Renewables Grid Initiative

PARTIAL UNDERGROUNDING FOR EXTRA-HIGH VOLTAGE AC CONNECTIONS

Understanding the option of 380 kV AC underground cables complementing overhead lines

Discussion Paper – October 2019

About RGI

The Renewables Grid Initiative is a unique collaboration of environmental NGOs and Transmission System Operators from across Europe. We promote transparent, environmentally sensitive grid development to enable the further steady growth of renewable energy and the energy transition.

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Introduction

In the context of the energy transition, there is an urgent need to develop the necessary grid infrastructure to facilitate the integration of larger shares of renewable energy.

Overhead lines have traditionally been the standard technology for transmission projects. Such lines are sometimes opposed by citizens due to the potential environmental and social impacts, among other factors. Such opposition can cause or prolong delays in project implementation, thus hindering the further growth and integration of renewable energy sources. Today, in Europe, transmission system operators (TSO) are increasingly complementing overhead lines with underground cable sections, primarily in densely populated areas, areas of important natural beauty, ecological value or when so defined by political decisions.

Unlike direct current (DC) cables, which have reached an operational maturity and an advanced level of knowledge of their impacts, relatively few extra-high voltage alternating current (AC) underground sections have been installed in transmission projects. They are two distinct technologies that are used depending on the specific power transmission role a new link is to fulfill. The option of extra-high voltage (EHV) underground cables in a meshed electric system, in particular the case of 380 kV AC connections, needs to be better understood.

Within different national legal and regulatory frameworks, the decision-making process behind each extra-high voltage cable weighs up several factors: primarily the electricity system requirements and restrictions, as well as environmental, social and cost considerations. Stakeholders have often raised questions as to the circumstances that make cables both feasible and suitable and have looked for a better understanding of the potential impacts of cables and how they differ from those of overhead lines.

This document, produced under the RGI umbrella, looks to provide clarity by giving an overview of the current and common drivers, the risks, as well as potential mitigation solutions available in the deployment of extra-high voltage underground connections. It is based on the limited project experience, reports and research available, and on discussions with multidisciplinary experts. Although it is recognised that all projects are specific and require a case-by-case analysis, this is an attempt for the TSO and NGO communities to find common ground[i].

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i) For the sake of brevity, in this paper we will refer to 380 kV AC underground cables as UC and to 380 kV AC overhead lines as OHL.

1. State of the art

1.1 Underground cable technology

The European Association of Transmission System Operators for Electricity (ENTSO-E) reports that the technological readiness of AC underground cable (UC) sections will shift from being a "system prototype demonstration in an operational environment" today to "an actual system proven technology with a competitive manufacturing by 2025" (1).

Globally there are almost 5000 km of EHV (EHV: 220-500 kV) AC cables, with over 2000 km in Europe (1). EHV AC UC make up less than 2% of the EHV AC land transmission systems in western Europe (2) where currently the maximum voltage used is 420 kV.

EHV cross-linked polyethylene (XLPE) power cables are today the core technology used in EHV AC UC sections and have been in service in Europe for almost 25 years, proving their reliability (3).

1.2 Partial undergrounding system

Cables are usually delivered in lengths of between approximately 700 to 1000 m, this is due to transportation limits for the weight and size of the cable drum. They are connected together by pre-manufactured joints which require careful on-site assembly to be cautiously executed by qualified staff.

Cable sections are linked to OHLs via transition stations whose size and layout are determined by the transmission capacity and the additional equipment installed. In some cases, they require a reasonably large plot of a land which can create a visual impact.

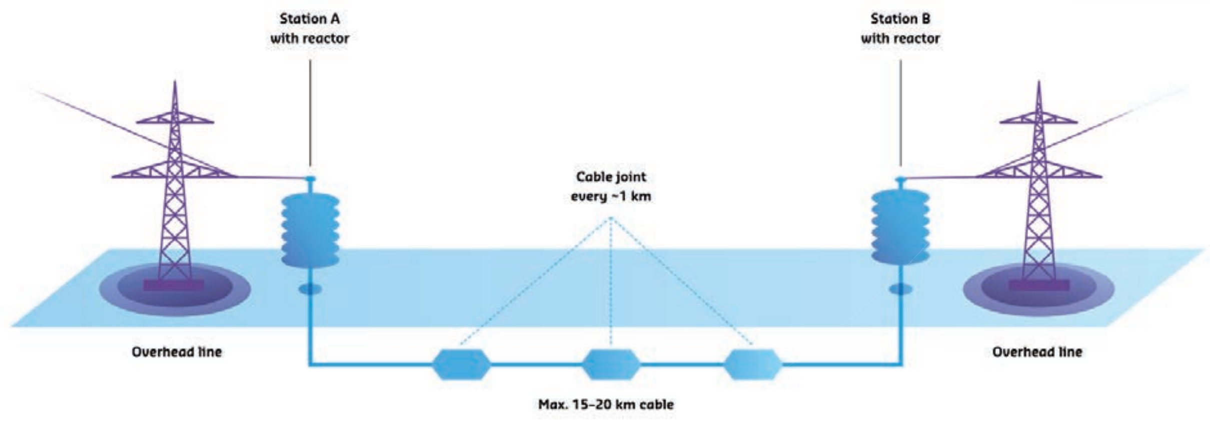

Figure 1: Partial underground cabling in the AC grid. Source: Amprion (4)

Cables can be buried, installed in tunnels, or in pipes through open or closed construction methods. The installation choice is determined by the specific route selection, the identification of obstructions and the requirements of the cables.

Open Direct Burial	**Closed Burial**
 *Figure 2: Direct Burial. Source: Europacable*	 *Figure 3: Horizontal directional drilling. Source: Terna*
Open direct burial techniques involve the laying of the cables in 1 to 2-meter-deep trenches, often surrounded by tubes or bedding material needed for heat dissipation, proper drainage and stability. Cable joints are generally laid in the ground like the cable itself or sometimes supported by buried concrete blocks. During construction, surface access points may be installed intermittently to allow for measurements and maintenance. Civil works for direct laying have a considerable, although temporary, impact on the immediate surroundings. The area usually becomes a major construction site where heavy excavation and haulage machinery are required along with staging and soil storage areas, as well as the required access roads and other associated construction infrastructure. Ducts, surface troughs and cut-and-cover tunnels are other open options, although more expensive, these methods can be used to reduce disruption due to their modular nature, which allows for a less open construction site. Ducts in particular can speed-up construction, minimise injections and allow the decoupling of civil works from cable delivery. However, they pose technical challenges due to the weaker heat dissipation.	Closed techniques are used in urban centres where open construction would cause disruption. The most common closed techniques for UC in Europe are microtunneling, a pit-launched technique and the horizontal directional drilling (HDD), a surface, launched trenchless installation technique. The latter is usually appropriate for crossing obstacles including waterways and roads as well as sensitive areas, where the risk of open trenches would pose an environmental issue. Tunnels, which are less frequent for UC in Europe, are another closed option. They are dug at an appropriate depth between two pits in order to avoid other urban subterranean infrastructures. The construction areas needed at the pit heads are large in order to accommodate the pit and to provide staging for construction materials and the associated machinery needed to run the tunnel boring machine itself. The main advantages of closed techniques throughout the construction and operational phases are the avoided surface disruption, contamination of trench excavations and the easier fault localisation and repair without the need for digging (except the case for HDD). Nevertheless, such methods are costlier than open trenches.

1.3 National legal and regulatory frameworks

European TSOs work within different legal environments and regulatory frameworks, which, with few exceptions, provide limited clarity on the decision between OHL and UC. The default technology has been traditionally OHL, mainly for costs and operational reasons.

In general, in countries where the regulatory regime has a strong focus on investment costs, underground solutions may not be favoured. In other countries, where investment costs are also weighed against performance, operational or nature protection or social indicators, the framework might be more technology-neutral. For instance, in the UK, National Grid has been incentivised to replace some OHL sections in legally protected Areas of Outstanding Natural Beauty with UC sections (6). In other cases, it is recognised that the choice to utilise underground cables can be influenced by political considerations and priorities.

Regulatory frameworks can also prescribe or incentivise the deployment of technological innovation. For instance, in Germany since 2009, the legislator through the Energy Grid Expansion Act (EnLAG) and the Federal Requirements Plan Act (BBPIG) supported a number of UC section pilot projects (in one case longer than 10 km) in order to test the technology and acquire more knowledge of construction and operational aspects.

For grid development, as the OHL option is the preferred one, the regulatory and the legal framework are generally not “technology neutral”. Therefore, TSOs use different evaluation criteria to make a technology choice and stakeholders require more clarity and transparency on the process behind the decision of the technological option.

2. Drivers and risks

2.1 Impact on system performance

Maintaining the availability and reliability of the grid is of paramount importance. A larger number of longer UC sections at high-voltage level changes the behaviour of the system.

Although difficult to determine, this change in behaviour poses a risk to the security of the electricity system that has to be properly assessed and thus managed. How EHV AC UC sections impact the performance of the system is still poorly understood; the possible solutions to counterbalance challenges posed by the presence of UC are still limited and under constant evolution. The main physical aspects to be considered are provided in the following paragraphs, while for a more comprehensive understanding of the subject we defer to technical studies.

As a premise, in network planning it must be considered that a 380 kV single circuit of XLPE AC cable can reach an average nominal capacity of up to 1000 megavolt-amperes (MVA), while a 380 kV single circuit OHL can reach 2000 MVA. Therefore, in order to compare the two technologies, reference to the same nominal capacity should be made. In addition, compared to OHL, UC back-to-back connections with OHL have a lower limit of transmitted power causing system stability limitations. In the case of longer UC sections, the stability aspects must be deeply investigated.

2.1.1 Reliability and availability

The reliability of 380 kV AC XLPE cables has improved over the past decade. However, the share of UC sections in the high-power backbone of the transmission system is still very low and the installed sections are relatively new. As a consequence, **the operational performance data for installed cable systems is limited, varies between European projects and is not widely available. In general, the interaction between cables and other components of a UC system is still challenging and the availability of such systems is still lower compared to OHL.**

Faults in UC sections can be caused either by internal or external damages (i.e. to the cable itself, the joints or the termination). UC sections themselves are in generally less likely to suffer a failure compared to OHL (2), even if joints among sections reduce the total reliability. The resulting outage time is higher than for OHL and depends on its severity, the chosen installation options which require the trench to be opened, the possibility of access to the site of failure as well as the availability of spare parts for replacement and repair crews. Repair duration for an on-land 380 kV cable is likely to take between two weeks and months depending on the location of the fault. The latest failure statistics for 380 kV UC systems at European levels were published by the International Council on Large Electric Systems (CIGRE) in 2009, meaning that there is a significant lack of up-to-date and consolidated data on the issue.

Due to the different electrical parameters (impedance), the mixed use of UC and OHL in meshed networks can affect the accuracy of fault localisation. To meet this challenge, the transition stations between UC sections and OHL can be equipped with additional differential protection units that allow for selective and precise fault localisation, either in the cable or in the OHL. These additional units require a more comprehensive design of the transition stations and, therefore, they increase the total costs of the installation of a cable section. On the other hand, they reduce the time needed for fault identification and repair.

In case of blackout, the quick restoration of the system is an extremely important and, at the same time, challenging action. Power lines with UC sections might result in significant reactive power imbalances during the restoration process and thus make the grid restoration process much more complex. Consequently, **for power lines that are of special importance to restore the electric system, there might be restrictions as to whether underground cabling sections are possible.**

2.1.2 Electrical effects

Since UC sections and OHL have different electrical parameters (impedance), special equipment known as reactive power compensation is required in order to maintain the voltage within the limits. The level of reactive power compensation must be carefully evaluated to avoid frequency shifts (resonance and resonant phenomena). **The shifting of frequency with an increasing share of (long) UC sections in combination with the necessary reactive power compensation may result in high voltage peaks which may lead to disruption of industrial consumers and even to outages/damages of high voltage equipment in the transmission or distribution network. This leads to a complex system which limits the length of cable systems between substations and which has to evaluated case by case** (see paragraph 2.1.3).

In addition, since the grid is always in different states of operation (lines switched on and off, e.g. for maintenance, load flow control), the frequencies shift depending on the overall topology of the grid system. Therefore, **the overall length and number of the cabling sections have to be designed in order to allow the system to have sufficient global operational flexibility**.

2.1.3 Planning aspects

In consideration of the systemic issues described, the length of a UC section up to approximately 10 km is increasingly common in Europe and usually manageable from a technical point of view. Lengths above approximately 10 km require special care in the design and are more challenging due to their reduced reliability, as well as technical implications and costs.

The potential length limit of a specific UC section can also come from systemic limits deriving also from the number of UC sections in a given region.

A recent study based on two Danish grid projects (although not sufficient to establish a firm reference) suggests that there is a considerable risk to system stability when the UC section is over 15% of total circuit length. This risk could potentially compromise Denmark's security of supply (5).

2.2 Environmental and social aspects

Understanding and weighing the environmental and social benefits and risks is an important step towards choosing the correct technology for the local context.

Bird and landscape protection can be considered as the main environmental drivers for cabling in environmental/spatial bottlenecks, while wetlands (and especially peat bogs) and soil quality can present some risk factors. Environmental management and mitigation measures (see appendices) are able to moderate these risks and need to be further tested.

2.2.1 Soil

The potential impact on soils of UC sections is a major consideration, especially regarding agriculture and nature protection.

The construction of UC sections needs to be conducted as carefully as possible in order to avoid soil degradation. Prior to construction, site-specific soil protection concepts should be designed and should be included in detailed agreements with contractors. Moreover, each project should be accompanied by experts during the construction phase, who should also be involved in the process of formulating contracts with landowners. All affected stakeholders should be informed about the scale of the construction site in order to avoid misunderstandings and negative outcomes once construction is underway.

In an open construction, the soil must be removed layer by layer – topsoil and subsoil layers separately – and stored temporarily, before each layer is backfilled. Moreover, a project developer should undertake measures to avoid compaction and wetting of soil during its storage. This is because after construction the cable trench is (mostly) backfilled with the original soil layers and the soil's functions should be maintained in their primary state.

In order to avoid the introduction of pollutants and other soil contamination, as well as to prevent soil erosion and other negative impacts, precautionary measures such as covering of the soil mounds or growing of a stabilising vegetation which can be removed afterwards (such as mustard) could be applied, especially if the soil will be stored for a longer period of time. To avoid impacts during construction, where necessary, construction roads or load distribution plates should be used.

During operation, the soil above the cable trench can be restored to a level of thickness that allows agricultural use without significant restrictions, meaning that farming activities are not limited over the cable trench.

However, given that no deep rooting trees may be planted within the cable corridor, this will remain visible when passing through woodlands and semi-open landscapes with hedges and tree rows.

Prior to construction, survey work should also be done to ensure that the hydrology of the land and the drainage channels are mapped. Any small streams or drains interrupted during the construction work should be restored to proper functioning as part of the restoration and compensation package.

Although research is ongoing, thermal effects in the soil from operational heat dissipation of the underground cables appear to be limited (7). Temperature measurements on existing underground cable installations show that the soil temperature in the upper soil layers above underground cables depends predominantly on seasonal and weather-related temperature fluctuations, and that the warming of the bedding material and the soil layers closer to the cable, although higher, lie within an acceptable temperature range. Thermal effects on soils, particularly soil biota, require further investigation.

2.2.2 Wetland and peatbogs

In comparison to OHLs, the construction and operation of UC sections can pose an increased risk to wetlands and peatbogs which can be sensitive to the construction of trenches. This is for the following potential risks associated with excavations:

- Interruption of existing hydrological processes
- Sediment runoff
- Introduction of surface and sub-surface drains
- Possible compaction of the surface layer and the underlying peat
- Direct disturbance of vegetation and upper bog surface during laying
- Alteration of the vegetation community in the corridor due to the invasion of opportunistic species as a result of disturbance (8)

Furthermore, activities that damage peatland can degrade habitats, worsen erosion and reduce water quality (9). Some countries like Belgium restrict/prohibit trench digging activities damaging or disturbing soil layers or requiring excavations in areas with sensitive waterbodies or groundwater used for drinking.

However, the implementation of UC sections (especially closed techniques) could be desirable in wetland ecosystems where there is an increased risk of vulnerable wetland bird species exposed to collision with OHLs.

2.2.3 Birds

During the operation phase, OHLs can pose a threat to bird species of collision with power lines, especially with the ground wire (10). **While mitigation measures can be effective on OHL to reduce bird mortality, UC sections are the only fail-safe way of eliminating collision risk during operation** (11). In addition, the nature of certain topographies, like migratory bottlenecks, valleys, and proximity to water bodies used for wintering, poses a special risk to some bird species. In this context, the use of UC sections can be desirable to eliminate this risk entirely.

UCs can, however, pose an increased risk for ground nesting bird species during construction. Due to the greater land take needed for (especially open techniques) UCs during construction, protected ground-nesting bird species are at a higher risk of a temporary loss of habitat at their preferred breeding sites. In cases of required forest clearances for UC construction, bird species breeding in trees could also potentially lose their habitat. In high-risk areas, timing construction to avoid the breeding season has been shown to minimise any expected negative impact (see appendix B. - Elia, Stevin project).

2.2.4 Landscape and heritage

Since OHL can have a negative visual impact on the landscape, especially in areas of high visual amenity and visibility, UC sections can be used to minimise the visual impact during the operation phase (12). Additionally, since many countries (e.g. Belgium, UK, Italy) also have areas of legally protected landscapes where some developments are forbidden, UC sections could be considered appropriate in such places. Landscape and Visual Impact Assessments (LVIAs), conducted in parallel to effective public consultation activities, can allow developers to identify potential landscape issues.

UC sections can also be desirable in order to avoid the impact of OHLs on the "setting" of a heritage asset (cultural sites, protected monuments etc.) (13). Underground cables have a negligible negative impact upon the setting of heritage assets during operation, with only a temporary impact during construction, as the majority of natural features (except for tree rows etc.) and some infrastructures (roads, etc.) can be reinstated or crossed with closed burial techniques such as HDD.

Although the cable itself is underground with little impact on visual amenity, partial AC sections require transition stations which connect the cable back to the overhead line. These stations can be relatively large. When considering the planning of UC cables and the impacts on heritage and landscape, the visual impact of these stations needs to be understood and mitigated where possible.

Conversely, UC sections may not be desirable in areas of archaeological importance because of the damage which the trench digging can cause during the construction phase (14). Risks can be identified in planning to avoid significant site degradation and destruction (15).

2.2.5 Population and health

Underground cables can be an option when lines must enter densely populated urban areas. In such cases cables are usually placed in trenches or pipes with partial use of microtunneling in order to cause minimal disruption during the construction phase. Open direct burial is carefully evaluated in urban areas due to restriction on the amount of land available.

For the acceptability of a line by local residents, questions regarding electric and magnetic fields (EMF) often play a relevant role. **The magnetic field directly above UC is typically higher than the one an OHL would produce at ground level. This is due to the proximity of the cable to the surface, but it falls away more rapidly with distance to the side** (16). Figure 4 shows an illustration of this for one particular UC and the equivalent OHL in a typical (avarage) situation during a year when the line is not operated at its maximum thermal capacity.

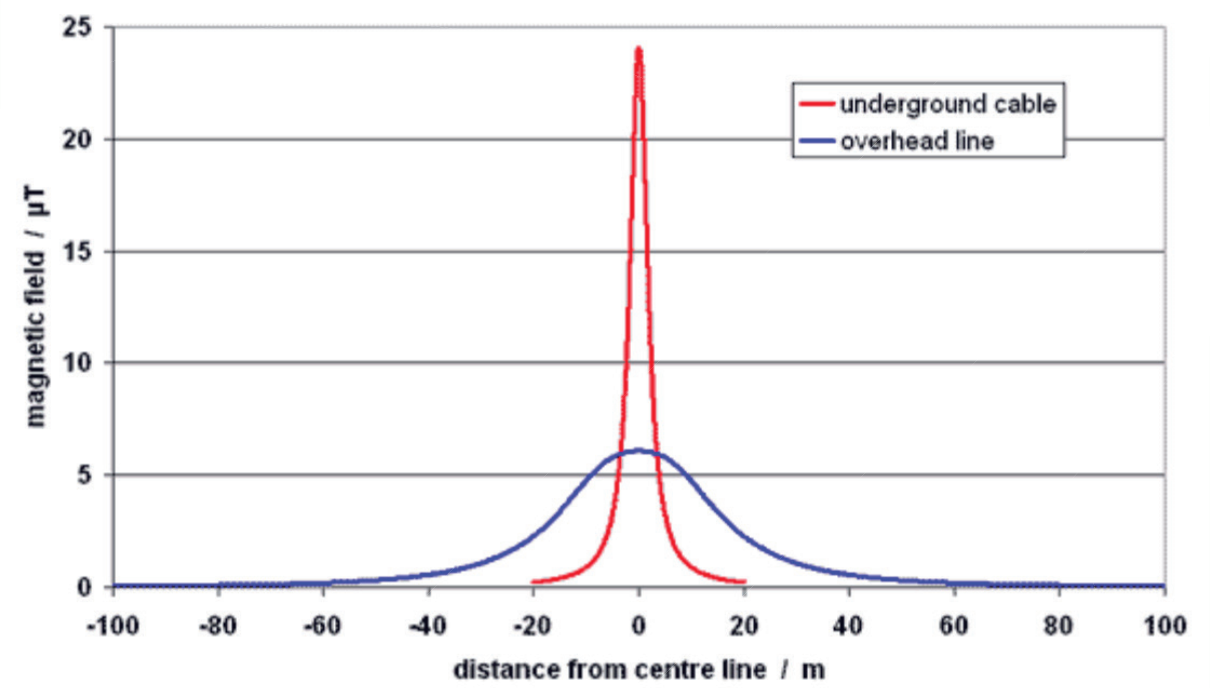

Figure 4: Typical magnetic field under 380 kV alternating current overhead lines and above underground cable routes. Source: Electric and magnetic fields and health (emfs.info)

As per today, in both cases (OHL, UC) the maximum values for public exposure are 100 µT, indicated by the EU Recommendation 1999/519/EC, based on values established by the International Commission on Non-Ionising Radiation (ICNIRP) (17) and transposed by Member States into national policies.

2.2.6 Public participation

The engagement of stakeholders and the transparent provision of complete and easily accessible information is paramount.

TSOs are responsible for assessing the feasibility and reliability of UC sections, as well as balancing the electric benefits and risks. It is also important for the TSO to engage in an open discussion with the pubic and to justify in a transparent way the reasons for the technology choice, aiming at building trust and acceptance.

Building underground lines might lead to higher acceptance with some parts of the public, but it is unlikely to be the solution for all issues of local acceptance because stakeholders assess the advantages and disadvantages of technological options in different ways. UC sections require a huge amount of stakeholder engagement and participation, especially with affected landowners, land users and adjacent residents at the OHL section of the project. In some projects, acceptance may rise at the UC section, but may decrease at the OHL part of the project.

Public participation remains a key element for good project design: the technological options should always be explained comprehensively in a clear and transparent way.

2.3 Financial aspects

The financial aspect is important as the costs of grid development are charged to the electricity consumer via grid fees. In general, UC are always more expensive to construct when compared to equivalent OHL.

Due to differing soil conditions, installation, operation, maintenance, environmental protection measures, transition stations and compensation devices, among others, each UC section is unique and as such costs may vary considerably.

A cost comparison between OHL and UC conducted by the Agency for the Cooperation of Energy Regulators (ACER) shows that 1 km of 380 kV OHLs with two circuits costs on average more than 1 M€, compared to 4.9 (mean) to 5.7 M€ (median) for underground sections of the same capacity (18). Howerver, the report refers to a very limited sample of 380 kV AC projects and therefore it is not possible to establish this as a firm reference. It must also be considered that these multiples apply only to the undergrounded part, so that the economic impact of partial undergrounding to the entire project costs can be limited, depending on the amount of undergrounding necessary. Using UC sections as a standard option in all major projects would have a non-negligible costs and therefore impact on the grid tariffs. The lack of data and comparability on costs related to UC sections do not allow for more precise estimations.

3. Conclusions

The project experience with partial undergrounding of 380 kV AC is limited but growing. UC sections have the potential to become an important option in the project development toolbox available to a TSO when planning and executing transmission projects.

The collaborative work concluded:

- **Technical safety and secure system operation** – There are limits to the number and length of UC sections that can be safely integrated into the transmission system. TSOs conduct complex analysis to identify the limits and to ensure when possible that any new sections do not compromise the technical safety of the transmission and distribution system, as well as the overall system reliability and performance.
- **Legal and regulatory frameworks** – The regulatory and the legal frameworks are generally not “technology neutral”, considering by default OHL as the option for grid development. Regulatory frameworks can prescribe or incentivise the deployment of technological innovation to test the potential and limits in pilot projects. Political considerations and priorities can influence technology choices as well.
- **Environmental considerations** – There are a number of drivers which make the option to go underground more attractive, such as the potentially lower impacts on some bird species and sensitive landscapes. Such considerations need to be balanced with other environmental risks, such as the disturbance of soils and sensitive water bodies, particularly during the construction phase. Mitigation measures should be assessed, implemented and complemented with research programmes which look to improve our knowledge of the impacts of cables during construction and operation.
- **Public Acceptance** – Different stakeholders may have diverging priorities with regards to technology choice, such as between residents and land-owning farmers. Going underground is unlikely to be the solution for all issues of local acceptance. Public participation remains a key element for good project design and the technological options should always be explained in a clear and transparent way.
- **Financial aspects** – Each UC section is specific and as such, costs may vary considerably. In general, costs for UC are higher than for OHL and have an impact on grid tariffs. The lack of available data and comparability do not allow precise estimations.

In conclusion, the number of projects in Europe which will include a UC section will likely grow over the next decade. This additional technology option for EHV AC lines needs further project experience, research and collaborations to identify how it interacts with the overall electrical system, which local contexts are best placed for it, and how to bring down costs through technological standardisation, as well as more project experience.

4. Recommendations

Along with the the need for more project experience on 380 kV AC partial undergrounding, the collaborative work identified the following recommendations which would enable a better understanding of this technological option.

- **Promote further research on UC sections impact on the system** – Research is needed on the systemic impacts of cable sections and the results of these research programmes need to be integrated.
    - Conduct and make available further studies and simulations to determine the maximum length of underground cables and the number of sections possible in meshed transmission systems.
    - Possibly agree on common protocols for data collection to enable comparability across projects.

- **Provide clarity and promote transparency through legal and regulatory frameworks** – NRAs and permitting authorities should promote further clarity and transparency on the selection criteria of the most appropriate technology option for current and future EHV AC transmission projects and enable a meaningful stakeholder engagement process.
    - Make the partial undergrounding option available at the early stage of project development, provided that it is feasible from an electric point of view.
    - Work together with TSOs to identify and describe possible improvements in national regulation and legislations to enhance clarity on the regulatory conditions on whether the UC is an appropriate option.
    - Incentivise more pilot projects and their evaluation to gain further experience.
    - Work together with TSOs to develop together indicators that recognise the costs of this technological option in view of its benefits.

- **Consolidate environmental impact monitoring/research programmes** – In compliance with national legislations, underground projects should be accompanied by environmental studies and monitoring programmes to identify and address the potential impacts, particularly on soil.
    - Deploy further environmental studies to eventually bring together ongoing environmental monitoring efforts.
    - Foster standardisation of data collection for comparative purposes.
    - Make the results of these research programmes freely available and understandable for the larger public.

- **Consolidate and connect project and research experiences** – TSOs, technical institutions and industry need to work together to update/collect, consolidate and share the experience gained in UC projects so far (e.g. faults, operational risks).
    - Update reports, such as on feasibility and technical aspects of partial undergrounding of extra-high voltage power transmission lines.
    - Update UC operational performance data survey.
    - Create a platform for UC projects to enable an exchange on legislation, operations and life cycle.

Appendices – Case studies: innovative solutions

The following 380 kV partial underground projects have been selected to provide practical examples of the way in which drivers and risks have been balanced and to showcase the mitigation measures adopted by TSOs in different national contexts.

A. Amprion – Raesfeld project

System Operator:	**Amprion**
Country:	**Germany**
Length of project (total):	**150 km (Wesel - Meppen)**
Length of cable sections:	**3.4 km**
Status:	**in trial operation since 2016**
Total Project Cost:	**not available**

› Why was the project needed?

- **Connect offshore wind** - to reinforce the North-South transport corridors due to changing energy production and the growth of offshore wind.

› What are examples of drivers for going underground?

- **Pilot Project:** gain experience on undergrounding that provided value for future projects.
- **Landscape/visibility:** citizens favoured a technology that is not visible after construction.

Risk	Mitigation measure
Soil – When laying UC in open trenches under agricultural land, there are risks related to the thermal and water balance of the soil.	**Research programme** – A 10-year agricultural research programme has been conducted to increase the understanding of UC thermal and hydrological impact on the soil and of any resulting ecological impacts on flora and fauna. The main findings of the research have been: • initial impact on earthworm populations but with rapid recovery, • no noticeable changes in the thermal behavior and chemical properties of the soil during construction activities and trial operation.
Public opposition – UC raised the concerns of farmers and of citizens because of the unexpected construction site size.	**Farmer involvement** – To overcome farmers' scepticism about the impacts of UC on soil, agriculture and harvesting, they were involved in the decision-making process. **Dialogue with citizens** – Public events were organised in the construction site and a Visitor Center was set up.

B. Elia – Stevin project

System Operator:	**Elia**
Country:	**Belgium**
Length of project (total):	**47 km (Zeebrugge - Zomergem)**
Length of cable sections:	**10 km**
Status:	**operational since 2017**
Total Project Cost:	**270M€**

› Why was the project needed?

- **Connect offshore wind** - to connect approximately 1700-1800MW of planned offshore wind farms to the onshore electricity grid.
- **Connect with the UK** - to transmit power coming from the new 1000 MW HVDC NEMO interconnector from the United Kingdom.
- **Increase local capacity** - to increase capacity at the Belgian coastal region.

› What are examples of drivers for going underground?

- **Environment:** bird protection. The route runs for 5 km through a Special Protected Area (SPA) of the Bird Directive. The site is of importance for both overwintering birds (inter alia large quantities of several species of geese) and breeding birds.

Risk	Mitigation measure
Impact on system performance – Since the UC section is part of the main 380 kV network, system risks must be avoided.	**Production of the cables** – Two manufacturers were used to reduce the risk on production faults. **Behaviour** – A continuous monitoring system has been implemented to study the behaviour of the connection.
Soil – As the open trench section passes through agricultural land, there is a risk of damaging the soil composition.	**Agricultural expert present** – The presence of an agricultural expert during construction ensured that the farms in question were affected as little as possible. **Soil stacking** – This ranges from the way the soil is best stacked, to the approach to drainage work or tips about sowing crops. After the works, Elia used the location description before the works as a reference so that the farmers could receive their land back in the original state.
Drainage systems – Since the area has many small drainages under the farmland, disruption can change the hydrology and damage productivity of the land.	**Reinstating channels** – Topographic measurement of the existing drainages was done so that they could be repaired after construction. When necessary, the drainage systems were redesigned over an entire area.

C. TenneT – Randstad (South and Northring) project

System Operator:	**TenneT NL**
Country:	**Netherlands**
Length of project (total):	**80 km (Wateringen-Bleiswijk-Beverwijk)**
Length of cable sections:	**20 km (10 km South ring and 10 km North ring)**
Status:	**South ring operational since 2013, North ring operational since 2019**
Total Project Cost:	**650-700M€**

› Why was the project needed?

- **Ensure security of supply, increase transport capacity and connect offshore windfarms** - to transport a large amount of renewable energy from northern windfarms to electricity consumers.

› What are examples of drivers for going underground?

- **Population and Regulatory:** rising demand for "underground solution".
- **R&D:** need to be innovative and to push the research forward.

Risk	Mitigation measure
Soil composition – For the open trench sections, the risk exists that the soil composition is damaged and the quality of the agricultural land impacted.	**Pre-construction agreements** – TenneT made detailed agreements with landowners which state: • how the soil will be treated, • how wide the operating corridor will be, • whether separate transport path or lane is required. **Soil storage** – When the excavated material is removed, the different layers are kept distinct and placed in storage areas to avoid contamination. After construction agreements are signed with suppliers for a 5-year aftercare of soil.
Drainage systems – The area is a lowland area with complex hydrology and drainage. Disruption could change the hydrology and damage productivity of the land.	**Reinstating channels** – Topographic measurement of the existing drainages was done so that they could be repaired after construction. When necessary, the drainage systems were redesigned over an entire area.
Destabilising impacts of UC sections on the system	**Academic research programme** – A research programme with several universities and institutes was implemented to understand the systemic risks better.

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