Submission No 35

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

Organisation: Energy Corporation of NSW

Date Received: 10 November 2023

EnergyCo

The Hon Cate Faehrmann MLC
Committee Chair
Select Committee on State Development
Legislative Council
NSW Parliament House,
Macquarie Street
SYDNEY NSW 2000

10 November 2023

Dear Ms Faehrmann

Thank you for the opportunity to provide a submission in the response to the Select Committee on the Feasibility of Undergrounding the Transmission Infrastructure for Renewable Energy Projects.

The Energy Corporation of NSW (EnergyCo) is a statutory authority responsible for leading the delivery of Renewable Energy Zones (REZs) as part of the NSW Government's Electricity Infrastructure Roadmap (the Roadmap).

The Roadmap sets out the NSW Government's vision to coordinate investment in electricity transmission, generation, storage and firming infrastructure and transform the NSW electricity system into one that is cheap, clean and reliable.

Under the *Electricity Infrastructure Investment Act 2020* (EII Act), EnergyCo has been appointed Infrastructure Planner for two priority transmission infrastructure projects (PTIPs) and the State's first five REZs in the Hunter-Central Coast, Central-West Orana, New England, South West and Illawarra regions. The minimum objectives in the EII Act are the construction of at least 12 gigawatts (GW) of generation and 2 GW of long duration storage by 2030.

EnergyCo is responsible for the planning and coordination of transmission, generation, storage and firming infrastructure in a way that benefits investors, consumers, and regional communities.

This submission sets out our views in relation to the feasibility of undergrounding the transmission infrastructure for renewable energy projects in relation to the inquiry's terms of reference.

If you would like to discuss the submission, please contact me at

Yours faithfully,

Andrew Kingsmill
Executive Director, Technical Advisory Services

EnergyCo

Inquiry on the feasibility of undergrounding the transmission infrastructure for renewable energy projects – The Energy Corporation of NSW Submission

Friday, 10 November 2023

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1. Background

The Energy Corporation of NSW (EnergyCo) is a statutory authority established under the *Energy and Utilities Administration Act 1987* and is responsible for leading the delivery of Renewable Energy Zones (REZs) as part of the NSW Government's Electricity Infrastructure Roadmap (the Roadmap).

The Roadmap sets out the NSW Government's vision to coordinate investment in electricity transmission, generation, storage and firming infrastructure to transform the NSW electricity system into one that is cheap, clean and reliable.

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2. NSW Energy System Context

Need for transmission infrastructure

For decades, electricity generation in NSW has been delivered primarily by a fleet of large coal-fired power stations. The existing transmission system consists of a network of high voltage alternating current (HVAC) overhead lines that were built to transport this electricity to where it is used around the State. As existing power stations retire, and the State transitions away from coal-fired generation, new transmission will be required to connect areas of high renewable resource to the existing grid, such that the new generation can be transmitted to where it is used around the State and shared between states.

The best onshore renewable energy resources in NSW are principally located along and west of the Great Dividing Range (Figure 1 and Figure 2). The Australian Energy Market Operator (AEMO)'s 2022 Integrated System Plan (ISP) has identified significant investment in transmission infrastructure to connect these areas as part of the optimal development path in the National Electricity Market (NEM), to maintain the security and reliability of electricity supply and deliver emissions reduction.[1]

[1] AEMO, *"2022 Integrated System Plan (ISP)"*, June 2022

The transformation of the NSW electricity system is considered in more detail in the Network Infrastructure Strategy (NIS) published by EnergyCo in May 2023. The NIS identifies 14 GW of new transmission to be delivered as soon as practicable over the next decade (by 2033). A further 3.6 GW of transmission infrastructure is recommended to be secured now for delivery by 2043, with another 6.4 GW identified under a strong electrification scenario between 2033 and 2043.

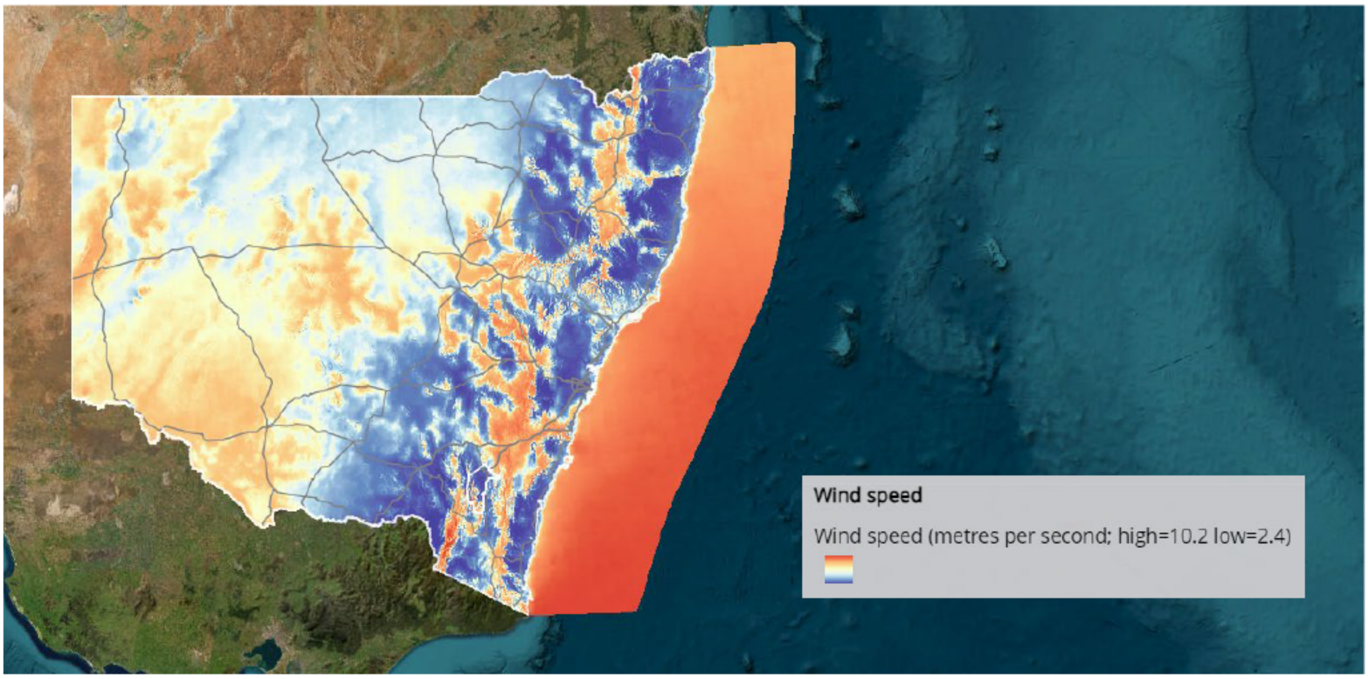

Figure 1: Wind resource availability in NSW[2]

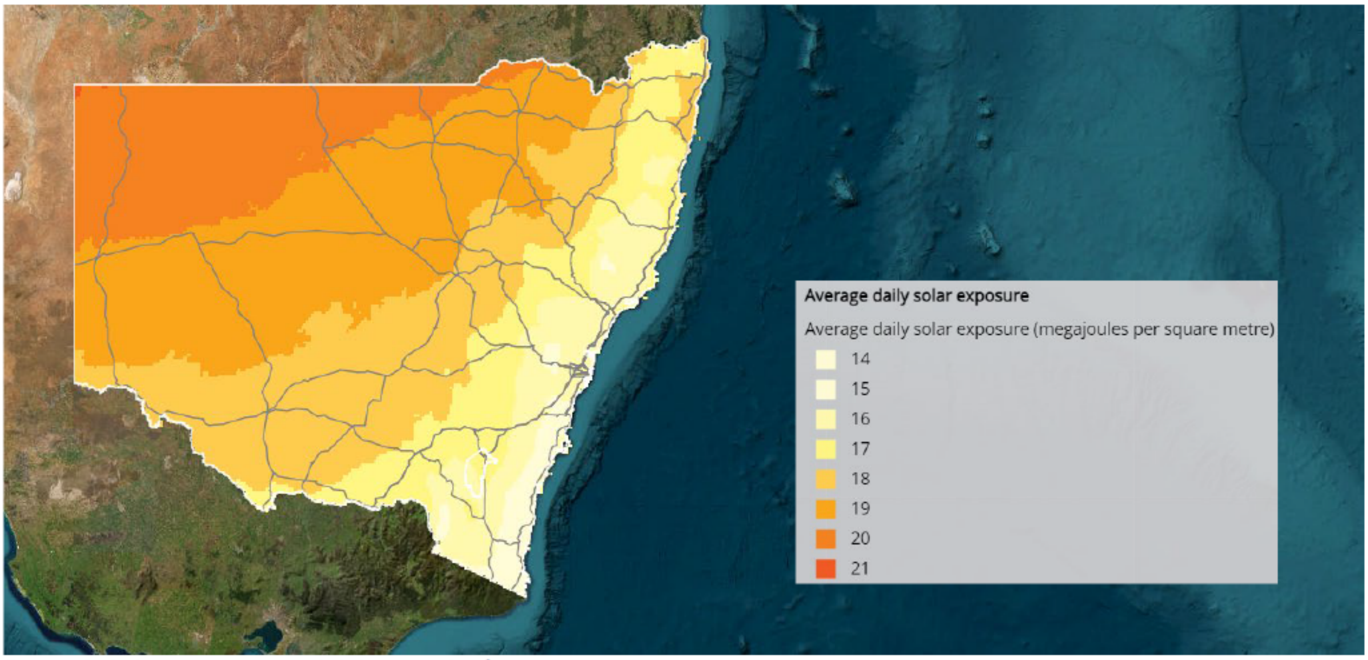

Figure 2: Solar resource availability in NSW[3]

[2] Data courtesy of the SEED database *[https://datasets.seed.nsw.gov.au/dataset/map-of-renewable-energy-resources-of-nsw]*

[3] *Ibid.*

NSW transmission overview

Transmission infrastructure operates at high voltages, and is used to transport electricity in bulk over long distances. Historically, almost all transmission infrastructure in NSW has been constructed as high voltage alternating current (HVAC) overhead lines, typically at voltages of 132 kilovolts (kV), 220 kV, 330 kV or 500 kV, depending on capacity requirements. Extra high voltages[4] are used over long distances to minimise electricity losses in transmission. Transmission lines are located on an easement, a corridor of land held by the State through the relevant Network Service Provider (NSP). Easement corridors provide "right of way" access for construction, operation, maintenance, and public safety. They span the entire length of the transmission line, and are generally maintained to ensure trees and other structures do not interfere with the safety or functionality of the network infrastructure.

Underground transmission in NSW

While overhead lines are typically used for high voltage transmission, there are particular circumstances in which underground cables may be more appropriate. Overhead transmission lines are more common globally as they balance the considerations of cost, risk, reliability and transfer capacity. Underground transmission is used in cases where it is not feasible to secure a corridor for overhead lines, such as in already developed urban areas or undersea. While underground or underwater cables offer less visual impact than overhead lines, at extra high voltages they have significantly higher capital and repair costs, materially longer construction and repair times and lower transfer capacity compared with overhead lines. These features become more material at higher voltages, and generally make underground cables unsuitable and less efficient for widespread application.

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3. Physical Challenges of Undergrounding Transmission Infrastructure

Underground transmission cables are larger and heavier than equivalent capacity overhead lines. They are typically installed in large, deep trenches, and require significant volumes of spoil to be removed and large volumes of thermal backfill to be installed in the trenches for heat dissipation.

Underground cable attributes and construction

When undergrounding transmission infrastructure, cables are typically placed in trenches, rather than strung on poles, and buried using thermally suitable engineered fill. Underground transmission cables are typically installed on mostly flat routes or slightly hilly terrain, limited by the bending radius (how sharply a cable can turn or bend).

Underground cables suitable for delivering power at the voltages required for long distance transmission are much larger than the conductor or wire used in overhead lines, and more complex to install. A typical 330 kV underground cable is approximately 160 mm in diameter, with a weight of approximately 40 kg/m and a bending radius of approximately 3.2 m.[5] For 500 kV, the cable has a diameter up to approximately 180 mm and a bending radius of up to 4.5 m.

Underground transmission trenches contain mechanical protection and thermal backfill which serves to conduct heat away from the cables, and typically takes the form of a low-grade concrete slurry.

Due to the poor heat dissipation capabilities of engineered fill as opposed to open air, the transfer capacity of underground cables is less than the equivalent cable in an overhead context. For high

[4] Extra high voltages are considered as voltages 330 kV and above.

[5] *https://www.cablegrid.com.au/wp-content/uploads/2019/03/Technical-user-guide-of-high-voltage-XLPE-cable-systems.pdf*

capacity transmission, multiple circuits are needed to meet the same transfer capacity as an overhead line.

For a typical greenfield REZ connection that would use four 500 kV overhead lines, an underground cable solution of the same capacity would require 5-10 underground cable circuits (comprising 15-30 total cables). Each cable trench would be typically 1-2 m deep and 2-5 m wide per circuit. Figure 4 shows a sample trench and easement for this arrangement. This example shows a 41.6 m operational easement width, with additional easement required for construction and major repairs. Such significant trenching requires an extensive quantity of engineered backfill and creates large volumes of spoil (excavated trench material). Section 7 provides more information on trench and easement widths and associated environmental impact.

Figure 3: Underground cable infrastructure[6]

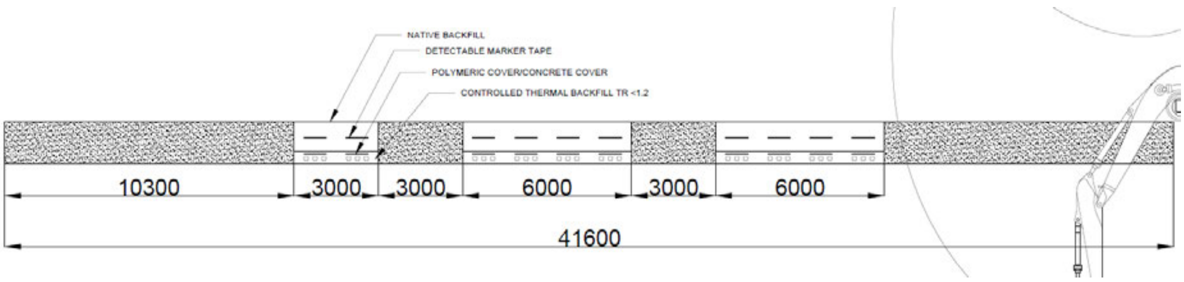

Figure 4: Indicative easement width for underground cables for a typical greenfield REZ[7]

Installation

The installation of underground transmission is a major civil undertaking, owing to the weight of the cable and the scale of trenching involved. 330 kV and 500 kV cables are typically directly buried as seen in Figure 3, with a bending radius of up to 4.5 m. Installation of these cables over complex terrain can be extremely challenging. Ground slopes in excess of 30% are unsuitable for a standard trenched setup, requiring the use of bridging, tunnelling or under boring. Trenched routes must contend with rivers and lakes, roadways and heritage areas. Each of these obstacles would require route deviations, which are further complicated by the large bending radius of the cables.

Comparison with distribution applications

Distribution networks operate at lower voltages, typically between 11 kV and 132 kV. Undergrounding of distribution lines is common, as they are much smaller than transmission lines due to the lower voltage, and do not have the same complexities as underground transmission. This is typically done in some urban areas, particularly where crossings of roads or existing overhead lines are required. A typical underground 11 kV cable might be 36 mm diameter and weigh 2.8 kg/m,

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[6] Moorabool Shire Council, *"Comparison of 500 kV Overhead Lines with 500 kV Underground Cables"*, September 2020. *Figure 38*

[7] RLB, "*New England REZ (High Level Cost Estimate for Undergrounding)"*, 10/11/2023

with a 590 mm bending radius.[8] With a mass of less than 10% that of a transmission-scale cable, underground installation of distribution lines is simpler than transmission, and easements are narrower due to the lower voltage levels.

Comparison with overhead lines

Overhead transmission networks consist of towers or poles with metal conductors, or wires, strung between. Transmission towers are typically steel towers 40 m to 80 m high and spaced around 500 m apart (subject to the terrain). They typically carry one or two electrical circuits, with one circuit of HVAC consisting of three bundles of conductors (one for each phase). The conductors in each circuit are arranged spaced apart from each other, either horizontally for one circuit or vertically for two circuits.

A standard winch arrangement used to string overhead lines requires much less labour, and often much less local disturbance, than the underground alternative. Overhead lines can address terrain concerns by strategically siting the tower locations and stringing conductors to avoid complex or sensitive terrain.

Easements for overhead transmission lines can be 45-80 m wide, depending on the tower design and line requirements. These easements are typically cleared of tall vegetation and structures, although in some cases, such as where lines span deep gullies, clearance is not needed except directly around the towers.

International context

Use of underground and underwater transmission infrastructure is increasing internationally, primarily driven by a large increase in offshore wind projects. There has been limited movement at a government level to encourage undergrounding of transmission projects. Germany has passed legislation which gives priority to underground technology for new transmission in some (but not all) cases.[9] The Netherlands has passed legislation to 'fix' the total quantity of overhead transmission, requiring every new kilometre of overhead line be offset by undergrounding a kilometre of existing overhead line. Currently these are the only two nations worldwide to have taken these actions. These nations operate in a substantially different context to NSW with much greater population densities, lesser overall land area and a higher number of electricity consumers over whom to allocate the cost.

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4. HVAC or HVDC Infrastructure

High voltage electricity can be transmitted using either alternating current (AC) or direct current (DC). The costs, technical performance, and typical applications of undergrounded HVAC and High Voltage Direct Current (HVDC) differ significantly. Both technologies are unsuitable in complex or sensitive terrain such as rivers, cliffs and aboriginal heritage sites, while overhead transmission can more readily avoid or minimise impacts on these features.

Underground HVAC technology has been used for many years throughout Australia for short cable lengths in certain terrain, particularly urban areas. The Powering Sydney's Future project in Sydney is an example of the use of underground HVAC technology. This project features a 20 km underground 330 kV link between Potts Hill and Alexandria in metropolitan Sydney, rated at 750

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[8] *https://www.prysmiancable.com.au/documents/copper-6-3511-kv-single-core-heavy-duty-screened-unarmoured.pdf.* Numbers for 185mm^2 CSA Cu cable

[9] This legislation applies only to new HVDC transmission links. There is currently no German legislation mandating the use of undergrounding for HVAC transmission.

MVA.[10] Installing this cable overhead would have been untenable due to the high population density and existing infrastructure – an underground solution allowed for the transmission line to be installed in a constrained corridor. The relatively short distance meant that HVAC technology was appropriate, as the cable connects to existing HVAC networks at both ends and the 20 km distance is not long enough to require reactive power compensation along the length of the cable.

The vast majority of existing transmission in Australia is HVAC, allowing for easy integration of new lines with the existing network. HVAC technology allows for 'meshing' of a network, where multiple lines are connected or 'meshed' together to robustly interconnect generators and loads, connecting via 'cut-ins'. This 'meshing' is key to the reliability and resilience of the power system.

Due to the capacitance of HVAC cables, reactive power compensation is required at regular intervals.[11] The exact interval varies with factors such as fault level and cable capacity, but is typically no greater than 40-50 km for 500 kV lines and 80-100 km for 330 kV lines. This reactive power compensation is provided via above-ground equipment. The longest existing 500 kV underground HVAC link is the Shin-Toyosu Line in Tokyo, measuring 40 km.[12]

Underground HVDC technology is newer and less widely used in Australia, and has both advantages and disadvantages. HVDC does not require reactive power compensation, allowing for longer cable runs. DC transmission has lower losses compared to underground HVAC, as it does not suffer from the skin effect, where alternating current mainly flows in the surface of a conductor.

However, HVDC technology requires complex power electronics at both ends of every line to convert the power from AC to DC. In addition to being expensive, these converter stations are incompatible with 'cut-ins' to allow the connection of future generators, do not allow practicably for meshed network configurations such as in REZs and are uneconomic in networks with large numbers of short connections. This is due to the large number of DC/AC converter stations which would be required, the insufficiency of existing DC circuit breaker technology to support high levels of meshing, and the cost. HVDC is limited in its ability to share ancillary services that are required for the stable operation of the power system, such as system strength and inertia, likely leading to a requirement for additional dedicated assets to provide these services.

A 2023 Aurecon white paper on undergrounding transmission infrastructure in Australia found that "To date, DC transmission is only feasible for point-to-point connections, because it cannot easily accommodate intermediate connections…. The majority of new transmission projects have to facilitate intermediate connections as a key requirement from the electrical network, which makes HVDC (underground or overhead) unfeasible."[13]

For these reasons HVDC technology is typically used for point-to-point electricity transfer and undersea applications over long distances (typically over 400 km). The proposed Marinus Link project is a key example of this, proposing HVDC technology to connect Victoria with Tasmania via the Bass Straight.

Implications for REZ Projects

REZ network infrastructure projects are typically highly meshed and include route lengths of 100-200 km or less, making them impractical for wholesale application of either HVAC or HVDC underground technology. Australian Energy Infrastructure Commissioner, Professor Andrew Dyer, recognised this at the inquiry into *Feasibility of undergrounding the transmission infrastructure for*

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10 Transgrid, "*Transmission Annual Planning Report*", 2022, p.45

11 Aurecon White Paper, "*High Voltage Overhead vs Underground Transmission Infrastructure (330kV and 500kV)*", 2023, p5

12 *https://www.fujikura.co.jp/eng/rd/gihou/backnumber/pages/__icsFiles/afieldfile/2008/10/10/32e_06.pdf*

13 Aurecon White Paper, "*High Voltage Overhead vs Underground Transmission Infrastructure (330kV and 500kV)*", 2023, p6

renewable energy projects, stating that "*if the requirement is to tap in and add projects along the way, you're limited sensibly to do above ground."*[14] The following sections detail considerations that, in EnergyCo's view, make overhead lines the more suitable option for transmission in the REZs.

5. Operational Reliability and Maintenance

Underground cables require ongoing maintenance to ensure they continue to function effectively. When cable failures occur, average repair times are significantly longer than those for overhead lines. The average downtime of an underground cable is typically greater than that of an overhead line.

While underground cables are more protected from the elements, the comparative difficulty of repair and maintenance activities means that operating costs for underground cables are typically the same or greater than those for overhead lines. Repair times are significantly longer at 1-3 months, and require specialist international labour. Overhead lines, by contrast, can typically be repaired in 1-2 days using local workforces. The European Transmission System Operators organisation stated in a 2003 undergrounding report that "For an underground cable, it takes more time to locate and repair a fault, on average 25 times longer than it does for an overhead line. The experience shows that the repair duration of cable damage requires between two weeks and 2 months depending on the technology and location of the fault."[15] Unavailability data recorded by the UK National Grid corroborates this noting the unavailability of 0.126 hr/km/year for overhead lines and 6.4 hr/circuit km/year for underground circuits.[16]

Many submissions to the previous parliamentary inquiry into the feasibility of undergrounding transmission infrastructure made comments that underground cables are 'maintenance free'. In reality, underground cables require links approximately every 500-1000 metres, where one drum of cable is joined to the next in joint boxes. These joint boxes are approximately 6 metres x 3 metres x 2 meters and the links require maintenance, as does other plant and equipment (e.g. AC/DC converter stations required for HVDC technology or reactive power compensation equipment required for HVAC technology). Figure 5 provides an example maintenance schedule for a HVDC project.

[14] NSW Parliamentary Inquiry, "*Feasibility of undergrounding the transmission infrastructure for renewable energy projects*". Hearing Transcript from 18/7/23, p.19

[15] European Transmission System Operators organisation, "*ETSO Position on use of Underground Cables to develop European 400kV networks*", Jan 2003

[16] Institution of Engineering and Technology, "*Electricity Transmission Costing Study*", 2012, p.238

Activity	Asset	Schedule
Non-outage scheduled maintenance	Converter stations	Quarterly
Outage scheduled maintenance	Converter stations	Twice/year
Outage scheduled maintenance	All links	Year one then every two years
Mid-life refurbishment	All links	Year 10, year 20 and year 30
Cable surveys and works	Cable stores	Every two years
	Cables	Seabed surveys in year two, year four and then every six years Remediation work every six years or as required

Figure 5: Proposed Marinus Link Maintenance Schedule. Marinus Link is proposed to contain an 80 km landed underground section.[17]

Underground cables are highly sensitive to ground movement, which can stretch and damage the cable. Any cable damage caused by these events would have lengthy repair times.

The average lifetime of underground cables is approximately half that of overhead lines, at 40-50 years for underground cables compared to 75-100 years for overhead lines. The Murraylink cable, for example, has a design life of 40 years.[18] This shorter lifespan results in increased cost, community and network disruption when these assets reach end of life.

Reliability case study: Basslink

In 2015 – 2016 the Basslink HVDC underground cable connecting Victoria to Tasmania experienced a six month outage. Combined with energy limitations within the state, this caused significant electricity supply shortfalls in Tasmania as a result of being isolated from the interconnected NEM. Managing the shortfall of supply for such a long period required the re-commissioning of a gas plant at Tamar Valley, installation of emergency portable diesel generators, and a 180 MW load reduction for major industrial customers. The repair time for the cable was originally quoted as 60 days, but repair work proved more difficult than expected and the timeframe eventually stretched to almost six months.

Overall underground cable reliability

The International Council on Large Electric Systems (CIGRE) has published fault statistics for underground power cables. These statistics suggest that "for a cable system over the full 75 km, it can be expected that there will be, on average, a fault every 9.5 months. Therefore, the forced outage rate is calculated as 0.79 incidents per annum. This is mainly due to the large number of joints required."[19]

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[17] *https://www.marinuslink.com.au/wp-content/uploads/2023/03/Community-and-Stakeholder-Information-Pack-Spring-Marinus-Link-2022-Web.pdf*

[18] *https://www.apa.com.au/globalassets/our-services/other-energy-services/electricity-interconnectors/oakley-greenwood----stakeholder-engagement---proposed-method.pdf*

[19] Moorabool Shire Council, *"Comparison of 500 kV Overhead Lines with 500 kV Underground Cables"*, September 2020.

Directlink's annual performance report (2022) notes similar performance to that predicted by CIGRE, quoting a '5-year average annual' failure rate of their underground transmission conductors of 7.6, over 366 km of line.[20] These proposed failure rates are comparable to those of overhead lines.

6. Construction and Procurement Timeframes

The current market for underground cabling is extremely tight, creating significant procurement challenges. Installation timeframes are also typically substantially longer, owing to the extent of trenching required and specialist procedures required to lay heavy cable without causing cable damage. Overall this means that meeting the proposed REZ energisation dates using underground cable technology is unlikely.

The current global demand for HVDC equipment and cabling is orders of magnitude higher than historically, primarily driven by the offshore wind industry. This has extended lead times, with forecasts indicating demand exceeds available manufacturing capacity over the medium term. Manufacturers are responding with significant investment in both new factory capacity and submarine installation vessels, however this is not forecast to completely address the supply imbalance for the foreseeable future. European demand has grown enormously in recent years, driven by the push to net zero and Government action to improve energy security in response to the war in Ukraine. As well as interconnectors, offshore wind farms in particular have driven up demand, as undersea cabling is the only option for the connection of these generators. Supply chains were heavily impacted by the COVID pandemic, with constraints and delays evident in valve semiconductor raw materials, converter power transformers, control and protection equipment and specialist HVDC engineering resources.

In the current market, commercial mechanisms such as 'framework agreements', 'capacity reservation agreements', 'preferred supplier status' and long lead time equipment deposits/payments are being used by project proponents to secure equipment supply providing certainty of timeframes to maintain project schedules. The Marinus Link project has recently entered into a stage 1 capacity reservation agreement with a cable supplier whilst the tender evaluation and negotiation process continues with the prequalified suppliers. This was necessary to secure an option for cable availability for the project which is scheduled to undergo final commissioning in 2029/30. Across the market the experience is similar, with cable lead times in the order of 5-7 years compared to the previously expected 3 years.

Costs of cables have increased materially, with Marinus Link experiencing increases in cable supply costs consistent with broader cost increases in transmission and renewable generation equipment.

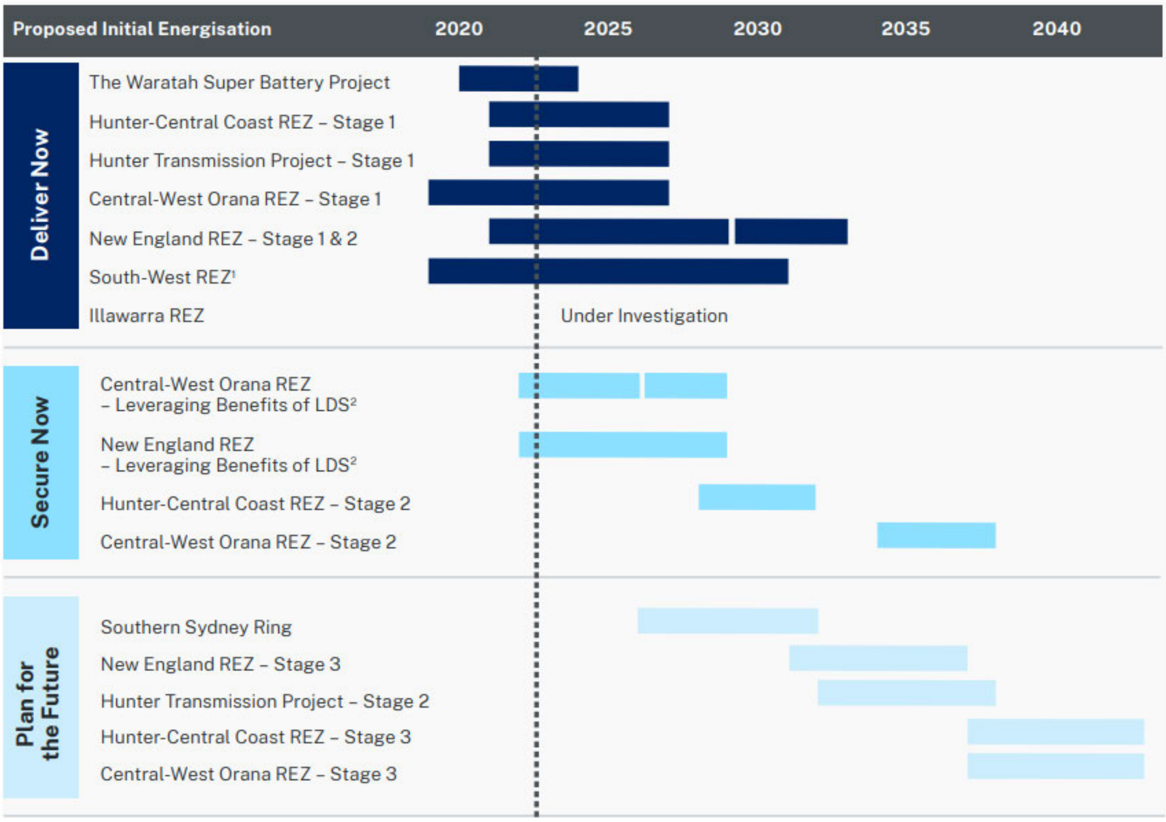
While international supply capacity is forecast to increase significantly, the growth in demand continues to outstrip supply meaning that lead times are expected to continue increasing in the near future (though may moderate in the medium-term).

Cable lead times make undergrounding of most REZ projects untenable. Even in the most optimistic case, if supply agreements could be put in place immediately, this would not allow for commissioning until 2030. Economic modelling for the 2023 Network Infrastructure Strategy indicates that commissioning of almost all REZ stage 1 projects before this date is required to meet Roadmap objectives and deliver the long-term financial interests of NSW electricity consumers (Figure 6).

Construction timeframes for underground cables are significantly longer than those of overhead lines, with most estimates placing timelines for underground cables at 2-4 times longer. This is

[20] *Always Powering Ahead, "Directlink Annual Performance Report", 31/10/2022, p.8*

mainly due to the increased labour associated with large-scale trenching. The trenching rate for underground cabling is approximately ~200 m/day, compared with 1-2 km/day for stringing overhead lines.



[1] Network augmentations creating this capacity are being delivered under the National Electricity Rules framework, in line with the timing outlined
[2] Long-duration storage

Figure 6: Proposed timeline for Network Infrastructure Options[21]

7. Environmental Impacts

Underground and overhead transmission projects both have potential environmental impacts which must be assessed in accordance with environmental assessment and planning requirements. The trenching requirements of underground cables may have greater environmental impacts through direct land disturbance and the creation of large quantities of spoil that need to be assessed through comprehensive State and Commonwealth environmental planning approval processes. Significant easements are required in both cases, and in many cases the land use restrictions for underground cable easements are more onerous. At a transmission level, the risk of bushfire ignition is generally considered to be virtually zero, for both underground and overhead solutions.

Installation

Installation of underground cabling is complex and involves extensive groundworks. Depending on the type and size of the installation, easements as wide as 50 m may be required, containing multiple trenches each of which are typically 1-2 m deep and 2-5 metres wide. 330 kV and 500 kV

[21] EnergyCo, *"NSW Network Infrastructure Strategy"*, May 2023

underground cables are typically direct buried with a bending radius up to 4.5 m. Installation of these cable over complex terrain can be extremely challenging, such as mountainous areas, rivers, lakes, roadways, and heritage area. Ground slopes in excess of 30% are unsuitable for a standard trenched setup, requiring the use of bridging, tunnelling or under boring. Each of these obstacles would require route deviations, which are further complicated by the large bending radius of the cables. Overhead lines, by contrast, can have spans in excess of 600 m and tower locations can be flexible (with small footprints), avoiding many of these issues.

Figure 7: Overhead lines at Shipley Plateau, Blackheath spanning a 100m escarpment[22]

Spoil

Excavation of underground transmission trenches creates a significant volume of spoil which can be up to 14 times that of an equivalent overhead project. EnergyCo has estimated that the volume of spoil if key network infrastructure projects were undergrounded using HVAC would be:

- New England REZ network infrastructure – 11 million cubic metres or 4,400 Olympic swimming pools (a similar volume as Snowy 2.0)
- Central-West Orana REZ network infrastructure – 5.5 million cubic metres or 2,200 Olympic swimming pools
- Hunter Transmission Project – 2 million cubic metres or 800 Olympic swimming pools (a similar volume as NorthConnex)

The excavation required for underground transmission lines can also create environmental and underground Indigenous heritage impacts.

Table 1 provides high-level estimates for the quantity of spoil which would be created by undergrounding REZ infrastructure, for both HVAC and HVDC options, as well as an estimate for an overhead HVAC option. Technical limitations would realistically necessitate the use of a combination of both HVAC and HVDC, so the true numbers would likely lie somewhere in the middle of these two estimates. For comparison, approximate spoil numbers for several other major infrastructure projects have been provided in Table 2.

[22] *Image courtesy of Google Street View*

Table 1: Estimated spoil quantities if EnergyCo projects were delivered with underground cables (to the nearest 1,000 m^3)

Project	Estimated Volume of spoil (m^3)		
	HVAC underground cables	HVDC underground cables	Overhead transmission
Central West Orana REZ	5,529,000	705,000	106,000
New England REZ	11,312,000	1,125,000	148,000
Hunter Transmission Project	1,971,000	188,000	32,000
Total	18,812,000	2,018,000	286,000

Table 2: Estimated spoil numbers for major projects in NSW

Project	Estimated Volume of spoil (m^3)
Snowy 2.0 main works	10,000,000
Westconnex M5 tunnel	3,260,000
NorthConnex	2,250,000

Excavated spoil volume is replaced by 'thermal fill', typically low-grade concrete slurry, which is used to fill the area surrounding the cables and dissipate heat away from the conductors. The volume of thermal fill required is approximately equivalent to the volume of spoil removed. If concrete is used, the production of these volumes of concrete may have a significant environmental impact – mining, refining, and firing of the cement required for concrete fabrication is a very intensive process, with the concrete industry alone responsible for approximately 8% of global greenhouse gas emissions.[23] If a concrete slurry were to be used as fill material for these projects, it would represent a significant fraction of total Australian concrete consumption, which currently sits as 29 million cubic metres/yr.[24]

Easement Requirements

The Inquiry into *Feasibility of undergrounding the transmission infrastructure for renewable energy projects* saw a significant range in the easement widths quoted for undergrounded projects. Inconsistencies in these numbers may be due to the variety of cable capacities available, omission of construction easements and relative lack of mature underground projects in Australia, particularly for HVDC. HVDC trenches are typically narrower than equivalent HVAC trenches for similar reasons, as each cable has a greater current carrying capacity and there are fewer cables required overall. Construction easements are also typically substantially larger than operational easements, leading to further inconsistency among numbers.

Figure 4 provides a sample easement for undergrounding of typical REZ transmission – In this case, 10 underground circuits have been allowed for to match the capacity of four 500 kV overhead lines, necessitating an easement width of 41.6 m. If a lesser line capacity were required, circuits could be removed, reducing the overall easement width. The 41.6 m figure represents an operational easement – during construction or major repairs, an even larger easement would be required. A report into undergrounding produced for the Moorabool Shire Council states (in reference to a HVAC project) that *"During construction, a corridor swathe of up to 100 m is not uncommon."*[25]

As a further example, Figure 8 and Figure 9 provide the proposed trench widths for the Marinus Link Trench (HVDC). Each stage of the Marinus project will be rated to carry 750 MW. The use of HVDC

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[23] *https://psci.princeton.edu/tips/2020/11/3/cement-and-concrete-the-environmental-impact*

[24] *https://www.ccaa.com.au/CCAA/CCAA/Public_Content/INDUSTRY/Concrete/Concrete_Overview.aspx*

[25] Moorabool Shire Council, *"Comparison of 500 kV Overhead Lines with 500 kV Underground Cables"*, September 2020

technology, and a lesser line capacity, allows for these easements to be significantly smaller – however during a 36 m working area is still required for construction and would also be required for major repairs.

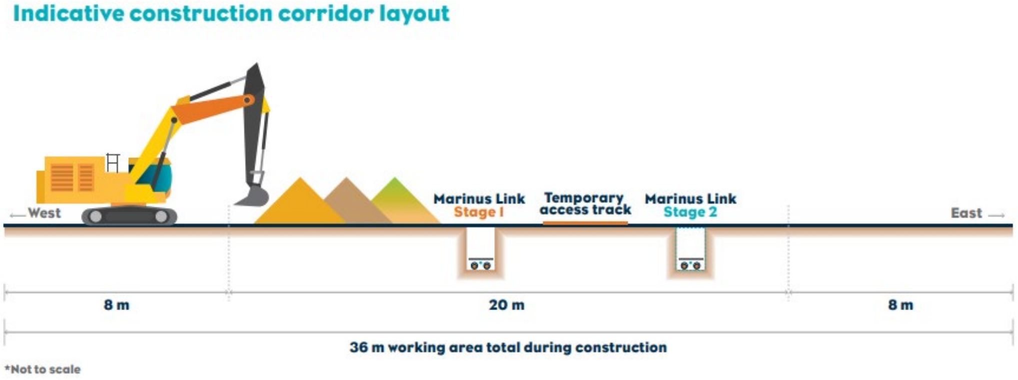

Figure 8: Proposed Marinus Link Construction Easement[26]

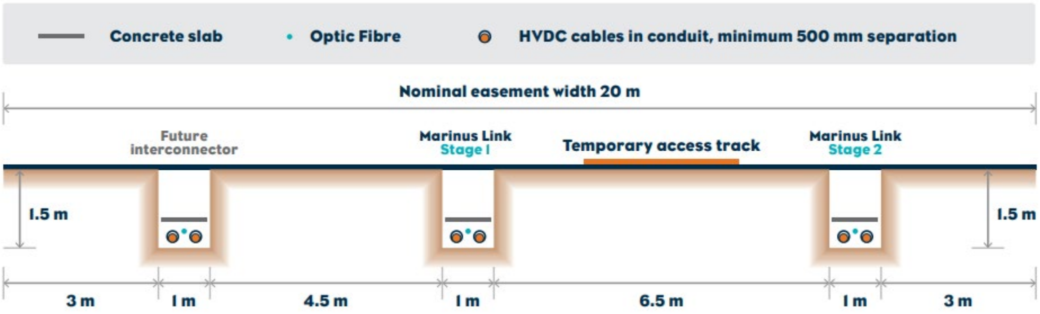

Figure 9: Proposed Marinus Link Operational Easement[27]

Land Use in Easements

Continual maintenance of both the underground cable and the easement are required. Due to the sensitivity of the asset, deep-rooted plants are not permitted within easement areas,[28] to avoid damage to the cables. This inhibits biodiversity recovery following construction, and prevents agricultural cropping. By contrast, within overhead line easements trees and shrubs of a height of less than 3 m are permitted,[29] allowing for more varied agricultural practices, with grazing and cropping typically permitted, and encouraging biodiversity recovery following construction.

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[26] Marinus Link – *"VICTORIAN LAND ACCESS AND EASEMENT ACQUISITION PROCESS"*, Nov 2021, p.12

[27] Marinus Link – *"VICTORIAN LAND ACCESS AND EASEMENT ACQUISITION PROCESS"*, Nov 2021, p.12

[28] Aurecon White Paper, "*High Voltage Overhead vs Underground Transmission Infrastructure (330kV and 500kV)*", 2023, p5

[29] Endeavour Energy, "*General Restrictions for Overhead Power Lines*", April 2020 [*https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSD-8477614%2120200805T051129.445%20GMT*]

Bushfires

Both underground and overhead transmission lines have extremely low bushfire risk. There has never been a fire recorded caused by a 500 kV transmission line in Australia. Bushfires have been linked to distribution lines in the past, with particular configurations such as "single wire earth return" (SWER) more susceptible to bushfire risk.

Transmission lines have lower risk, as they are suspended higher above the ground than distribution lines, significantly reducing the likelihood of physical contact with vegetation or arcing to ground.

It was noted in the recent Standing Committee on State Development Inquiry on the *Feasibility of undergrounding the transmission infrastructure for renewable energy projects* (Parliament NSW, 2023) that the risk of a bushfire being ignited by high voltage transmission lines is low.

In the previous Inquiry into *Feasibility of undergrounding the transmission infrastructure for renewable energy projects*, Australian Energy Infrastructure Commissioner Andrew Dyer stated:

> *"If you define high voltage transmission as being, say, 220 kV and higher, the risk of that igniting a fire is virtually zero"* [30]

This is reflected in a report by Energy Safe Victoria on Electricity Transmission Lines – Bushfire Mitigation and Community Safety, which states that:

> *"Transmission lines, when managed and maintained properly, pose a very low risk of starting a fire. This is due to factors such as the height clearance between the transmission lines and the ground, as well as the managed vegetation beneath the lines that runs for the length of the line."* (p4) *"By comparison, distribution powerlines, which transport the electricity from substations to consumers, operate at lower voltages in the range of 230 volts to 66,000 volts. Distribution power lines cover a much larger geographical area and are much closer to the ground and to trees, increasing the likelihood of fires being ignited."* (p5)

Transgrid, as part of its submission to the inquiry reported that bushfires in Australia caused by electricity infrastructure were usually ignited by distribution powerlines or equipment below 66 kilovolts (kV), rather than transmission equipment in voltage ranges of 110 kV and above. As part of their participation in the hearings during the inquiry, it was reported that Transgrid could not find a record of a bushfire being started in Australia by a Transgrid transmission line operating at over 66 kV.

A fault which occurs on a transmission line is immediately visible to the control room for action and the line is automatically de-energised within approximately 120 ms. Exact fault locations are harder to identify for underground cabling.[31]

Existing bushfires can impact overhead lines, principally through dense smoke causing arcs or 'flashovers' of the lines. These impacts are typically temporary, and the overhead line can be returned to service after a flashover. This risk is also managed through vegetation clearance bushfire management practices. Network operators work with fire authorities to co-ordinate firefighting in the vicinity of overhead transmission lines.

Underground transmission lines are typically unaffected by aboveground fires – grass and scrub fires move quickly enough that the temperature of the ground surrounding the cable is not raised significantly. The Rural Fire Service (RFS) use transmission line easements as fire breaks when required. Easements also provide quality access tracks for RFS and other associated fire agencies access in times of need to remote locations. Access tracks identified for use as fire trails are

[30] NSW Parliamentary Inquiry, "*Feasibility of undergrounding the transmission infrastructure for renewable energy projects*". Hearing Transcript from 18/7/23, p.22

[31] ESV publication: *'Electricity Transmission Lines – Bushfire Management and Community Safety' (2023))*

maintained in accordance with NSW RFS Fire Trail Standards under the Rural Fires Act 1997 (NSW) and Rural Fires Regulation 2022.

The RFS and associated fire agencies can protect power lines as best as possible if they are aware of their location/s. Location identification is generally managed through area familiarisation activities of local RFS brigades and maintaining relationships with NSPs. NSPs are required to maintain their easement access and keep clearances between vegetation and their infrastructure.

Whilst the impact of bushfires is lesser for underground transmission, bushfire impacts on and firefighting operations around overhead transmission lines are well understood. Easements in both cases provide good access to fires and natural vegetation breaks to conduct firefighting operations from.

When asked in the previous Inquiry if the addition of new overhead transmission lines would cause more bushfires, RFS Assistant commissioner Jayson McKellar responded *"I couldn't say that, no. There are so many variables to that question".* When asked if they would worsen existing fires he responds again *"No, I don't think so",* arguing that the presence of additional infrastructure *"might work both ways. We may well use the access trails as part of our fire trail network or as a firebreak. Just by virtue of having infrastructure out there, it would come into the risk equation of what we would do to mitigate a fire, and it would also pose some limitations to how we would do that."*[32]

8. Cost

While cost estimates vary, most estimates find that the cost of underground transmission infrastructure would be significantly greater than the overhead equivalent. The cost of undergrounding varies between projects, and given that REZ projects are relatively incompatible with underground infrastructure due to the need to connect generation and storage projects at multiple locations in a REZ to the transmission infrastructure, it is likely that cost impact of undergrounding would be greater than for most other projects.

Cost estimates for undergrounded projects are highly variable and are dependent on a number of case specific factors. Ground conditions vary significantly between projects – as do topography, compatibility with existing land use and geology. This can have a major impact on project suitability, costs, program and risks.

Cost estimate variation for undergrounding is also attributable to the wide range of technologies available. As stated in Section 6, long distance point-to-point applications, such as the proposed Marinus Link beneath the Bass Straight, are only feasible utilising underground HVDC technology. Complex, meshed networks with shorter cable lengths, such as most REZs, may use some HVAC technology and are typically more expensive compared with the overhead equivalent. The lack of large operational underground projects in Australia reduces the ability to benchmark estimates, contributing to the large range in cost estimates.

[32] NSW Parliamentary Inquiry, "*Feasibility of undergrounding the transmission infrastructure for renewable energy projects*". Hearing Transcript from 27/7/23, p.19

EnergyCo conducted a literature review of the cost estimates of a number of undergrounded projects, with the results depicted in Figure 10.

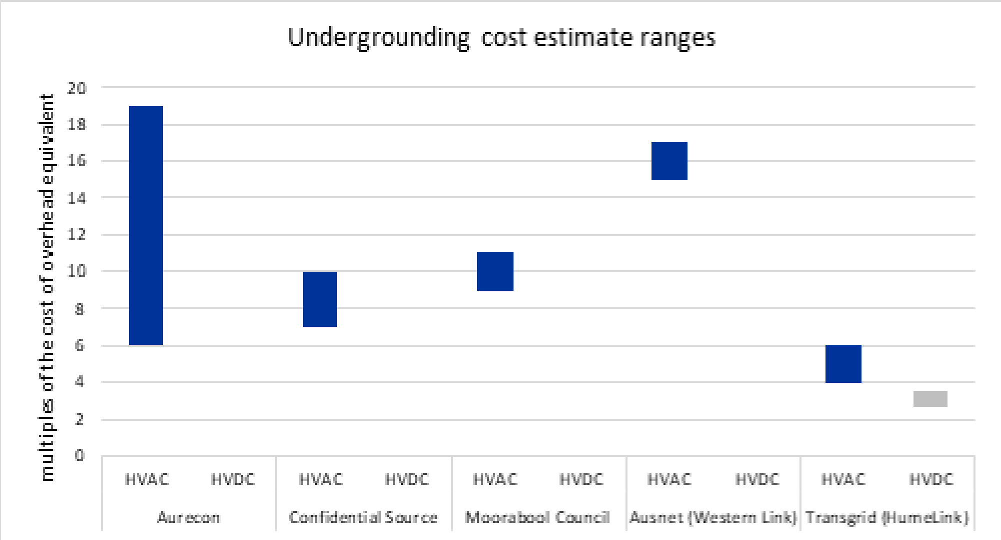

Figure 10: Undergrounding cost estimate ranges

Undergrounding is consistently and significantly more expensive than its overhead equivalent, ranging from 3 to 19 times higher. It is expected that REZ projects would land at the higher end of this range, if feasible.

To better understand the cost implications of undergrounding REZ transmission assets, EnergyCo contracted quantity surveyors RLB to prepare a cost estimate for undergrounding of a typical greenfield REZ. For the purposes of the estimate, RLB assumed that mountainous regions could be trenched with no requirement for bridging or under boring, which be at additional cost if required.

The report assumes the use of HVAC technology, noting that a more detailed investigation would likely include some HVDC transmission lines at potentially lower cost. In order to meet the required capacity, the estimate allowed for 8 sets of 3 x 3000 mm^2 aluminium cables, installed in three stages to match the planned rollout of the REZ. These 24 cables would require a total easement width of approximately 41.6 m.

The RLB report found that the cost of undergrounding would be approximately 19 times the cost of the overhead option, with an indicative cost of $113 billion.

High-level cost estimates using the AEMO Transmission Cost Database were conducted by EnergyCo for other projects. These analyses suggested that complete undergrounding of the lines would increase the cost by a factor of approximately 10.

The Inquiry on *Feasibility of undergrounding the transmission infrastructure for renewable energy projects* discussed the findings in a report by GHD commissioned by Transgrid, investigating the feasibility of undergrounding the HumeLink project. The Inquiry heard diverging claims that the estimated costs were both much lower, and much higher, than would be expected in reality. Amplitude Consultants have also released a review of the GHD report, providing their own proposed circuit designs and costings.

The following table provides an overview of the proposed circuit designs, and corresponding capacities, of the various reports. Line capacities are not equivalent across the options – the proposed Amplitude HVDC solution provides a total capacity of 2000 MW, in contrast with 3259 MW for the AC overhead solution.

Table 3: Comparison of circuit designs and line capacities in GHD and Amplitude undergrounding reports compared to the overhead line equivalent.

	Overhead line	GHD – HVAC underground circuit (Option 1A)	GHD – HVDC underground circuit (Option 2A-1)	Amplitude – HVDC underground circuit
Circuit Configuration	Double circuit 500 kV overhead towers	2 cables per phase per circuit (6 cables per trench)	3 bipoles (2000 mm^2)	3 bipoles (1600 mm^2)
'N-1' Capacity[33]	3259 MW	2750 MW	2750 MW	2000 MW
Cost	$5.0 billion (2023)	$17.1 billion (2022)	$11.5 billion (2022)	$7.3 billion (2023)

Much of the discrepancy between the numbers quoted is explainable by this inconsistency in line capacity, and therefore cable diameter and trench width.

Since most of these estimates were completed, the market for underground cables has tightened significantly (as noted in Section 6). The Marinus Link project has seen significant cost increases, primarily driven by the price of cables and power conversion equipment. In October 2022, the total cost of the project was placed at approximately $3.5 billion,[34] while estimates just 11 months later indicated a cost of $3.0-3.3 billion for just the first stage of the project, delivering half of the total capacity.[35] It is likely that re-estimates of other underground projects would be subject to similar price increases.

9. Economic impacts

Undergrounding of transmission infrastructure would cause significant price increases for the NSW electricity consumer. It is unlikely these projects would be approved under the existing regulatory framework – therefore significant government intervention would be necessary for these projects to proceed.

Impact on Energy Bills

Under the EII Act, electricity consumers pay for the cost of new infrastructure, with costs recouped through higher electricity prices. As discussed in Section 8, cost estimates for underground transmission projects vary greatly, precluding accurate estimation of energy bill impacts. The estimate for a typical REZ of $113 billion would be equivalent to a capital cost of approximately $33,600 per NSW household. If REZ network infrastructure was to be undergrounded, NSW would still require the same transmission capacity to meet energy requirements. This means that the projects would still be constructed, passing on the costs to consumers.

Regulatory Approval

Before progressing to delivery, projects delivered under the EII Act in NSW must be authorised by the Consumer Trustee or Minister for Energy and undergo a determination by the Australian Energy Regulator (AER). Under the Roadmap, as part of the authorisation the Consumer Trustee must determine whether authorising the recommended project would be consistent with the long-term

[33] Line capacities provided here are 'N-1' capacities. This represents the line capacity available after the failure of any single circuit element, which is the standard metric used for NSW transmission planning

[34] *https://www.marinuslink.com.au/wp-content/uploads/2022/02/quadfold-Marinus-Link-Fact-Sheet-FEB22-WEB.pdf*

[35] *https://minister.dcceew.gov.au/bowen/media-releases/joint-media-release-investing-future-tasmanian-energy-marinus-link*

financial interest of NSW electricity customers. Among other factors, the Consumer Trustee must consider the financial value to consumers, the total project cost and the network cost per MW of generation capacity. It must conduct a cost-benefit analysis by determining the total benefits of the recommendation to NSW electricity customers through a modelling exercise and confirming that the forecast costs do not exceed the modelled benefits. Finally, the Consumer Trustee must set a maximum amount for the prudent, efficient and reasonable capital costs for development and construction of the REZ network infrastructure project that may be determined by the Regulator.

As the Regulator appointed under the EII Act, as part of the determination the AER must conduct a transmission efficiency test (TET), whereby it calculates the prudent, efficient and reasonable capital costs for development and construction of the network infrastructure project and determines the amount payable to a network operator by the Scheme Financial Vehicle.

For projects delivered under the NER, the AER must undertake a RIT-T, a public cost benefit analysis test to identify the credible option (network or non-network) to address the identified need at the greatest net benefit (or least net cost), to the National Electricity Market.

Due to the significantly greater cost of undergrounding, it is unlikely that an undergrounded project (where an overhead network option is available) would be authorised by the Consumer Trustee under the EII Act, or considered the network option which addresses the identified need at the greatest net benefit as part of a RIT-T under the NER. This reality was accepted by the previous parliamentary Inquiry regarding the HumeLink project; "*The evidence is clear that an undergrounding proposal would not be approved by the regulator and could only occur with a sizeable financial contribution from state or federal governments*"[36] In the event of an undergrounding mandate, intervention would be likely to be required to allowing for construction of the projects at the additional cost compared with overhead lines, with the cost borne by electricity consumers.

10. Conclusions

When developing its projects, EnergyCo considers the most appropriate technology solutions for each project on a case by case basis.

Taking into account the above considerations, EnergyCo's view is that in general, at extra high voltages, overhead transmission best balances the considerations of cost to consumers, project delivery schedule, construction risk, environmental impact, reliability and transfer capacity.

Underground transmission may be an appropriate solution when it is not feasible to secure a corridor for overhead transmission lines, such as in already developed urban areas or undersea.

[36] NSW Parliamentary Inquiry, "*Feasibility of undergrounding the transmission infrastructure for renewable energy projects*", Report 51, Aug 2023, p.34