near power lines. It emphasises taking proactive measures to reduce exposure to EMF, even in the absence of conclusive scientific evidence of harm.

There are various measures that can be incorporated in the design of transmission lines to mitigate or reduce EMF field levels. Most measures involve some trade-offs, but the cost of doing so is not usually significant. Such measures include (a) increasing the height of overhead conductors, (b) reducing conductor/cable spacing, and (c) transposition arrangement of phase conductor/ cables in a double circuit line to have a cancelling effect.

4 https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/electricity
5 Source: ARPANSA Electricity and Health, ARPANSA Extremely Low Frequency Electric and Magnetic Fields (www.arpansa.gov.au)

2.5 Comparison of Technical Performance of Overhead and Underground Transmission

A comparison of the key technical and performance factors for overhead and underground transmission is provided in *Table 2*.

Table 2. Comparison of Technical Performance Factors of Overhead and Underground Transmission

Factor	HVAC Overhead Transmission	HVAC Underground Cable	HVDC Transmission
Feasible maximum line route lengths	Overhead transmission lines can traverse long routes up to around 1000km.	500kV – 40 to 50km	Route lengths greater than 1000km are possible.
Auxiliary plant requirements	Overhead lines require less reactive compensation plant (per km) compared to underground cables	Reactive compensation plant such as shunt at termination points are required for underground transmission to counteract the more significant capacitive effects of cables compared to an overhead line	Reactive plant not applicable. HVDC converter stations are required at terminal points of the line.
Power Transfer Capacity	500kV - 2000 MW to 3000 MW per circuit	500kV – Up to 2500MW per circuit is feasible using multiple 2500mm² copper conductor XLPE cables	Typically, less than equivalent rated HVAC overhead or underground lines.
Corridor and easements	500kV double circuit - 70m	500kV double circuit - 30m to 35m Additional land requirements for overhead to underground transition stations must also be considered.	Typically, less than equivalent rated HVAC overhead or underground lines.
EMF (Electro Magnetic Fields	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 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.	DC magnetic fields are static and subject to higher reference limits (i.e., less onerous) compared to AC. **Overhead** - DC electric fields are static and subject to higher reference limits (i.e., less onerous) compared to AC. **Underground** - Electric field are contained within a cable with outer earth bonded metallic sheath. Design measures to ensure compliance with standard limits are applied.

Factor	HVAC Overhead Transmission	HVAC Underground Cable	HVDC Transmission
Reliability performance	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 - CIGRE 2010 [13]) 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 are longer duration than overhead lines due to excavation, cable jointing and electrical testing work required e.g., up to 4 weeks. [14]	Not Assessed in this study but would tend to be similar to HVAC overhead and underground given similar hardware and constructions.
Audible noise	Audible noise can sometimes be emitted from overhead transmission lines due to wind effects and (2) a corona discharge. However, these issues are addressed through appropriate design and maintenance.	No audible noise.	**Overhead** – similar to HVAC is dependent on voltage and size of conductors. Design measures are applied to ensure noise levels are within compliance limits. **Underground** – No Audible noise **HVDC converter stations** – noise will occur. This needs to be considered in the design and location of converter stations in order to minimise impact.
Construction timeframes	500kV double circuit, 100km 2 years	500kV double circuit, 50km 3-4 years	Similar to HVAC Overhead and Underground
Expected service life	60 to 80 years	40 – 50 years for XLPE cables	Similar to HVAC Overhead and Underground

3.

Economic Aspects

There have been many studies by government bodies, TNSP's, industry organisations and stakeholders comparing the cost of overhead and underground cable transmission infrastructure either generally or for a specific project. The UK Parson Brinkerhoff transmission costing study [3] is often referred to in the industry for its methodology when evaluating lifetime costs. This study concluded *"Cost ratios are volatile, and no single cost ratio comparing overhead line costs with those of another technology adequately conveys the costs of the different technologies on a given project. Use of financial cost comparisons, rather than cost ratios, are thus recommended when making investment decisions.*

HVAC Transmission - the cost ratio of HVAC underground to overhead transmission based on published literature including Parsons Brinkerhoff [3] and AEMO [4], are generally in the range of 3 to 20 depending upon many specific factors in a project. It is difficult to get accurate cost estimates for 500kV HVAC transmission infrastructure in Australia due to the lack of recent projects at this voltage, as well as current global and local economic factors influencing the cost and availability of resources. A lower cost ratio of 3 to 5, for example would tend to apply for the lowest cost option of direct buried underground, or long cable routes (with better economies of scale). A ratio of 5 to 10 would correspond to higher cost options of cable in ducts or for shorter lengths of underground cable. A higher ratio of 10 to 20 would tend to apply to more expensive cable tunnel installations.

HVDC Transmission generally becomes more economic for longer route interconnector transmission lines. HVDC overhead and underground lines are generally lower cost per km to construct compared to equivalent rated HVAC, but the significant costs of AC/DC converter terminal stations must be included in the total project cost. There is a "break even distance" for the cost of HVDC versus HVAC transmission. This is illustrated in the diagram by Stan et al., in Figure 5 [15]. The "break even distance" will depend on project specific parameters such as power transfer capacity, number of circuits, system voltage, converter technology, installation conditions and environmental factors. As an indication, based on data from Acaroğlu

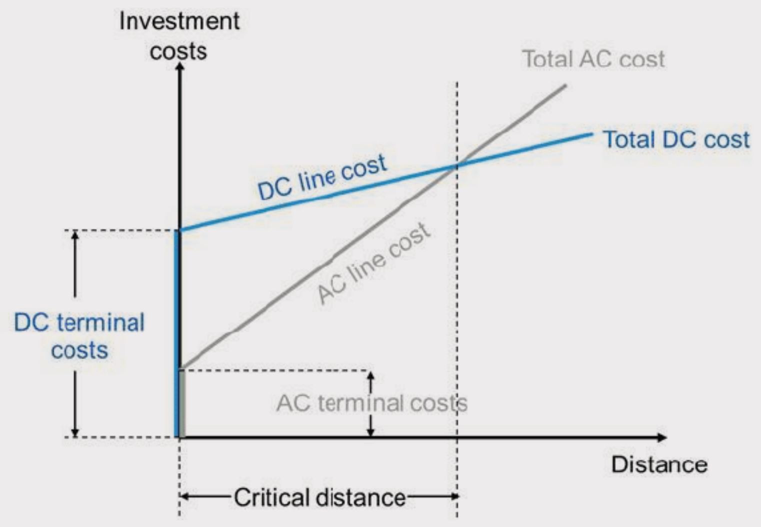


Figure 5. HVDC Transmission Line Economics (Stan et al [15])

et al [5], ABB [6], Amplitude Consultants [7], and the AEMO Transmission Cost Database, the break-even distance for HVDC overhead transmission is around 600 to 700 km when compared to a 500kV HVAC line. The cost ratio of HVDC underground to HVDC overhead is around 5, and the cost ratio of HVDC underground to HVAC overhead was 3.3 for a 1500MW, 1000km case study [5]. The Suedlink 2 x 2000MW 700km underground HVDC project in Germany is currently estimated to cost €11B EUR (2022) ($18.3B AUD) which is approximately $26.2M AUD per km.

The economic feasibility for application of HVDC compared to HVAC, ultimately depends on project specific requirements, factors and constraints which determine whether HVDC should be considered. Regulatory investment test requirements also need to be satisfied.

Current Challenges - There is no doubt that transmission infrastructure projects are facing several challenges as a result of global, national and local factors. For example, internationally, many countries have similar large scale grid expansion programs linked to renewable energy targets and will be competing for many of the same material and labour resources required in Australia.

Reports published by Infrastructure Australia [16] and AEMO [17] highlight additional challenges including:

- Demand driven risks having increased over the last 12 months
- Supply side risks have surged in 2021-22 and continue (COVID-19, Ukraine War, labour shortages)
- Increasing project costs and complexities
- The market is arguably at capacity, so project slippage is now expected
- Availability of skilled labour resources in the energy industry
- Delays in gaining approvals due to social licence issues and other factors which tend to exacerbate the cost challenges.

These issues have also been recognised in the recent recommendations from the UK's Electricity Networks Commissioner, *Nick Winser*[5]. In response to similar challenges the Commissioner made a number of recommendations to speed up the deployment of transmission infrastructure. Notable was to reduce the time for commissioning from twelve to fourteen years by half to reduce the burden of costs for society.

[5] Accelerating electricity transmission network deployment: Electricity Networks Commissioner's recommendations - GOV.UK (www.gov.uk)

4.

Environmental Aspects

The body of knowledge regarding overhead transmission line impacts on biodiversity has clearly grown over the years. However, while context dependent, it mainly points to overall negative impacts. Despite this, the quantification of the size, pathways and details of such impacts are still not well known. This shortcoming is reflected throughout the literature, with existing research largely failing to address cumulative impacts of transmission projects (combined with renewable energy projects), or pre- and post-installation impacts.

4.1 Potential Impacts and Mitigation

It is well documented that transmission lines can act as a physical barrier hindering movement across and along them for some animals. This is usually as a result of vegetation clearance for the required easements (overhead and underground) along with the physical presence (size, shape etc.) of transmission lines and towers. Such an effect can start as early as the construction phase and last throughout operation and decommissioning [18]. Mitigation measures proposed in the literature for overhead lines include the use of coloured line markers, different tower designs, and sounds to scare the birds away. [19]. On the flipside, one of the most recognised benefits of transmission lines for biodiversity is the use of the infrastructure itself, as a resource. Transmission towers provide a tall, permanent structure, mostly free of human interaction which makes them suitable for birds to perch, rest, hunt and nest.

Habitat loss and fragmentation are other key negative outcomes of the construction of transmission lines on the natural environment. The degree of fragmentation will depend upon the transmission voltage, the associated easement width, the type of tower for overhead transmission (lattice, tubular….), and the transmission infrastructure within the landscape, and their location within the landscape. [20]. Impacts can occur with mammals, birds, and amphibians due to altered movement patterns, isolation, and changes in population.

The clearing of vegetation for easements needed for the construction of both overhead and underground lines is likely to have a significant impact on wildlife habitats as well as cause changes in the microclimate by restricting the growth of plants and trees. Associated species including insects, birds and other mammals will thus experience secondary impacts as a result of these changes. However, the review reported mostly positive impacts being established within easements for overhead transmission, mainly because the sites under towers are often undisturbed for extended periods of time facilitating seed dispersal and plant development, being below bird perching sites, increasing biodiversity abundance. Where transmission lines are constructed in highly sensitive natural environments including watercourses, wetlands and national parks, special attention is required as any biodiversity effects would likely be heightened.

The generation of electromagnetic fields and noise from transmission lines, particularly overhead lines, has the potential to disrupt not only local communities when constructed near populated areas, but also the behaviour and health of some species including bats and pollinators. Knowledge on the extent of these impacts is less developed than other areas. However, it is an important factor to consider, given the significant role these species can play in an area's overall biodiversity and environmental stability.

Both underground and overhead options share some similar environmental costs although they each bear unique opportunities for positive outcomes when utilised in suitable areas. For example, while overhead lines are likely to create a barrier effect, causing changes in bird migration patterns as a result of collision and avoidance of the transmission lines, the selection of underground transmission cables in some areas would be able to somewhat mitigate this cost. In contrast, despite the high likelihood of soil degradation and hydrological alterations throughout the lifetime of underground HVAC lines, these impacts tend to only occur during the construction of overhead lines and so are much less significant for overhead transmission lines.

In this light, conducting due diligence into what is the most effective approach for each environment as part of the formal *Environmental Impact Assessment* can help to mitigate the overall negative impacts of a project. This includes understanding the geographical context to provide insights into the surrounding ecosystem and how exactly local flora and fauna will likely respond to the new transmission infrastructure. One example of this approach being beneficial comes from habitat conversion whereby a close understanding of the area being cleared has the opportunity to provide new significant ecosystems for a variety of species. However, to be successful, management practices that are tailored to the local context are required. A context dependent approach opens the opportunity for a more holistic attitude towards the environmental impact of a project. In this light, stakeholders understand not just how different aspects of the environment are affected, but how these aspects interact with one another to see the overall impact of a project.

Beyond the direct effect of transmission lines on the natural environment, projects must also consider how their construction is likely to impact archaeological and cultural heritage of the surrounding area. Given the potential impacts and the lack of literature predicting these effects, minimising and understanding the effects of a transmission line project must be a key priority in any new transmission line project's planning stage. The lack of studies considering the environmental impacts through an Indigenous lens and utilising traditional knowledge is a gap in the literature and more work in this area will provide a valuable perspective and understanding of other dimensions of environmental impacts.

4.2 Environment Impact Processes

Hand in hand with environmental impacts is the need for an Environmental Impact Assessment (EIA) - an essential and critical stakeholder engagement activity forming part of the approval process for a transmission project. The purpose of an environmental impact assessment is to systematically evaluate and understand the potential environmental, social, cultural and economic impacts associated with the construction and on-going operation of a project. The triggers, requirements and process for EIA's are stipulated in legislation which is generally similar in principle around the world.

The **Federal Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)**[6] and regulations are Australia's main environmental law. It provides a regulatory framework to protect and manage matters of national environmental significance including unique plants, animals, habitats and places. These include heritage sites, marine areas and some wetlands. The Act also protects listed threatened and migratory species [21]. It requires detailed assessments and surveys with a typical timeframe to complete the process being approximately two years.

The Queensland **Environmental Protection Act 1994**[7] is the key legislation in Queensland to manage and regulate environmental protection and conservation. Its primary purpose is to safeguard Queensland's natural environment, including land, air, water, and biodiversity. Environmental Impact Statements (EIS) is a key element of the Environmental Protection Act and is applied to evaluate and assess the potential environmental impacts of proposed activities, developments, or projects.

To streamline the process and avoid duplication between Federal and State regulatory processes, the Australian government and state governments, including Queensland, can enter into **bilateral agreements**. These agreements aim to harmonise and integrate the environmental assessment and approval processes between the Commonwealth (EPBC Act) and the state (Queensland's environmental legislation). In Queensland, the bilateral agreement applies to proposals that are ‘controlled actions’ requiring assessment under Part 8 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Controlled actions are defined in Section 75 of the EPBC Act. They include actions that are likely to have a significant impact on a matter of national environmental significance, or that involve a change in the population, distribution, or migration of a listed migratory species.

An EIA for a transmission project covers a range of factors and impacts that may arise during the design, construction, operation, or maintenance of the infrastructure including:

- project need, justification and feasibility, and any alternatives that have been considered
- a review of the planning laws and approvals which are relevant to the proposed infrastructure
- environmental considerations including the existing environment and any potential impact on factors such as biodiversity, flora, fauna, air quality, noise, waterways, vegetation, and soils
- matters of environmental significance in the area
- transport and traffic
- bushfire risk
- health and safety
- land use
- social considerations
- economic considerations including benefits such as local jobs
- current and future land use

[6] Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) - DCCEEW (www.dcceew.gov.au/environment/epbc)
[7] Environmental Protection Act 1994 - Queensland Legislation - Queensland Government (www.legislation.qld.gov.au/view/html/inforce/current/act-1994-062)

- visual amenity
- electric and magnetic fields
- cultural heritage – Indigenous and non-Indigenous
- the community and stakeholder engagement and consultation process
- the location of other infrastructure and industry
- the actions the proponent will take to manage and minimise environmental and social impacts that may result from the design, construction, operation, or maintenance of the new infrastructure.

For a transmission line project, the process starts with early engagement of key stakeholders to develop alternative solutions including route corridor options to inform the draft Terms of Reference for the environmental impact assessment. The regulatory requirements for environmental impact assessment process typically include the following formal stages[8]

1. Submission of a draft Terms of Reference (ToR)
2. Publication notification of a draft (ToR)
3. Final ToR issue – EIS in preparation
4. Public notification of EIS
5. Proponent responds to submissions
6. EIS Assessment report

[8] Types of EIS | Environment, land and water | Queensland Government (www.qld.gov.au)

5.

Social and Cultural Aspects

There is a large body of research that identifies frameworks that describe the key factors influencing a social licence and acceptance of transmission projects. All these factors are currently being observed in local community opposition to the proposed transmission projects in NSW and Victoria, resulting in significant project delays along with increased angst for the individuals involved. The weight of public concerns cluster around issues of **procedural justice** (is the process fair and transparent) and **distributive justice** (are the project benefits distributed fairly), as well as **trust** in the project developer. This clearly demonstrates that the public's response to transmission projects extends well beyond the physical features of the technology.

The literature also highlights that whether an individual feels positively or negatively towards a project and how they evaluate the balance of costs, risks and benefits will also affect their willingness to accept or tolerate it. Additionally, research by Devine-Wright, [22], [23], [24] suggests that rather than a "Not in my Back Yard" (NIMBY) response to a project, it is an individual's strength of **place attachment** (length of time in the place) and **place identity**, that if threatened by impending changes in their area, will influence their response to a project.

Regardless, public opinion is not static and the public's attitudes and responses will continue to be influenced by project related events throughout its life, but once formed can be difficult to change. This is particularly important in the context of the Australian cases, where opposition will likely travel across states, based on the shared identities of local land holders and communities, rather than solely on the techno-economic project properties.

5.1 Factors Influencing Social Licence and Acceptance

Given that each site has its own unique characteristics, the **context** in which a project occurs is very relevant to the social and cultural considerations of a project. Context considerations include not only on what has happened to that community in the past (either positive or negative) but also what is happening in the present along with the reputation and performance of the project developer. How the distribution of benefit and burden is perceived, is at the heart of distributive justice considerations. That is, it is often local host individuals and communities in **close proximity** to transmission infrastructure who bear the major burdens (**visual impacts, potential loss of livelihoods**, impacts on **property values**; **loss of tourism** etc.) and risks of projects (**human health** including concerns about EMF and noise impacts) while benefits are often realised far away in cities, or even globally when it comes to emissions reduction. To overcome the likely negative reaction to projects, **compensation** has been an important factor in positively influencing local host acceptance. This includes the expectation that neighbours are also included in considerations of compensation to ensure fairness in the process. Balancing individual and collective compensation will also influence acceptance of projects.

However, it is never solely about the financial incentives. Individual values strongly influence attitudes towards a project and ultimately its acceptance - the more open, transparent and just project processes are - will significantly help to build trust in the project developer. The literature was clear, trust in all entities and individuals, involved formally or informally in the process, effect overall acceptance. Other requirements included the need for adequate **information and knowledge sharing**, and the presence of good **governance** mechanisms to minimise any potential risks arising from projects and ensure adequate **engagement** and consultation.

Similarly, if the process of engagement has not been seen to be respectful, fair, and transparent then it is unlikely any amount of compensation will guarantee project progress. This was evidenced in the current Australian transmission projects where the *speed of delivery and the need to build a lot* has caused concerns for many stakeholders. For example, with the Humelink project, landholders complained about a lack of transparency around the proposed routes, with only those landholders who fell directly into the proposed route being first engaged. This meant there was limited information about what the project was about for the wider community. It resulted in complaints about the limited time to subsequently learn and engage with the project once it became more widely known and alternative routes were proposed. There was also a feeling that with the route selection already decided, it was a fait accompli and there was limited opportunity to provide any meaningful input into the selection despite their local knowledge.

Constraint mapping is an essential tool for transmission experts when route planning. Common constraint considerations include cultural heritage, endangered species, areas of environmental significance, population density, existing land use and so forth and are well documented in the CIGRE Report 147 [25]. A mix of qualitative and quantitative assessment is then undertaken to identify the most preferred routes. The list of constraints are usually shared with communities to build transparency in the siting process but also to identify if there are any additional local constraints that may have been overlooked by the proponent and need to be included in the constraint mapping exercise. To help build support for the final outcome, undertaking a weighting exercise, that brings together community and proponent preferences will help reach agreement on the preferred priorities for siting. While such processes can be exacerbated by individual preferences and values, such rigor goes some way in helping to gain broad community support for the final route selection 147 [25] p.26.

5.2 First Peoples' Impacts

The implementation of transmission line projects in Australia will also bring proponents and government, and in some locations, other stakeholders, into contact with First Peoples. First Peoples are fundamental rights-holders in many locations in Australia with approximately 60% of mainland Australia expected to soon be managed or jointly-managed by First Peoples. While transmission projects may impact First Peoples in ways similar to other groups of rights-holders and stakeholders, very little time and effort have been invested in understanding the impacts upon First Peoples. This is a substantial knowledge gap, given the typically marginalised status of First Peoples, and the situation-specific character of their connections to the world around them.

First Peoples may be impacted by transmission line projects in ways that differ to other rights-holders and stakeholder groups, as a result of fundamental differences in the perspectives, attitudes, responsibilities and behaviours of First Peoples individuals, groups and Communities to the wider Australian community. These may include:

- *Loss of species of cultural significance and important for subsistence,*
- *Compromising intangible sites* of cultural significance,
- *Degradation or destruction of tangible sites* of cultural significance,
- *Visual disruption* of the night sky,
- *Ecological impacts* associated with these losses rendering First Peoples unable to meet their cultural, social and personal responsibilities,
- *Social and personal health and wellbeing impacts and costs* associated with individual and collective losses that leave First Peoples unable to meet the social and personal cultural responsibilities
- *The weaving of transmission lines into contemporary stories and Songlines*
- *Declining opportunities for self-determination*, which exacerbate existing marginalisation of First Peoples as individuals and Communities.

Unlike planning to avoid health impacts where in most cases the application of prudent avoidance can be implemented without the need for a specific assessment, cases where First Peoples are potentially impacted will require comprehensive assessment of the tangible and intangible aspects of Country.

5.3 Principles for Collaboration and Engagement

Illustrating the importance of gaining social licence and acceptance, there are a multitude of guidelines that exist in Australia for engaging with communities on transmission and energy projects, with many more emerging. For example, the Queensland Farmers' Federation recently released their Renewable Energy Toolkit; The Energy Charter, The Landholder and Community Better Practice Engagement Guide which underpins their Better Practice Social Licence Guideline; and the Energy Grid Alliance, and Acquiring Social Licence for Electricity Transmission: A Best Practice Approach to Electricity Transmission Infrastructure Development. Internationally, the Renewables Grid Initiative provides a wealth of resources (videos, fact sheets etc.) and publications, that explain impacts and trade-offs for transmission infrastructure projects.

The First Nations Clean Energy Network *Best Practice Principles for Clean Energy Projects*[9] provides useful guidance for transmission line project proponents. They are not dissimilar to the social licence and acceptance

[9] Accessed from: https://www.firstnationscleanenergy.org.au/

factors for engagement and are intended to help ensure projects provide economic and social benefits and ensure Free, Prior and Informed Consent (FPIC) is secured for First Peoples as rights-holders, for the activities conducted. The 10 Principles are: “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; and Implement, monitor and report back.”

Already reflecting some of these principles, *Table 3* summarises the key recommendations for stakeholder engagement from CIGRE, 2017 [26] and enhances these with additional contributions from the PRISMA review.

[9] Accessed from: https://www.firstnationscleanenergy.org.au/

Table 3. Merging CIGRE, 2017 [26] Engagement Principles and Systematic Review Findings

Principles as per (CIGRE, 2017)	(CIGRE, 2017) - Recommendation	Enhanced Principles	Additional contribution from the PRISMA literature review
Approach to stakeholder relationships	Stakeholder engagement processes should be consistent and aim to build trust.	Approach to developing relationships	Highlights that consistency in collaborative protocols and processes across industry and economic sectors, combined with coordinated and efficient processes, can help to reduce engagement fatigue and frustration. Thus, improving the quality of the process for host communities, rights-holders, and the broader public.
Project scoping (Proportional approach)	The scope of stakeholder engagement for each project stage, must be defined including its objectives, constraints and limitations.	Project scoping (Proportional approach)	To minimise the contestation of the need for new OHTL and avoid compromising First Peoples' and other stakeholders' rights, early collaboration and engagement at the electricity system planning level is required.
Stakeholder identification	The stakeholder mapping and selection process needs to be consistent. Local stakeholders including those with specific community interests and those difficult to reach need to be specifically targeted. The engagement also needs to reflect an understanding of stakeholders' requirements and preferences.	Rights-holder and stakeholder identification	Culturally appropriate dialogue and clear communication of stakeholder and rights-holder mapping and selection processes is an integral part of the relationship building and engagement processes.
Start engagement early	Early engagement, i.e. during the formative stage, is valuable for knowledge creation including for subsequent engagement and for establishing the integration of stakeholders' input into routing and design.	Start collaboration and engagement early	The literature goes further and advocates for rights-holder and stakeholder collaboration at electricity system level planning and potentially even earlier when planning the transition to a low carbon economy. However, this is outside the scope of transmission company remits. Collaboration should ideally begin prior to the conceptualisation of a project.
Targeted mix of consultation/ engagement methods	Engagement methods need to be tailored to their targets and allow for regular engagement. A dedicated community liaison representative is suggested.	Targeted mix of methods for building relationships and engagement	Amongst other challenges, collaboration and engagement processes need to account for individual and community willingness and capacity to engage with the complexity of the electricity system and its governance, as well as the process more broadly. The literature emphasises the value of a single point of contact for stakeholders and rights-holders which can contribute to a more fair and just process.

Principles as per (CIGRE, 2017)	(CIGRE, 2017) - Recommendation	Enhanced Principles	Additional contribution from the PRISMA literature review
Create an open and transparent process	The scope of the engagement is transparent at each stage of the project and broadly communicated.	Create an open and transparent process	Transparency of the collaborative process and quality information provision contributes to procedural fairness and building trust.
Provide feedback to stakeholders (Monitor and evaluate)	A clear and transparent process is established to demonstrate and communicate how stakeholders' input was integrated into the project and provide rationale for inclusion and exclusion.	Provide feedback to rights-holders and stakeholders (Monitor and evaluate)	The literature shows that this step is amongst the most important, if not the most important, for building trust and fostering subsequent constructive engagement and participation.
Engagement should be proactive and meaningful	For engagement to be meaningful, it needs to have influence on the project outcomes. As such the scope of influence need to be clear and clearly communicated. Engagement should be proactive, accessible and inclusive.	Collaboration and engagement should be proactive and meaningful	Meaningful relationship building is paramount. Acknowledging that full consensus is unlikely to be reached even with best practice public engagement. Having a clear picture of "good enough" consensus and communicating it upfront improves transparency and perceptions of fairness.

6.

Case Studies

6.1 Current Australian NEM Project Stakeholder Engagements

The related factors necessary for achieving social licence and acceptance are highlighted and reinforced in the current Australian 500kV projects: Humelink (NSW), VNI West (Vic) and Western Renewables Link (Vic). A key finding from all three is the importance of recognising the context, both historical and current, in which the project is occurring.

Noting that project proposals and announcements, technology type, levels of communication and engagement, host individual and communities' knowledge and awareness of the technology, will influence the context and how the project is perceived. There were multiple findings from across the three projects. Key findings and observations include:

- The need to have clear justification for route selection, why the decision was made and to provide enough time for community members to understand the implications of the proposal.
- A sentiment by host communities in all three projects was that project coordinators were quite dismissive of the topic of undergrounding, including their sentiment regarding the long-term advantages of underground transmission. Many in host communities argued that the initial cost and time investment of undergrounding would be far outweighed by the significant benefits it offers.
- Community Consultant Groups were established to improve the dialogue between project proponents and local stakeholders.
- A lack of leadership at the local level, in some instances, meant that decisions were delayed and without clear communication, led to misinformation being introduced into the community.
- Indigenous groups raised concerns around construction ground disturbance directly disturbing and destroying archaeological artifacts and structures, along with vegetation clearance removing the protective cover and concealment of archaeological sites that could impede the ability to effectively protect the site during a fire.
- The proponents, sought expressions of interest for cultural heritage surveys which have now been conducted in collaboration with Registered Aboriginal Parties, providing valuable insights for assessing impacts and implementing appropriate mitigation measures.
- Impacts on health and safety included concerns about increased mental health and wellbeing - coupled to this were examples of engagement fatigue where people were being asked to engage in multiple processes, not only for transmission line projects but also renewable energy projects.
- The potential for increased bushfire risks was also raised as both a health and safety and environmental concern, in particular transmission lines hindering effective bushfire responses therefore increasing their risk of exposure in the case of a fire.
- There were significant concerns raised around the impacts on land use and property values including increased traffic on local roads, decreased tourism in some areas, impacts on farming operations and access.
- Alternative transmission technologies such as HVDC or hybrid HVAC and HVDC networks are being promoted by some stakeholder and advocacy organisations.
- A NSW parliamentary inquiry on undergrounding released its report in late August 2023, recommending that Humelink should proceed as an overhead transmission project. While Powerlink Queensland is progressing the Borumba Pumped Hydro Connection and Copperstring 2032, given the infancy of these projects when the review was undertaken, they were not included as case studies.
- September 13, a further inquiry by a Select Committee in NSW was announced and their findings are expected in March 2024.

6.2 International Case Studies

The six case studies are projects that have been completed or are currently in construction and include five overseas projects and one Australian project. The projects involve 400 and 500 kV HVAC overhead and underground, 330kV HVAC underground and one HVDC transmission project. Key findings include the importance of extensive community and stakeholder consultation, with on-going engagement undertaken to gain approval and minimise the risk of project delays and opposition. For example, the National Grid UK's document - the Preliminary Environmental Impact Assessment (PEIA) set out the preferred route, explained their methodology and identified the likely impact of the proposals on the environment from the beginning. This transparent approach was deemed by the proponent to help minimise opposition to the project.

Other factors that were considered to influence project success included the use of aesthetic overhead transmission line structures combined in some cases with the need for underground sections to be installed. The Hinkley Point Connection Project (UK) involved the replacement of an existing 132 kV lattice steel tower line with new aesthetic 400kV T-Pylon structures. The community had become used to the existing transmission line and the new structures were designed to be more aesthetically pleasing. In the case of the UK T-Pylons and in the Danish case, Thor-gi tubular steel structures were used; which are more compact with a lower height compared to traditional steel lattice towers for the same system voltage. The downside of these structures, however, is the greater width of the structures and larger easement requirements and land-use restrictions. Additionally, the proponents were prepared to underground 8.5 km of the route in an area, because it was recognised as an area of natural beauty. Case studies from Denmark (400kV) and California (500kV) also demonstrated the need for underground sections; ranging from 5.6km to 26km respectively. The rationale for underground sections were in response to community concerns, or political / regulatory interventions.

Appropriate compensation was also deemed a critical facilitator, particularly to farmers and landholders. For example, in Denmark the company, Energinet, established an agreement with the farmers' organisation on how to compensate farmers and landowners if overhead lines or underground cables are located on their property. Landowners adjacent to line were also eligible for compensation based on a proximity distance criteria scale.

The Powering Sydney's Future project is a 20km long 330kV underground cable transmission line, linking major substations in a heavily populated urban environment. The case study provides perspectives on managing a project that has significant impacts during the construction phase, affecting many diverse communities, major roads and local businesses.

The case study of the Baleh-Mapai 500kV transmission line in Sarawak involves a double circuit overhead line traversing 177km of mainly rural and remnant forest areas. The case study provides an overview of the project's detailed Environmental and Social Impact Assessment and stakeholder engagements with affected communities.

7.

Conclusions

1.

There is no doubt that transmission infrastructure projects are facing several challenges because of global and national factors. Reports published by Infrastructure Australia [16] and AEMO [17] highlight challenges such as:

- Demand driven risks have increased over the last 12 months.
- Supply side risks have surged in 2021-22 (COVID-19, Ukraine War, labour shortages)
- Increasing project costs and complexities
- The market is arguably at capacity, so project slippage is now expected.
- Availability of skilled labour resources in the energy industry
- Internationally, many countries have similar large scale grid expansion programs linked to renewable energy targets and requiring the same material and labour resources.
- Delays in gaining approvals due to social licence issues and other factors tend to exacerbate the cost challenges.

2.

HVAC underground cable transmission is feasible only for relatively short route lengths e.g. around 50km for 500kV. This is due to the high electrical capacitance of transmission cables which requires expensive reactive power compensation plant (e.g. shunt reactors) to counteract the resulting transmission impacts from this phenomenon.

3.

Case studies involving 400 to 500kV HVAC transmission lines in UK, Europe and USA demonstrated that to gain public acceptance and obtain regulatory approvals, undergrounding some short sections ranging from 5 to 20km was necessary in certain locations e.g. urban areas, areas with a congestion of existing overhead infrastructure, and areas of environmental significance or natural beauty. Visual impact was the main influencing factor. However, the picture is far more complex, as overhead and underground impacts and trade-offs require high levels of contextualised understanding and consultation with all stakeholders in order to potentially lead to social acceptance.

4.

It is difficult to get accurate cost estimates for 500kV HVAC transmission infrastructure in Australia due to the lack of recent projects at this voltage, as well as current global and local economic factors influencing the cost and availability of resources. The comparative cost ratio of underground to overhead construction is reported to vary from 3 to 20 depending on the type of construction, route length and other project specific factors [3], [4]. A lower cost ratio of 3 to 5, for example would tend to apply for the lowest cost option of direct buried underground, or long cable routes (with better economies of scale). A ratio of 5 to 10 would correspond to higher cost options of cable in ducts or for shorter lengths of underground cable. A higher ratio of 10 to 20 would tend to apply to more expensive cable tunnel installations.

5.

HVDC can be a feasible alternative to HVAC transmission for specific applications requiring high power transfer capacity over very long route lengths (i.e. several hundred kms depending on power transfer) that are point to point without intermediate connections. The economic feasibility for application of HVDC compared to HVAC, ultimately depends on project specific requirements including construction and environmental factors which determine whether HVDC should be considered. Regulatory investment test requirements also need to be satisfied.

6.

While TNSP's use constraint mapping internally to inform their route selection which includes checking in with the community that they have not overlooked local constraints, there is an opportunity to improve overall buy in for the final route selection by involving the community in weighting the importance of each of the constraints at the early planning stages and creating agreement for prioritising the various constraints. This can build community ownership of the final decision and ultimately minimise overall opposition to the project.

7.

There is a need for more consistent public education and information which explains in plain language: (1) Why we need to build more transmission infrastructure; (2) What HVAC and HVDC transmission infrastructure is; and (3) How transmission costs will be reflected in state capital borrowings and electricity bills – more transparent conversations around this at both the federal and state level should help increase the public's understanding of the trade-offs required.

8.

Context specific considerations also includes First Nations People and ensuring adequate engagement and collaboration with Traditional Custodians is in place from the start – the First Nations Clean Energy Network have published principles for engagement which provide an excellent basis for informing these processes.

9.

While there is an urgency to have projects built, stakeholders are requesting more time to understand the implications of the project. This suggests proponents need to build some flexibility into the project timeline and see it as an investment in the final outcome – the more open this process is the more likely it will lead to improved outcomes.

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SEPTEMBER 2023

1.

Comparison Table

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

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Contents

Acknowledgements

We would like to acknowledge the contributions of:

Susantha Wanniarachchi

For his help in seeking copyright for the images included in the document

Sheree Stokell

For her help in identifying the key literature for the environment section of this report

Members of Powerlink's Customer Panel

Who guided us through the research design elements of the project

Report Reviewers

Who generously gave up their time to provide much needed feedback on the report and chapters

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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