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STUDY ON THE COMPARATIVE MERITS OF OVERHEAD ELECTRICITY TRANSMISSION LINES VERSUS UNDERGROUND CABLES

-Confidential-

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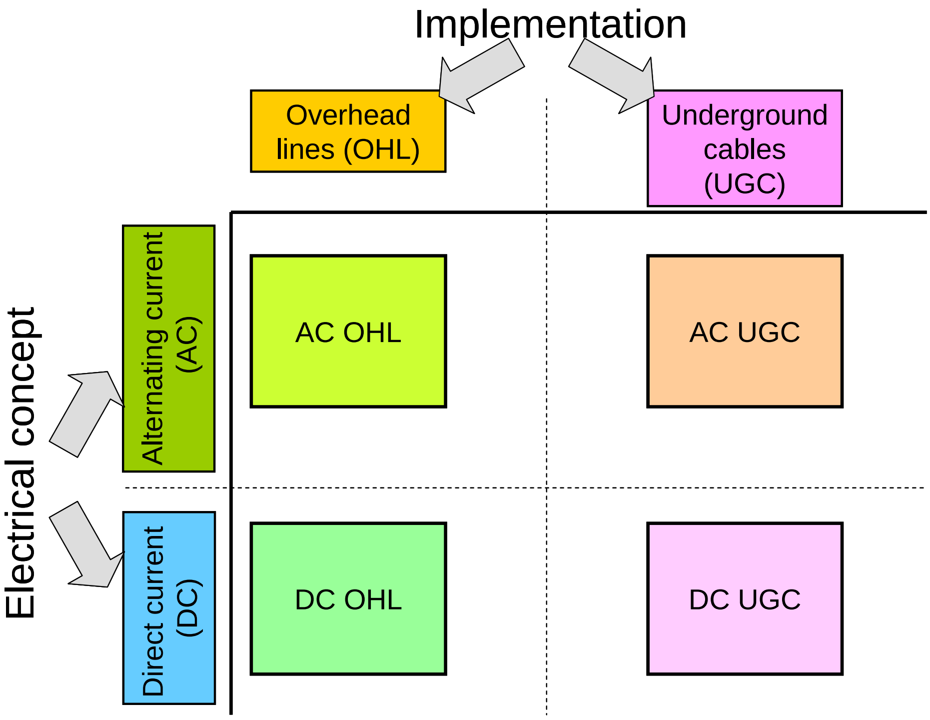
EXECUTIVE SUMMARY

Section 1 Introduction

Over the next decade, substantial extensions of the transmission infrastructure in Ireland and related investments are needed in order to accommodate increasing loads and generation of renewable electricity in line with policy targets. Overhead lines (OHL) are the reference technology for transmission of electrical power. However, the construction of new OHL and general reinforcement of the transmission system raises considerable concerns to local communities. The feasibility of potential technology alternatives to OHL is likely to be discussed publicly in all future transmission development proposals. In response to these concerns, the Minister for Communications, Energy and Natural Resources commissioned an independent study in relation to underground cables (UGC) as an alternative for OHL for transmission of electrical power.

Both options can be combined with power technologies based on alternating current (AC) or direct current (DC). The scope of the study covers the complete range of combinations as illustrated below.



The **objective** of this study is to provide an independent view on the relative merits of constructing and operating OHL compared to UGC. Technical characteristics, reliability, operation and maintenance factors, environmental impact, possible health issues and costs are regarded.
Simultaneously, a purpose of the study is to contribute in a constructive way to the ongoing dialogue between the various stakeholders in Ireland related to the matter by communicating the key findings in an unbiased and effective manner to a broader, partly non-technical public.

Section 2 Analysis of stakeholder submissions
Prior to the study the Department of Communications, Energy and Natural Resources invited the submission of statements concerning the issue in general which consequently should be reflected in the study. 522 submissions have been evaluated and the issues raised have been classified and analysed. Finally they have been put into relation with the characteristics of the technology options and in that way the submissions directly influenced the setup of the study. The review process showed that the major public concern regarding the transmission projects under discussion is related to their perceived environmental impact, mainly land use, ecology and nature conservation as well as their impact on communities and property.

Section 3 International practice
UGC at transmission level (400 kV) is a young technology showing dynamic growth. Respective components became commercially available during the last decade. The total installed circuit length is several hundreds of km worldwide, representing about 0.5% of the existing 400 kV transmission connections. With a few exceptions, however, 400 kV UGC projects were only mplemented over short distances (10 km to 20 km) and in cases where OHL simply was not feasible under the specific conditions (densely populated cities, airports, etc.). The majority of the projects do not represent transmission connections in meshed networks in a conventional sense.
In recent years, internationally, the diminishing public acceptance for new OHL became an important driver for the assessment of UGC as an alternative to OHL. Up to now, respective projects are still under discussion. Because of dedicated legal and regulative measures UGC transmission developments may accelerate in the coming years in various countries (e.g. Germany).

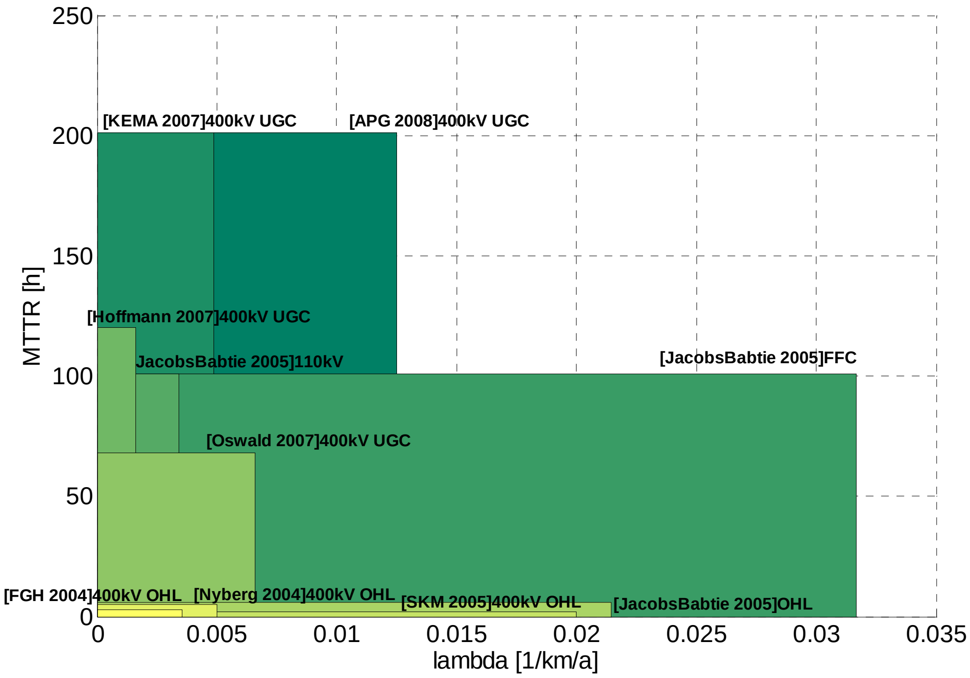
Section 4 Technology characterisation

The existing differences between the techno-economic characteristics of OHL and UGC on one hand and AC and DC technologies on the other hand hamper a direct comparison. Nevertheless, these differences have a clear impact on the suitability for a specific field of application. A detailed understanding of the components belonging to each technology option and their characteristics is a precondition for evaluating this suitability. The review describes these characteristics and possible technology developments. Finally it identifies the key cost components per technology.

Section 5 Comparison of specific techno-economic characteristics

On system level there are some key issues where the techno-economic performance of the technology options has to be compared directly. Important issues are:

- Impact on transmission system adequacy:
  Operational experience with UGC is limited and reliability figures provided in literature are highly diverse. From the current perspective the forced outage rate of UGC transmission is expected to be one to two orders of magnitude higher than that of OHL (see figure below). This figure is highly influenced by the concept of implementation[1]. This is a severe limitation of UGC. Though UGC is considered as state-of-the-art technology for 400 kV connections, the option cannot be considered being equivalent to an OHL solution from a transmission adequacy perspective in power systems.



Reported values for forced outage rate λ and mean time to repair MTTR for 400 kV OHL circuits (four bars in the lowest part of the graph) and UGC circuits; the area corresponding with each reference indicates the respective forced outage rate (FOR)

With successful demonstration this may change rapidly, but evidence of performance levels similar to those of OHL is a precondition for roll-out of large scale UGC projects.

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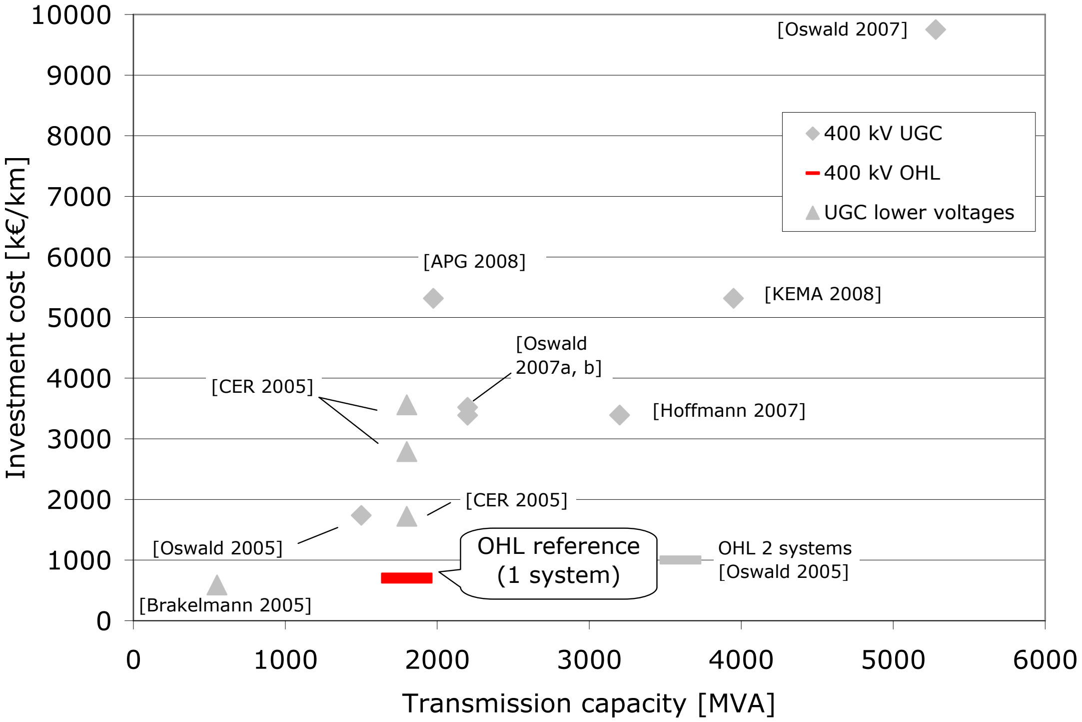
[1] The forced outage rate of UGC in accessible tunnels may be significantly lower than that of UGC buried in soil. This has not been specifically addressed in the figure above. The difference in investment costs hampers a direct comparison of UGC in soil and in tunnels.

- Operations and Maintenance
  Over the life cycle, the costs associated with transmission losses dominate the total operational costs for both OHL as well as UGC. Losses are strongly dependent on line loading. Under the operational conditions typical of the Irish transmission system, resulting cost differences between both options are likely to be insignificant. This is analysed more in detail in section 9.
  Due to the limited experience, reliable figures for maintenance costs for UGC transmission are not available. Regular UGC maintenance may be slightly less labour intensive than that of OHL. Work related to UGC repair, however, is substantial and, hence, O&M costs are extremely dependent on UGC reliability.

- Capital costs
  Capital costs for UGC are clearly higher than for an OHL of the same transmission capacity. Estimates in literature vary significantly (see figure below). This is due to the decisive influence of site specific conditions along the route. For specific cases section 9 provides estimates.



Capital costs for various UGC projects (◇ 400 kV, Δ lower voltages) in k€ per km depending on design transmission capacity and in comparison with common OHL investment levels (–)

Section 6 Comparison of environmental impacts

The purpose of this section is to provide decision-makers with an unbiased, comparative assessment of the general environmental implications of either option in environments typical of Ireland to enable them to make informed decisions in this regard. A site-specific Environmental Impact Statement (EIS) incorporating site surveys would be required to ensure a full understanding of the environmental issues associated with a specific area.

The potential positive and negative impacts of the installation and subsequent operation of OHL and UGC are considered under the following headings:

- Land Use
- Geology and Soils
- Water Resources
- Ground Restoration
- Ecology and Nature Conservation
- Landscape and Visual
- Cultural Resources
- Traffic and Noise
- Air Quality
- Communities
- Recreation and Tourism.

Under each heading facts relating to each impact listed are stated for both OHL and UGC. Proportions of issues raised by the Public Submissions are also presented and integrated where appropriate. Potential mitigation measures are presented for each impact addressed where feasible. Finally the impacts and their severity are placed side by side with potential mitigation in a summary table. The comparison between OHL and UGC is complex, and impacts are often interrelated. Mitigation measures range from where no practical mitigation is possible to where mitigation is likely to avoid discernible impact. The most significant mitigation measures can be taken during the planning and construction phases.

Section 7 Policy implications

Implementation of OHL and/or UGC requires alignment with existing policies as well as strategic preparation for future national policies. Hence, both options are described in terms of their alignment with existing and anticipated national policies relating to energy, the natural and social environment, and enterprise development. The impacts of a certain technology choice on energy policy areas are indicated in the table below and are directly associated with the outcomes of the comparative analysis in section 5.

Overview of energy policy impacts of UGC compared to OHL

Impact category	**Explanation of impact**	**Energy policy impacts of UGC compared to OHL**		
		Price competitiveness	**Security of supply**	**Environmental impacts of energy production**
Construction time	Possibly higher public acceptance of UGC → maybe shorter construction time	+ (temporal)	+ (temporal)	+ (temporal)
Electric Losses	UGC may have lower losses than OHL (high loading, same transmission capacity)	− / +		− / +
Investment cost		−		
Operational security	Less operational experiences with UGC, probably higher forced outage rate		−	

Legend: +: positive impact, - negative impact

A brief overview of relevant policies provides an overall context and serves as a basis for the environmental policy assessment. The comparative implications for each system are then assessed in tabular format for both options. As the implications during project planning, construction and operation would vary, the implications for each of these stages are distinguished from one another. It is concluded that the comparative implications of the two options as they relate to EU and National level framework legislation are generally similar. The difference in the comparison is primarily associated with three distinct stages: project planning, construction and operation.

The comparative implications for both OHL and UGC grid schemes are assessed in terms of their general alignment with both the EU enterprise policy priorities, the Lisbon Strategy and Ireland's related National Reform Programme (NRP) guidelines. The comparative assessment indicates that there is little difference between the enterprise and employment policy implications when comparing the options. Overall, both scenarios are anticipated to have the same type and degree of implications for each policy priority and NRP integrated guideline. None of the policies were determined to be adversely affected by the implementation of either scheme, as long as security of supply is not compromised.

It is concluded with regard to policy that due to a range of factors, legislation on a global scale is generally becoming more stringent and complex. Policies which were once more locally-driven and isolated are now being transformed to international framework legislation with broad, cross-cutting implications. This shift in the development of policies implies that simply complying with existing policy could be a potential risk as new, interrelated policies emerge.

Section 8 Cost allocation issues

The allocation of costs associated with a certain technology choice (OHL versus UGC) is complex and affects a variety of stakeholders. In particular external costs (e.g. devaluation of property, employment effects and possible costs of lost load in case of transmission system failures) are hard to quantify. This hampers the design of appropriate allocation schemes for these societal costs.

Section 9 Case studies

The economic performance of a set of UGC configurations has been compared with an OHL with a nominal transmission capacity of about 1700 MVA on a life cycle basis. Because of the extended distances considered (50 km and 100 km), only conventional UGC configurations with cables buried directly in soil have been evaluated in detail.

With current price levels, a double circuit UGC configuration with 3000 mm^2 aluminium conductors in soil is the option coming closest to OHL from an economic perspective[2]. With UGC investment ratios of about 5 compared to OHL and life cycle cost ratios of about 3 the cost implications however are significant (see figure below).

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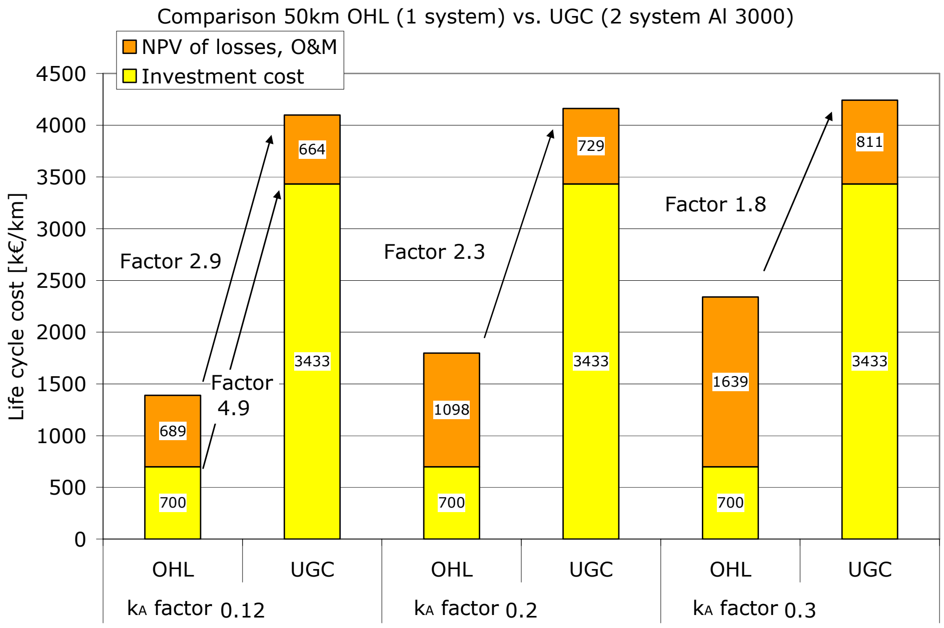
[2] Other, also more sophisticated options with lateral cooling or installations in accessible tunnels have been included for illustration in section 9. They may be promising in future but are considered being inappropriate for long distance transmission at this point of development.



Comparison of life cycle costs of reference (OHL) with AC UGC: 2 circuits Al 3000 mm2 for a distance of 50 km and various line loadings (kA = 0.12 … kA = 0.3)

The uncertainties of these outcomes are high. Depending on routing, conditions construction costs (investments) may be higher for the UGC option.
The results of the case studies, however, assume similar reliability levels. Economic impacts of potentially higher forced outage rate of UGC have not been included in the life cycle cost analysis. Given the potential differences between UGC and OHL in terms of forced outage rate, a comparison focusing on economic performance only is inappropriate, simply because the options are not directly comparable from a security of supply point of view.

Berlin, **30 May 2008**

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Introduction

On 12 March 2007 the Government White Paper *Delivering a Sustainable Energy Future for Ireland – The Energy Policy Framework 2007-2020* was launched which, inter alia, committed to ensuring completion of the ongoing capital investment programme in the transmission and distribution network by 2010 and overseeing further extensive investment. EirGrid plc, a State owned company under the aegis of the Department of Communications, Energy and Natural Resources, among others is responsible for planning the construction of high voltage transmission lines. In line with its Transmission Forecast Statement [EirGrid TFS 2007] and the Government's Energy White Paper, EirGrid is currently planning the construction and reinforcement of a number of transmission lines. In the long term, substantial extensions of the transmission infrastructure and related investments are needed in order to accommodate increasing loads and generation of renewable electricity in line with policy targets. Respective needs are identified in the recently published All Island Grid Study [DETINI DCENR 2008] as well as in preliminary results of EirGrids Grid Development Strategy [EirGrid GDS 2008].

However, the construction of new transmission lines and general reinforcement of the transmission system raises considerable concerns to local communities. In response to these concerns and noting that the feasibility of potential technology alternatives to overhead transmission lines (OHL) is likely to be discussed publicly in future transmission development proposals by EirGrid, the Minister for Communications, Energy and Natural Resources announced on 6th February 2008 that his Department would commission an independent study in relation to overhead and underground transmission lines. The aim of this initiative is to provide clarity on issues in relation to overhead versus underground transmission lines, thereby informing policy decisions on current and future transmission line projects.

A thorough assessment and consideration of all existing technology alternatives to overhead transmission lines will be an inevitable part of a successful energy policy. This study is meant to provide such an assessment supporting an informed discussion, rational choices and successful policy making related to strategic transmission planning.

Objectives

According to the tender request, "the purpose of this study is to provide the best available professional advice to the Minister on the relative merits of constructing and operating overhead transmission lines compared to underground cables, having regard to technical characteristics, reliability, operation and maintenance factors, environmental impact, possible health issues and cost". This advice has to support the Minister in further developing the policy areas affecting electrical infrastructure in Ireland. These policies cover the next decade and will be decisive for the success in a number of key policy areas (including security of supply, renewable energy and climate targets, economic growth). In this perspective, an underlying objective of the study is to incorporate recent international achievements and the best available knowledge, assuring a strategic and societal view on the matter.

Simultaneously, a purpose of the study is to contribute in a constructive way to the ongoing discussions between the various stakeholders in Ireland related to specific projects (Tyrone – Cavan – Meath connection). The report has to communicate the key findings in an unbiased and effective manner to a broader, partly non-technical public.

Methodology

The time frame for the study was ambitious and in line with the Terms of Reference the approach was limited to a desk study. The methodology was based on the following components:

1. *Analysis of the stakeholders' submissions:* the submissions provided by the stakeholders were analyzed in order to identify the issues raised by the public consultation.
2. *Existing expertise:* the extensive knowledge and experience of the consultants with respect to the subject formed the foundation for problem definition and the following assessments.
3. *Literature review:* the related literature has been thoroughly reviewed with particular emphasis on most recent references.
4. *Expert consultations:* for specific issues industry representatives have been approached for testifying assumptions and checking the quality of references.
5. *Case studies:* in two case studies the techno-economical performance for transmission line projects has been investigated, supporting an indicative, but quantitative comparison between the different technology options. The assessment was based on existing in-house models, which have been adapted to the dedicated calculations required in the course of this study.

Structure of this report

Section 1 introduces the technologies being considered and justifies the selection.

In section 2, the review of the stakeholders' submission is presented. The main issues raised by the public are discussed and the related statistics are presented.

Section 3 provides a review on the current international practice with particular emphasis on underground cabling as a potential alternative to OHL transmission. Statistics on UGC projects are presented, followed by a review of projects that present similarities to Irish conditions. For illustration, related policy developments in other countries with a focus on Germany are reflected.

Section 4 provides an extensive review of the latest commercially available technologies under consideration. This review results in a comparison of the key techno-economic characteristics of the different technologies from a transmission system perspective.

In Section 5, the environmental impacts of the different technologies are addressed. The subjects raised by the stakeholders' submissions in chapter 2 are extensively analyzed.

Section 6 presents the policy implications induced by the different technological options. Again, special focus is given to the issues raised by the public consultation, followed by an analysis of the main related issues.

The allocation of existing cost differences between the technology options is addressed in section 7. This section contains a limited assessment of the impact of costs and their allocation on different stakeholders.

In section 8, the economic performance of the technology options is assessed for two specific cases. The cases are concrete in a sense, that they are reflecting specific routing conditions. However, they do not represent real projects currently under development in Ireland. The outcomes serve as support for the generic technology comparison.

Finally, section 9 summarises the key conclusions of this study.

1 Electrical power transmission technologies

1.1 Transmission systems reinforcement and extension

The electricity transmission system is the backbone of electrical power systems. In its planning a variety of objectives have to be balanced, being:

- maintaining the security of supply;
- ensuring well-functioning competition on the power market;
- ensuring optimum integration of renewable energy and other energy sources;
- minimizing the environmental impact;
- creating robustness in relation to future requirements; and
- doing all this against lowest possible societal cost.

From different perspectives, the All Island Grid Study [DETINI DCENR 2008] and the Transmission development strategy of EirGrid [EirGrid TDS 2008] quantified the substantial need for further reinforcement and extension of the transmission system in Ireland.

1.2 Transmission technology options

Internationally, **overhead transmission lines** (OHL) transporting electrical power as **alternating current** (AC) are the standard choice for transmission connections in Ireland and elsewhere, certainly for voltages of 220 kV and higher. However, a number of alternatives exist.

- Technologies allowing transport of electricity via **direct current** (DC) evolved dramatically during the last decades. Because of the limitations associated with AC cable transmission over long distances, DC is the standard technology for submarine interconnectors. Examples are the 500 MW Moyle interconnector between Northern Ireland and Scotland and the 700 MW, 580 km NorNed HVDC interconnector under construction between Norway and The Netherlands[3].
- Recently, progress has also been achieved with high voltage (HV) and extra high voltage (EHV) **underground cables** (UGC) for AC. Respective technologies are commercially available for voltages up to 500 kV. From an implementation perspective UGC forms a potential alternative for OHL. Up to now, application of AC UGC at 400 kV levels is restricted to projects where implementation of OHL was impossible.

Both alternatives can be combined (see Figure 1-1). A prominent example of DC UGC onshore is the 180 km Murray link interconnector in Australia with a transfer capacity of 220 MW.

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[3] The converter stations required for DC offshore interconnectors often are not installed directly at shore but close to the connection point with the AC network. In such cases the onshore part of the connection sometimes is implemented as UGC too.

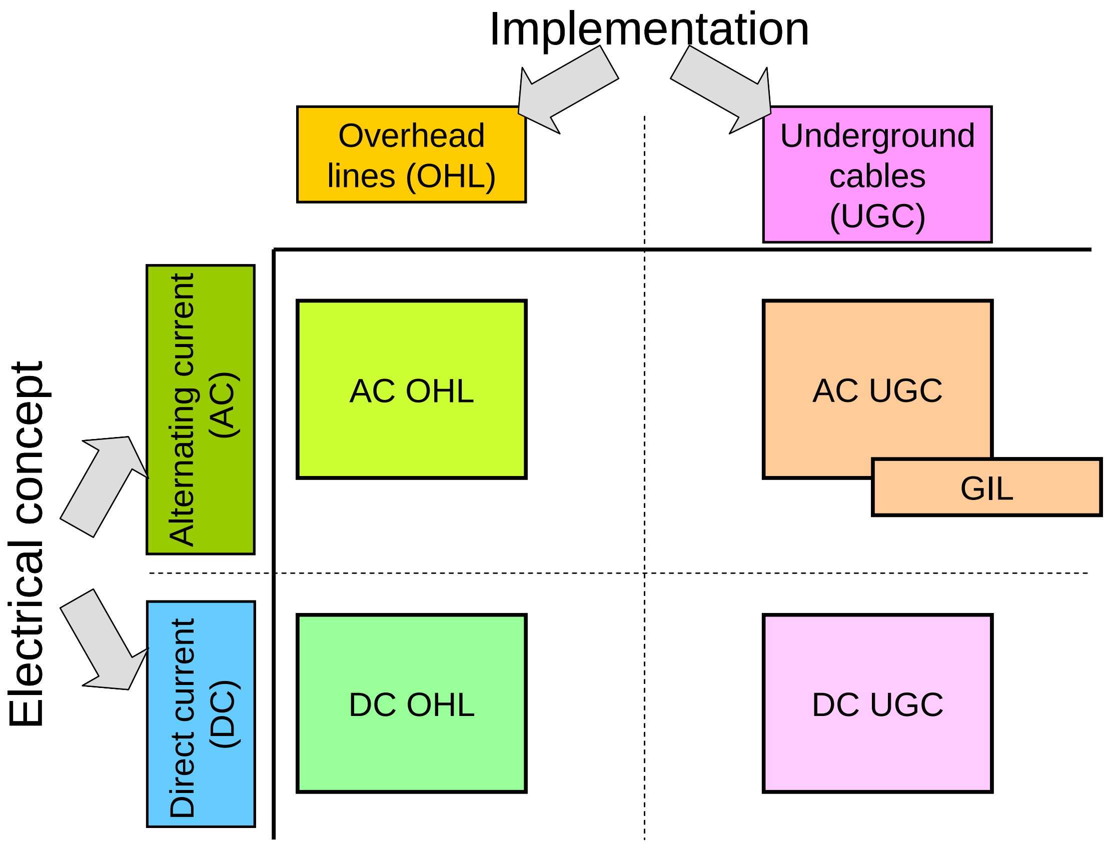

Figure 1-1 Technology choices for electrical power transmission

A special technology for AC underground transmission is the so called **Gas Insulated Line** (GIL) conductor. This technology has been included in comparative assessments in a number of desk studies as another option next to UGC [KEMA 2008] [Oswald et al 2005] [Oswald 2008]. However, up to now, GIL connections have never been planned, permitted, engineered and certainly not realised over distances as of interest for this study. For that reason this technology is addressed in Appendix 5 – Gas Insulated Line Conductors – GIL but not included in the analysis in the main part of this report.

Hence, this report will assess the technical and economical capabilities and implications of the alternatives to AC OHL and, in that course will cover the complete range of options indicated in Figure 1-1, except GIL.

2 Review of stakeholder submissions

2.1 Background

On 1st October, 2007, EirGrid issued a press release presenting two new projects in the North East. Three open days for public consultation on the projects were proposed (11th, 16th and 17th October, 2007), where related stakeholders would have the opportunity to make their views known before route options studies were completed and a final route was chosen [EirGrid 2007a]. In response to a request from the public, in a new press release on 9th November, 2007, EirGrid proposed three new open days (27th, 28th and 29th November, 2007) where discussions on the issues of EMF and other factors relating to overhead lines and underground cables would be held [EirGrid 2007b]. Additionally, EirGrid invited those with comments regarding the proposals to take part in a four-month consultation process. In a new press release dated 22nd January, 2008, EirGrid invited submission of statements on the projects via email or post by 11th February, 2008. In a press release dated 12th February, 2008, the Department of Communications, Energy and Natural Resources (DCENR) invited the submission of statements concerning the issue in general by 7th March, 2008 as part of the study to be undertaken by independent consultants [DCENR 2008].

In this period, a total number of 522 stakeholder submissions were received, from single-page submissions from inhabitants of affected areas, to extensive reports compiled by external consultants for groups opposing the project. This chapter presents the results and conclusions from the review of the stakeholder submissions which reflect the general opinion of the stakeholders on the project. The methodological approach followed for the analysis of the submissions focuses mainly on preserving the integrity of the information contained in the submissions and presenting it in a comprehensive manner. First, the methodology followed for the classification and analysis of these non-uniform submissions is discussed, and subsequently the results from their analysis are presented.

2.2 Classification of submissions

The submissions were classified by the DCENR into three main categories according to their extent and origin and were as such delivered to the consultant. The categories defined by the DCENR are the following:

A. ***State submissions:*** this category corresponds to submissions from state bodies, public representatives and representative bodies. A total of 27 were received. They correspond to reports, presenting a holistic analysis on the related issues.
B. ***Detailed submissions:*** this category contains mainly lengthy submissions from single persons (or petitions) and submissions from local representative groups. There was a total of 60 submissions in this category.
C. ***General submissions:*** this category corresponds to non-extensive submissions, mainly from single persons (inhabitants of the affected areas). There was a total of 435 submissions in this category.

All submissions were scrutinised by Ecofys and Golder. No single submission was considered to carry any more or any less value than another. Therefore it was agreed that no special weighting was to be applied based on the categories defined above. For the sake of clarity, this classification is kept through the course of the analysis presented in the following sections.

2.3 Methodology for the analysis of the stakeholder submissions

The focus of the approach for the submissions analysis has been the preservation of the enclosed information without any interference from the analyst, in order to achieve the objective presentation of the public opinion as indicated in the submissions. For this, the following points were of main interest:

- ***Categories:*** the three categories were considered as different and were treated independently. The results from the analysis are therefore presented for each category separately.

- ***Petitions:*** some of the submissions in category C were signed by more than one person. The number of persons signing each submission has been used as a weighting factor in this case. In total, 806 signatures were counted for the 435 submissions in category C.

- ***Classification of submissions:*** the issues presented in the submissions were organised in the form of a matrix (*submissions matrix*). The issues were classified according to three main themes: environmental, policy and technical. Furthermore, a number of issues were sub-categorised under each main theme. Therefore, each main theme includes a number of sub-issues presented in the submissions. The structure of the submissions matrix is as follows:
  - ➢ *Environmental issues:*

    1. Land use: disruption to agriculture, route flexibility, access rights, length of construction, farm buildings, land take, livestock, land sterilisation.

    2. Geology and soils: agricultural soil, alluvial soil, digging trenches, peatland, deep cultivation, temperature variation, rock blasting, tunnelling, waste rock removal.

    3. Water resources: water courses, drainage, disruption to groundwater, risk of pollution.

    4. Ecology and nature preservation: migration, birds, flora, mammals, insects, habitat, aquatic ecosystems, pollution.

    5. Landscape and visual impact: access tracks, character, features/monuments, infrastructure interfaces, urban areas, rural areas, water vistas.

    6. Cultural impacts: agricultural heritage, archaeological, irish language, historic.

    7. Traffic and noise: construction traffic, construction noise, operations traffic/noise.

    8. Air quality: greenhouse gas.

    9. Impacts on communities: severance, future developments, non-EMF related safety issues, educational enrolment, cohesiveness/quality, personal liability for associated risks, business/economy, health issues, property prices.

    10. Recreation and tourism: public rights of way, tourism industry, GAA, hot air ballooning, aviation, soccer, shooting, nature trails, hiking, water sports, animal breeding (non-equine), fishing, golf, canoeing, cycling, horse riding, filming.

    11. Ground restoration: mitigation measures, tree felling, ground recovery.

    12 Decommissioning: recycling, system dismanting effects.

  - ➢ *Policy issues:*

    12. Best international practice: energy, environment, enterprise, future.

    13. Best EU practice: energy, environment, enterprise, future.

    14. Best national practice: energy, environment, enterprise, future.

  - ➢ *Technical issues:*

    1. Technology choice: type of transmission technology (OHL/UC, AC/DC), availability of joints, intersectional undergrounding, reference projects (general, voltage levels, distances), cable technology (fluid-filled/XPLE).

    2. Technical performance: energy losses, electric/magnetic fields, availability & reliability, reactive power compensation, power quality, security of supply.

    3. Costs: life-cycle/capital costs, costs of energy losses, maintenance costs, decommissioning costs, costs ratios, costs for permissions.

    4. Others: necessity of the circuit, construction time, project delays if OHL, impacts on system stability, construction time.

Each time a comment related to a specific issue is presented, one point is allocated in the submissions matrix under its corresponding theme or sub-category. These points were used for the quantification of the issues presented in the submissions. Pie charts illustrating the emphasise put on certain issues by the submitters are presented at the beginning of each relevant section.

2.4 Results

The vast majority of submissions favour underground cables rather than overhead lines. Although the necessity of the energy infrastructure in the country's development is generally recognised, the stakeholders argue that the negative impacts from overhead lines necessitate the use of underground cables. In the following section, the stakeholder issues are presented in graphical form in accordance with the categorised themes of the submissions/issues matrix, i.e. environmental issues, policy issues, technical issues.

An overview of the issues arising in the submissions is presented in Table 1.1 below, together with the total number of submissions. Clearly, the vast majority of issues correspond to concerns on the environmental impacts. Policy issues mainly appear in the state submissions (category A), while in the general submissions (category C), technical issues are generally absent.

Table 2-1: Overview of the issues and total number of submissions for each category

	Environmental issues	**Policy issues**	**Technical issues**	**Number of submissions**
SUBMISSIONS A	119	24	48	27
SUBMISSIONS B	176	8	45	60
SUBMISSIONS C	795	3	14	435
TOTAL	**1090**	**35**	**107**	**522**

2.4.1 Environmental issues

A histogram of the points for the issues on the environmental theme is presented in Figure 2-1 below, for the state and detailed submissions, while in Figure 2-1 the same graph for the general submissions is presented (in this case the y-axis corresponds to number of signatures). The areas of most concern fall under potential impacts to the following three categories:

1. Communities
2. Land Use
3. Ecology and Nature Conservation

Under the category of Communities, 474 of the 522 submissions expressed concern over perceived health risks: 19 from Category 1, 50 from Category 2 and 405 from Category 3. A further major issue under this category includes perceived property value depreciation as a result of the installation of OHL.

143 submissions addressed Land Use as a result of the installation of OHL: 11 from Category 1, 21 from Category 2 and 111 from Category 3. Of these, the majority raised concerns over the perceived health risks to livestock.

148 submissions expressed concerns over the effects on Ecology and Nature Conservation: 12 from Category 1, 22 from Category 2 and 114 from Category 3. These concerns centred on the possibility of birds striking OHL and the OHL acting as a barrier to feeding and migratory pathways. Other areas of concern include possible effects on mammals and habitats.

The impacts that directly relate to everyday living are those that are of most concern i.e. Communities and Land Use. The other categories which include geology and soils, water resources, landscape and visual, cultural, traffic and noise, air quality, recreation and tourism, ground restoration and decommissioning are of no lesser relevance to impacts from OHL or UGC. However, the number of submissions that addressed these categories was significantly less.

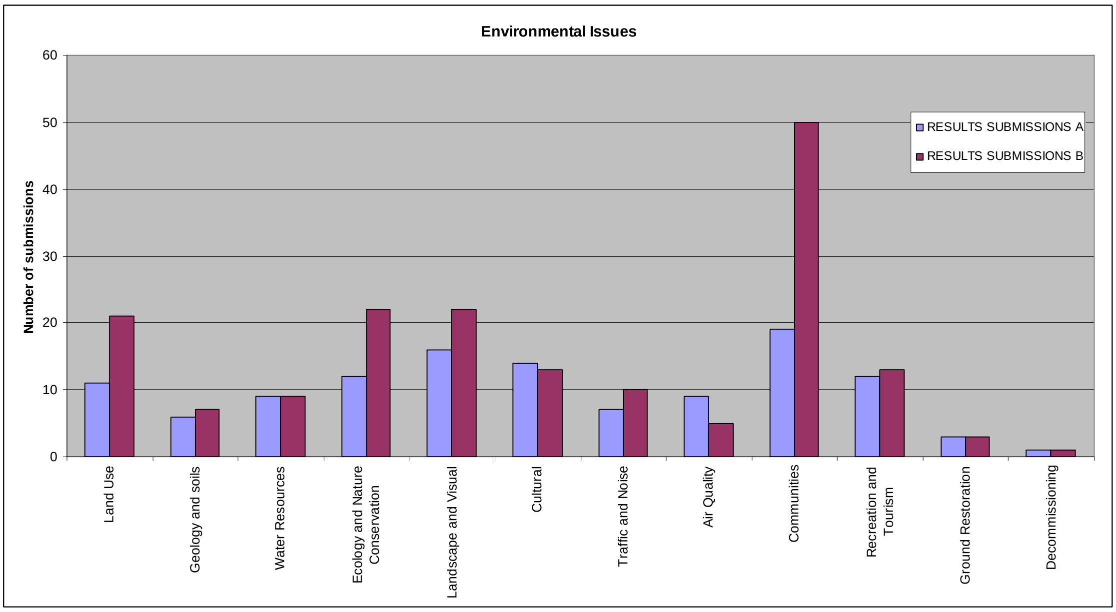

Figure 2-1 Environmental issues - Categories A (state submissions) and B (detailed submissions)

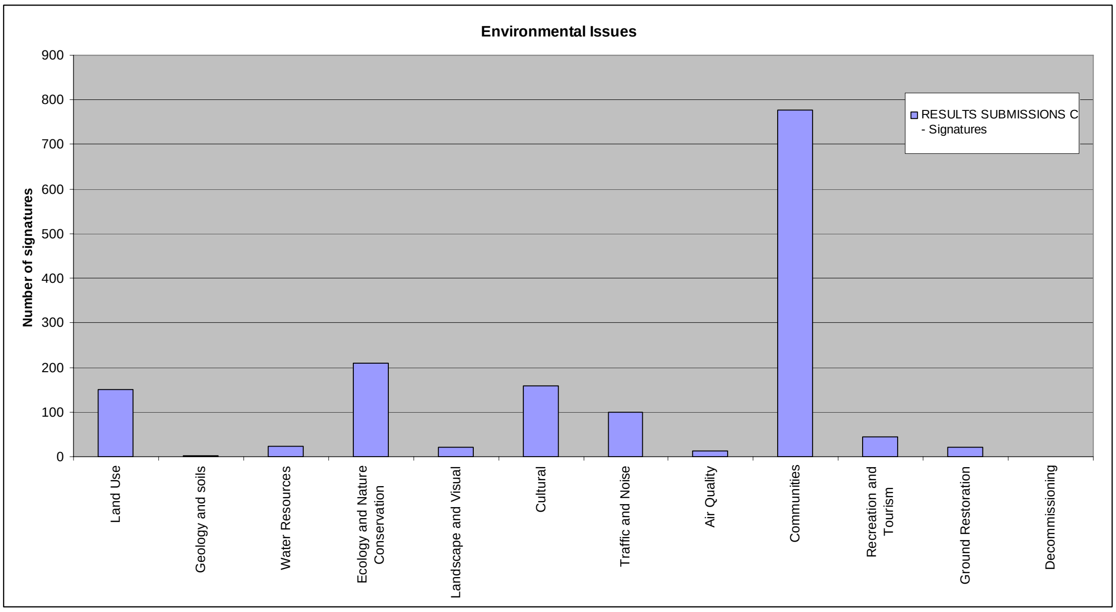

Figure 2-2 Environmental issues - Category C (general submissions)

2.4.2 Policy issues

As shown in Table 2-1, submissions addressing policy issues were considerably less than those addressing technical or environmental issues. Issues relating to policy mainly appeared in the state submissions and were rarely mentioned in the other two categories. Of these, the majority related to EU- and National-level policies.

It should be noted that the majority of the submissions which mentioned policies did not address concerns directly related to the policies themselves; rather, the references to certain policies were generally used to support their primary concern related to technical, environmental or enterprise issues. Furthermore, many of the policies discussed were related to specific local development plans, which is beyond the scope of this report.

2.4.3 Technical issues

Technical issues are mainly addressed in the state and detailed submissions. In Figure 2-3, the histogram of the related issues is presented. The different issues appear in a uniform manner in the state submissions. In the detailed submissions, most submissions centred on the technology choice.

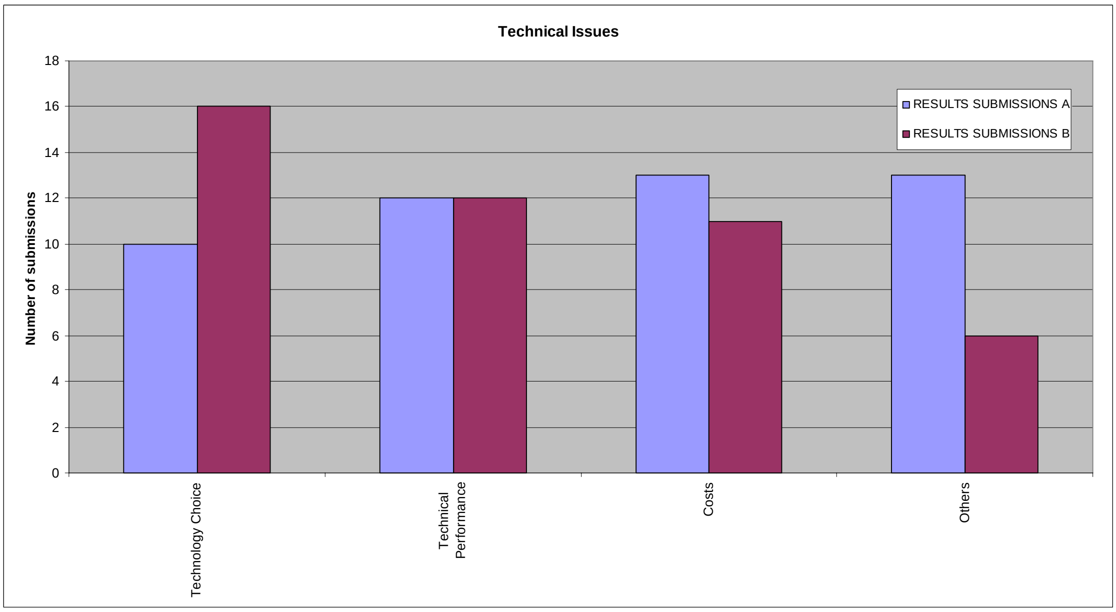

Figure 2-3 Arguments on technical issues Categories A (state submissions) and B (detailed submissions)

2.5 Summary and conclusions

A total number of 522 stakeholder submissions were received and were classified by DCENR into three main categories based on their origin and extent. The analysis of the submissions mainly focused on the preservation of the enclosed information in order to achieve the objective presentation of the public opinion. The submissions were scrutinised and an argument matrix was populated accordingly, the submissions matrix. In this matrix the criteria inherited in the submitted arguments were put in relation with the transmission technology options.
The review process showed that the major public concern regarding the transmission projects under discussion is related to their perceived environmental impact, mainly land use, ecology and nature conservation as well as their impact on communities and property. Policy related and technical issues were mainly raised in the state and detailed submissions. The technical issues then supported the consultant's selection of technologies that were to be considered in the comparative analysis of techno-economic performance (sections 4 and 9).

3 Current international practice

The objective of this section is to illustrate the latest commercially available technology in transmission systems and to qualify the technology options by international reference projects. This review provides a clear understanding for fundamental design choices and investment decisions. Simultaneously, this work package identifies the realistic options for implementation in the Irish context and acts as a filter for the complete set of options to be reviewed.

The section is divided in three main parts:

- First, some basic statistics are presented, illustrating the status of the UGC implementation worldwide.
- Secondly, a number of UGC projects and country cases being relevant for the Irish situation is discussed. These are projects which have been initiated or realised and were driven by two criteria, being
    - visual amenity and
    - health arguments and similarity of general conditions (part of transmission system, distance, capacity).

  The reasoning behind the implementation of these projects is investigated and the lessons learned by each case are highlighted. Special focus is given on the performance and status update of the projects identified as relevant (in the sense of the above mentioned criteria) and reported in [Jacobs Babtie 2005]. The update does not refer to projects reported as non-relevant in [Jacobs Babtie 2005]. Where appropriate, further projects are presented as for example an ongoing important case in Austria, where a new EHV transmission line has been discussed for several years now.
- Thirdly, political discussions about the possible undergrounding of new transmission circuits are presented. Germany is taken as a showcase for this since the challenges related to transmission extension are regarded as comparable to the Irish case.

It should be noted that submarine cables are not included in the analysis, since they are considered as irrelevant to this study.

3.1 Basic Statistics

As mentioned, the majority of the transmission grid around the world is overhead. In Table 3-1, the total length of underground cable circuits (km) installed worldwide by 2006 is presented, based on the findings of the CIGRE Working Group B01.07 reported in [CIGRE_B01.07 2006]. In this summary submarine cables were excluded from the scope as well as DC cables since these also are predominantly submarine.

Table 3-1 and Figure 3-1 show that the proportion of UGC circuits internationally decreases with voltage from 6.7% for the 50 kV to 109 kV range down to 0.5% for the 315-500 kV range. In absolute numbers, this 0.5% for circuits in the voltage range of 315 kV to 500 kV corresponds to 1397 km. However, it should be noted that these statistics include both fluid filled (FF) and XLPE technologies. Until now, 400 kV to 500 kV AC cables for transmission are nearly exclusively used in short sections in urban areas and only rarely in open country.

The percentage between UGC and OHL is closely related to the geographical area of reference and the voltage level. In particular, certain geographical areas have such high population density and such high land values that it is difficult to find suitable overhead line routes, for example central Paris, Singapore and Hong Kong island.

In several countries a political decision has been taken on undergrounding the lower voltage networks. For example, in the Netherlands, the low voltage and medium voltage networks have been put underground apparently completely since the late 1970's. Nevertheless, the technology differences between low and medium voltage UGC on the one hand and extra high voltage UGC on the other hand are substantial. This trend at lower voltage levels cannot be extrapolated directly to transmission system planning.

In Figure 3-2, the percentage of the total length of UGC related to OHL at the 315 kV to 500 kV voltage level is presented for different countries.

Table 3-1: Total length of UGC circuits (km) installed worldwide by 2006.

Country	50-109 kV	110-219 kV	220-314 kV	315-500 kV
Denmark	1930	515		52
France	2316	1	903	2
Germany	857	4972	45	65
Italy	0	907	197	34
Japan	11760	1769	1440	123
Korea	2	2144		221
Netherlands	2558	1068	6	7
Singapore	1185		651	111
Spain	509	181	479	80
United Kingdom	1457	2967	496	166
USA	946	2904	663	536
Total (km)	**23520**	**17428**	**4880**	**1397**
Percentage (%)	**6.7**	**2.9**	**1.7**	**0.5**

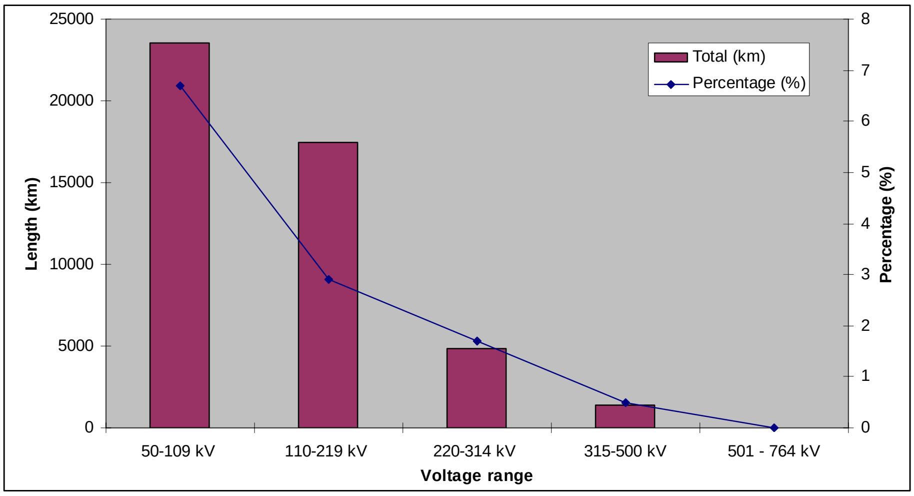

Figure 3-1 Total length of underground cables installed worldwide in 2006 and percentage relative to overhead lines. [CIGRE_B1.07 2006].

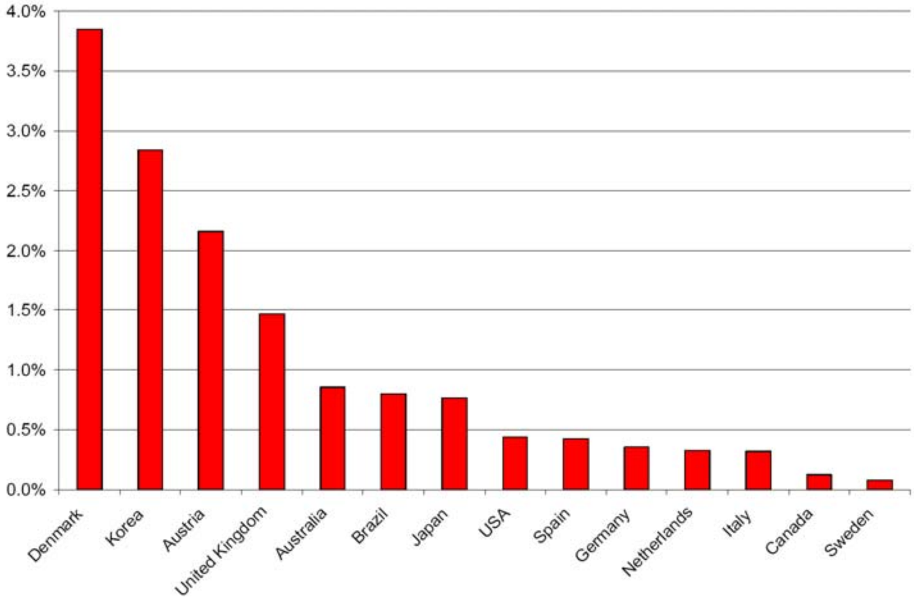

Figure 3-2 Percentage of the total circuit length underground at the 315 kV to 500 kV voltage range; data for 2006 [CIGRE_B1.07 2006]

For UGC transmission lines as discussed in the context of this report only XLPE cables are of interest and, hence, the following analysis focuses on them. As can be seen in Figure 3-2, Denmark is the country with the highest percentage of UGC for the higher voltage range (315 kV to 500 kV). According to [Elinfrastrukturudvalget 2008b] from the total of AC XLPE cable at the 400 kV to 500 kV level installed in the world today, about one third has been laid in Denmark. The longest cable in Denmark is found in Copenhagen. It is 20 km long but consists of two sections as a substation has been added halfway. The longest XLPE cable at the 400 kV to 500 kV level in the world is found in the city of Tokyo. A 40 km long 500 kV cable circuit implemented in a dedicated, accessible tunnel transmits power to downtown Tokyo from an overhead line network encircling the city. In addition, the city of Tokyo has an extensive 275 kV cable grid.

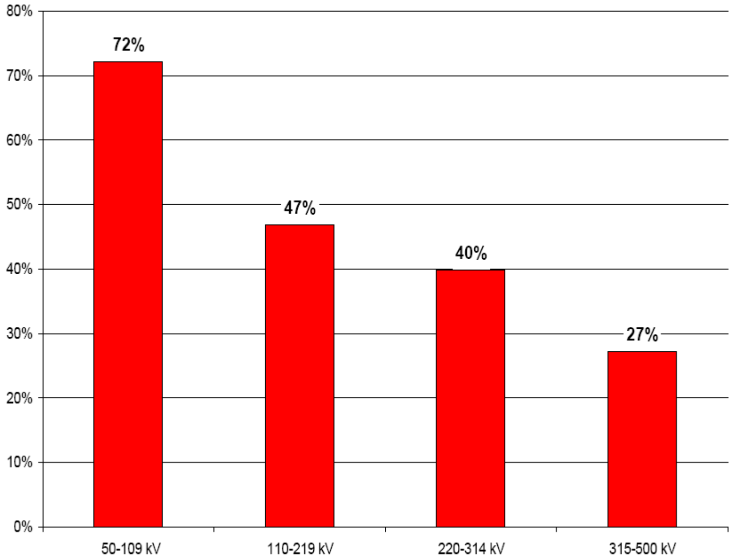

Figure 3-3 Share of XLPE in total installed UGC circuit length depending on voltage level [CIGRE_B1.07 2006]

In Figure 3-3, the percentage XLPE cables in total UGC is presented for the different voltage ranges [CIGRE_B1.07 2006]. The decreasing proportion of XPLE insulation used at the higher voltages reflects the incremental development of these cables. Lower voltage cables were developed first and as the technology improved XLPE was applied to higher voltages representing higher electrical stress. 50 kV XLPE cables have been in use since the early 1960s, whereas 400 kV and 500 kV transmission circuits using extruded insulation were introduced only in the late 1990's.

The latest reported length of totally installed 400 kV XLPE circuits worldwide differ according to the source: [Elinfrastrukturudvalget 2008b] estimates the length to 250km whereas [KEMA 2008] reports 830km.

To show the market penetration of this technology in another example Figure 3-4 and Figure 3-5, indicate the length of the installed XLPE cables for EHV levels in Europe per year [Ritter 2007]. From the mid-1990's a steep increase in the implementation of XLPE cables takes place.

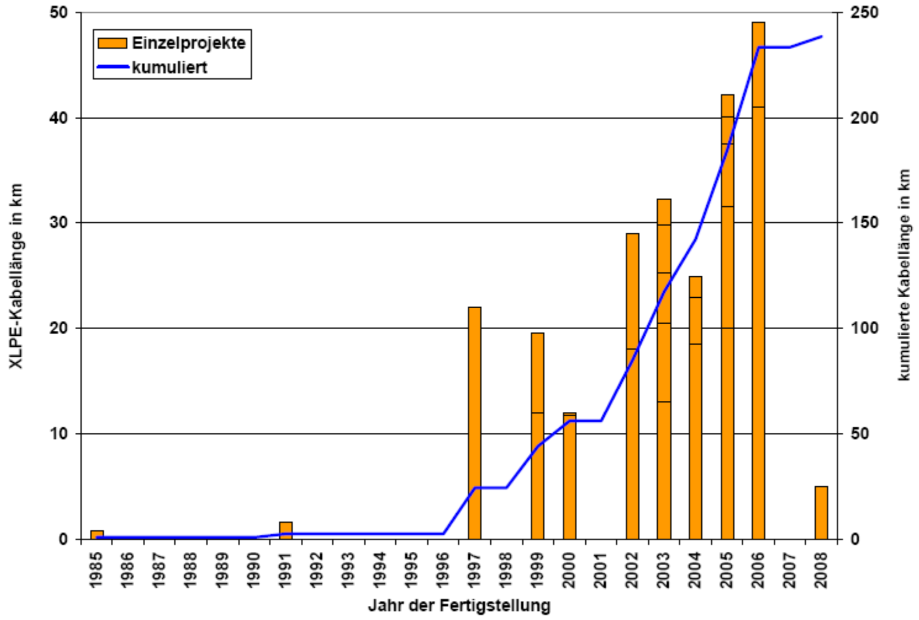

Figure 3-4 Annual growth and cumulated circuit length of ≥220 kV / <400 kV XPLE UGC in Europe [Ritter 2007]

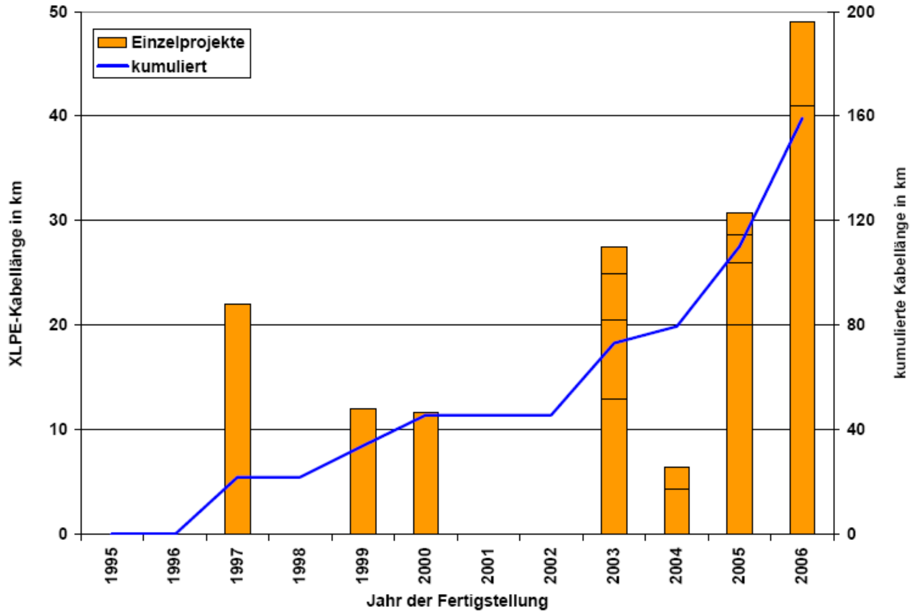

Figure 3-5 Annual growth and cumulated circuit length of 400 kV XPLE UGC in Europe [Ritter 2007]

The figures clearly indicate the growth of UGC application in the last number of years, illustrating that this technology has reached maturity.

In addition to the AC UGC figures, a Figure 3-6 provides an overview of projects realised with HVDC VSC by one manufacturer. The figure also includes submarine cabling projects. The following projects have been implemented as UGC due to environmental issues among others according to [ABB 2007] [ABB 2005]:

- Gotland (Sweden, 1999): 70 km
- Directlink (Australia, 2000): 65 km
- Tjäreborg (Denmark, 2000): 4.4 km
- Murraylink (Australia, 2002): 180 km
- Estlink (Estonia, 2006): 105 km, partly subsea

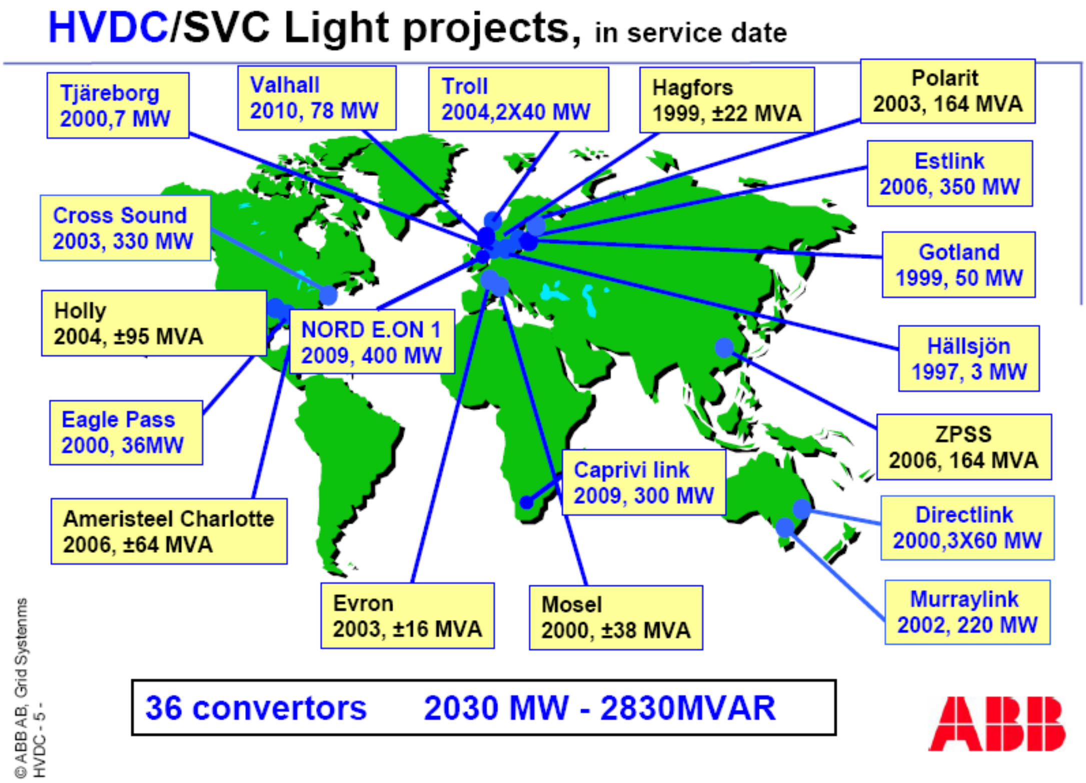

Figure 3-6 Overview on ABB's HVDC VSC projects worldwide (blue characters)

3.2 UGC projects and study cases

The objective of this paragraph is to review relevant UGC projects worldwide and identify the main drivers that lead to their realisation. This review is not meant to be complete but provides a status update of the most relevant projects reported in [Jacobs Babtie 2005] and additional projects that have been realised since 2005. Finally, policy developments related to the appropriate technology choice for new transmission projects in selected European countries are reviewed. As an illustrating example the case of Germany is discussed in more depth.

3.2.1 Existing and ongoing UGC projects

An overview on relevant worldwide UGC projects realised before 2005 is presented in Table 3-2.

Table 3-2: UGC projects realised before 2005 [HOFFMANN 2007] [Jacobs Babtie 2005]

Project Name / Place	Voltage Level	Distance	Start-Up	Drivers	Source/ Remarks
Nesa South Project (Kopenhagen I)	400 kV	22.0 km	1997	Urban Area	Jacobs Babtie 2005, HOFFMANN 2007
Nesa North Project (Kopenhagen II)	400 kV	12.0 km	1999	Urban Area	Jacobs Babtie 2005, HOFFMANN 2007
Shinkeyo –Toyosu	550 kV	40.0 km	2000	Urban Area	Jacobs Babtie 2005, HOFFMANN 2007
Berlin	420 kV	12.0 km	2000	Urban Area	Jacobs Babtie 2005, HOFFMANN 2007
Taipeh -Taiwan	345 kV	20.0 km	2003	Urban Area	HOFFMANN 2007
Barajas Airport, Madrid, Spain	420 kV	13.0 km	2004	Urban Area	Jacobs Babtie 2005, HOFFMANN 2007
Aalborg – Aarhus, Jutland, Denmark	420 kV	14.7 km	2004	Environmental Issues Urban Area Active Local Objectors	Jacobs Babtie 2005, HOFFMANN 2007
TOTAL		133.7 km			

An overview on UGC projects realised since 2005 is shown in Table 3-3 [HOFFMANN 2007] [Jacobs Babtie 2005]. More than 60km of new 420 kV XLPE UGC systems were installed in the years 2005 – 2006 with another 33 km of new 345 kV XLPE UGC systems being installed in 2006 – 2007. Others projects are to be realised shortly.

Table 3-3: UGC projects realised since 2005 [HOFFMANN 2007] [Jacobs Babtie 2005]

Project Name / Place	**Voltage Level**	**Distance**	**Start-Up**	**Drivers**	**Source/ Remarks**
London	420 kV	24.5 km	2005	Urban Area	HOFFMANN 2007
Oslo	420 kV	2.1 km	2005	Urban Area	HOFFMANN 2007
Abu Dhabi	420 kV	12.5 km	2005	Urban Area	HOFFMANN 2007
Thessaloniki	420 kV	6.0 km	2005	Urban Area	HOFFMANN 2007
Dartford Cable Crossing, England	400 kV	2.6 km	2005 ?	Urban Area	Jacobs Babtie 2005
Mailand	420 kV	8.4 km	2006	Urban Area	HOFFMANN 2007
CL&P's Bethel - Norwalk project	345 kV	3.4 km	2006	Urban Area	HOFFMANN 2007
Taipeh –Taiwan	345 kV	1.2 km	2006	Urban Area	HOFFMANN 2007
Wien	420 kV	5.2 km	2006	Urban Area	HOFFMANN 2007
NU - UI for NUSCO	345 kV	13.0 km	2006 ff	n/a	HOFFMANN 2007
NSTAR Boston	345 kV	28.8 km	2007 ff	Urban Area	HOFFMANN 2007
Davutpasa–Ikitelli (Istanbul)	420 kV	13.0 km	2007 ff	n/a	HOFFMANN 2007
Westham–Hackney England	420 kV	12.6 km	2007 ff	Urban Area	HOFFMANN 2007
PhVII–GTC/124 Qatar	420 kV	15.0 km	2007 ff	n/a	HOFFMANN 2007
TOTAL		148.3 km			

The updated information on realised projects worldwide shows that application of EHV XLPE UGC is growing dynamically. Clearly, the main driving factor remains restricted space in urban areas, prohibiting implementation of OHL and leaving UGC as only technically feasible alternative. At the same time, no UGC of remarkable system length was realised in the last three years. The majority of all projects remain below a distance of 30 km. Thus, the 40 km long Shinkeyo Toyosu JP 550 kV cable installed in the year 2000 remains the longest project so far.

Up to now, construction and operation of an EHV UGC in Ireland with a length of up to 100 km would not be backed by any experience worldwide.

3.2.2 Transmission projects with UGC considered

An overview on UGC projects under consideration in 2008 – 2020 is shown in Table 3-4 [HOFFMANN 2007] [Jacobs Babtie 2005] [EC TEN-E 2007] and others.

Table 3-4: UGC projects under consideration for implementation between 2008 – 2020 [HOFFMANN 2007] [Jacobs Babtie 2005] and others

Project Name / Place	Voltage Level	Distance	suggested implementation date	Drivers	Source/ Remarks
P/Ser - Singapur	400 kV	9.0 km	2008	n/a	vgl. Transpower 2005
P/Ser - Singapur	400 kV	10.0 km	2008	n/a	vgl. Transpower 2005
ConEDCrawford, Taylor and West loop	345 kV	16.0 km	2008	n/a	HOFFMANN 2007
Taweelah Area, Abu Dhabi and EMAL smelter	400 kV	22.0 km	2008 ff	n/a	HOFFMANN 2007, http://press.xtvworld.com/article23222.html
CL&P's Middletown - Norwalk line	345 kV	39.0 km	2008/ 2009	n/a	HOFFMANN 2007
Neptune RTS Duffy AV –Newbridge	345 kV	4.0 km	2009	n/a	HOFFMANN 2007
Südburgenland - Kainachtal (Styria), Austria	380 kV	98.0 km	2009	Public Opposition	Jacobs Babtie 2005, EC TEN-E 2007
St. Peter - Tauern (Salzburg), Austria	380 kV	161.0 km	2009/ 2011	Public Opposition	KEMA 2008, OSWALD 2007, HOFFMANN 2007
Shanghai -Shiboand Sanlin	550 kV	17.0 km	2010	n/a	HOFFMANN 2007
LIPA NY –Newbridgeconnector projekt	345 kV	20.0 km	2010 ff	n/a	HOFFMANN 2007
Lienz - Cordignano (Austria - Italy)	n/a	154.0 km	2015	Public Opposition	EC TEN-E 2007
Brenner Pass Thaur-Brixen (Austria - Italy)	n/a	52.0 km	2020	Public Opposition	Jacobs Babtie 2005, EC TEN-E 2007
TOTAL		600 km			

The European entries in the overview above are some of the priority projects identified in the TEN-E programme of the European commission. As many other transmission connections in the programme originally they have been drafted as OHL connections but are subject to massive objections from local authorities, interest groups and individuals. This local resistance is related to concerns about the negative effects of OHL being:

- Perceived visual impact on landscape;
- Perceived health risks related to Electromagnetic Fields (EMF);
- Impact on property prices;
- Impact on local flora and fauna;
- Impact on tourism and recreation in particular and local economy in general, etc.

System operators respond to these concerns by adjusting routing, introducing new tower designs and by other mitigating measures. Still, these concerns have been identified as the main reason for the lack of progress in the majority of onshore transmission projects [EC TEN-E 2007] and, thus, became the main driver for the intensive investigation of and discussion around alternatives, mostly UGC. In that sense, the table above lists projects where UGC is being considered by certain actors but does not qualify the likelihood of a particular technology choice in the end. Prominent examples for transmission connections being subject to massive local resistance are found in Austria (e.g. St. Peter – Tauern “Salzburg 380 kV”). In the recent past, these projects became cases for extensive UGC studies [Oswald 2007], [Hoffmann 2007], [KEMA 2008]. Also in Spain / France (Sentmenat – Bescano – Baixas [Cova 2008]), The Netherlands [Cole 2006] and Germany (see following paragraph) UGC have been investigated as alternative to OHL.

Recently, in Denmark the issue of the future development of the transmission infrastructure and suitable technologies has been assessed not only on a case by case base but in a national perspective and with a strategic view beyond 2030 [Elinfrastrukturudvalget 2008a], [Elinfrastrukturudvalget 2008b]. In summer 2007 a commission was established with the task to provide an informed view on the required extension of the transmission (and distribution) systems and, simultaneously, investigate the implications of an increased share of UGC in the electrical infrastructure. The commission was formed by representatives of the Danish TSO Energinet.DK, the ministries of Transport and Energy, Environment and Finances as well as the association of communities. In the course of the study a number of scenarios for transmission extension and the share of UGC have been defined. In the most extreme scenario the complete infrastructure is put underground before 2030 with associated costs estimated at about 37 billion Danish Crones (about € 4.9 billion). Still, the report emphasises that many technical issues associated with such a change require attention and further research, and a discussion limited to the economical impact would neglect the fundamental challenges. Issues mentioned in the report are, for example, overvoltages, dynamic, transient and voltage stability and operational complexity. Solving related questions is critical for an extensive rollout UGC at transmission level without compromising security of supply.

3.3 Policy on transmission development in Germany

3.3.1 Background

The German Federal Government is aiming to increase significantly the proportion of power generated from renewable energies. According to policy targets, by the year 2030, the proportion of onshore and offshore electricity generation from wind power is to be increased from its current level of around 6 % to at least 25 % (onshore: 10 %, offshore: 15 %). An installed offshore output of between 20,000 MW and 25,000 MW is regarded possible by the year 2030. [BMU OFFSHORE 2007]

From these scenarios, the German Energy Agency (dena) published a report in 2005 identifying the necessary grid extension on the high voltage and extra-high voltage level up to the year 2015, related to the integration of wind power into the German power system only [DENA 2006].
The study resulted in an extensive list of necessary new transmission circuits that equal in total a length of 850 km of new 380 kV lines. An overview of these projects is shown in Figure 3-7.

Until 2010	**461 km**
1. Hamburg/Nord–Dollern	45 km
2. Ganderkesee–Wehrendorf	80 km
3. Neuenhagen–Bertikow/Vierraden	110 km
4. Lauchstädt–Vieselbach	80 km
5. Vieselbach–Altenfeld	80 km
6. Altenfeld–Redwitz	60 km
7. Franken (179 km grid refurbishment)	6 km
8. Thüringen (187 km grid refurbishment)	
Until 2015	**Additional 390 km**
9. Diele–Niederrhein	200 km
10. Wahle–Mecklar	190 km

Figure 3-7 Construction of new transmission lines up to 2015, Source: [DENA 2006]

In addition to new 380 kV lines, projections of distribution system operators show that new transmission capacity is also needed in the high-voltage grid (110 kV) in various regions of the country. In the North of Germany the output from several wind farms is currently being curtailed significantly to ensure the safe operation of the (overloaded) high-voltage grid.
At the same time, as in many other countries, at the same time, the construction of new overhead transmission lines faces strong opposition from local communities and interest groups. This leads, eventually, to very long planning and permitting times. Generally, the public accepts the necessity of transmission extension but requires an UGC solution. This is illustrated by the fact that for the 400 kV network sections 2 and 10 in the table above reports have already been published evaluating the techno-economic viability of UGC variants [Oswald et al 2005], [Oswald 2007a], [Oswald 2007b].

3.3.2 Legislative and regulatory changes

The following examples illustrate how the controversial discussions regarding new transmission projects in Germany affect planning processes. After a more detailed introduction of two other prominent projects the analysis will show how the lack of societal consensus translates in amendments of existing and development of new legislation and regulation.

Breklum-Flensburg (110-kV) – Federal State of Schleswig-Holstein

The planning permitting hearings began in 2006 and were closed in 2007. The discussion of realisation as an UGC began several years before the beginning of the planning permitting hearings.

It is expected that the plan approval will be given in summer 2008 for the construction of a 27 km OHL.

In December 2004, the Social Democratic Party and the Green Party launched a petition in the Federal State Parliament of Schleswig-Holstein. This petition calls at the grid operators to prefer UGC to OHL where technically feasible [PARL S-H 2004a, b].

In the context of the discussion, two technical reports compared the technical and economical feasibility of an OHL and an UGC. The study published in 2004 [BRAKELMANN 2004] came to a total UGC/OHL cost ratio for two systems of 1.6 …1.8 to 1. Whereas the study published in 2005 [BRAKELMANN 2005] based on new assumptions (46 % higher transfer capacity, less loss hours, lower costs for losses, higher cable costs and longer life time) came to a total UGC/OHL cost ratio for two systems of 1.9 … 2.1 to 1.

South-West Connector (380-kV) – Federal States of Thuringia and Bavaria

The South – West interconnector is to substantially strengthen the coupling between the control areas of E.ON Netz and Vattenfall Europe Transmission. Even though the necessity of the 380 kV South-West Connector (Sections 4, 5, 6 in Figure 3-7) crossing the Federal State of Thuringia was challenged by the opponents [Jarass 2007], final planning permission for the second part has been granted in April 2008 for major parts of the line [TLVwA 2008].

Responding to massive public objections the TSO Vattenfall Europe Transmission suggested to initially implement two circuits instead of the originally planned four when crossing the popular long distance track 'Rennsteig' (section 6, last with planning permission pending). This allows usage of lower towers reducing visual impact. According to Vattenfall Europe Transmission capacity extension expected later may be implemented as an UGC section, being considered as a pilot by the TSO [Voigt 2008]. As suggested by the TSO, in case of positive experience, removal of the existing OHL circuits to underground is an option for later. It is expected that the additional costs would be approved by the German Regulation Authority (Bundesnetzagentur).

North-South Connectors (380-kV) – Federal State of Lower Saxony

In the Federal State of Lower Saxony the construction of a total of five new transmission circuits is under discussion. These are shown in Table 3-5. Three of the circuits were defined as necessary by [DENA 2006]:

Apart from the circuit Ganderkesee-St. Hülfe, the regional planning procedure has been finalised. The latest proposal by the grid operator analysed the option of a circuit with 56 % share of underground cables in a total of seven pieces. However, many questions remain unsolved. The planning permission procedure is expected to start in 2008. A detailed techno-economical feasibility study was performed for this circuit in [Oswald et al 2005] and updated in [Oswald 2007a].

For the circuit Wahle-Mecklar, the regional planning procedure is currently under preparation. The total length of the circuit is around 160 km of which up to 41 km could be underground cables. No information about the beginning of the planning permission hearings was available. A detailed techno-economical feasibility study was performed for this circuit in [OSWALD 2007b] For the circuit Diele-Niederrhein, the regional planning procedure will begin in 2008. The total length of the circuit is around 120 km but no information was available about the share of underground cables. No information about the beginning of the planning permission hearings was available.

The other two circuits do not require a regional planning procedure. The corridor for the circuit Wilhelmshaven-Conneforde was already defined in detail within the development of the State's regional planning programme; and the circuit Stade-Dollern is regarded as too little invasive.

Table 3-5: Overview of new transmission circuits in Lower Saxony

	Length	**Share UGC**	**Regional planning procedure**	**Planning permission hearings**
Ganderkesee-St.Hülfe (part of N°2 in Figure 3-7)	56 km	56 % (7)	Finalised	2008
Wahle-Mecklar (part of N°10 in Figure 3-7)	144 - 174 km [E.ON NETZ 2008]	8 - 41 km [E.ON NETZ 2008]	under preparation	n/a
Diele-Niederrhein (part of N°9 in Figure 3-7)	120 km	n/a	start in 2008	n/a
Wilhelmshaven-Conneforde	36 km	n/a	not required / defined in LROP	soon
Stade-Dollern	2 x 16 km 1 x 12 km	n/a	not required	mid 2008

Federal level - Infrastructure Planning Acceleration Act 2006

In December 2007 the "Infrastructure Planning Acceleration Act" was put into force by the Federal Parliament in order to simplify the planning procedures for important infrastructure projects [GERMAN PARL 2006].

Among others the Law contained a dedicated regulation for the undergrounding of 110 kV transmission circuits close to the coasts. The law does not apply to higher voltage levels. Driven by the need to connect offshore wind farms to the onshore grid, the Law gives legitimacy to planning permission hearings for UGC for 110 kV circuits in an in-land corridor of not more than 20 km distance to the coast as underground cables.

Moreover, the Law declares the extra costs resulting from the use of high and extra-high voltage underground cables – only if they are permitted by the planning permission hearings – instead of overhead lines as unavoidable costs that can be allocated via the network charges to final electricity consumers.

State level (Lower Saxony) - UGC legislation

The construction of new 380 kV transmission circuits faced many political discussions and strong opposition from local people and interest groups in the Federal State of Lower Saxony. As a result the State leaders developed a dedicated legislation for undergrounding. The “Law on the Planning Permission of Underground High- and Extra-High Voltage Lines” [LOWER SAXONY 2007] and the “Regional Planning Programme of Lower Saxony” [LOWER SAXONY 2008] came into force in December 2007.

The new legislation creates the legal framework for realising high and extra-high voltage transmission circuits as underground cables. The Law gives legitimacy to planning permission hearings for UGC under certain circumstances which were not present in former times; the Planning Programme sets the rules for when UGC should be favoured over OHL. The latter is based on the politically motivated choice to guarantee extended distances between OHL and residential areas (200 m to single houses; 400 m to residential areas; no transition of protected landscape). In all cases where these rules cannot be followed, an underground cable is obligatory.

The new legislation enforces grid operators to allocate extra costs resulting from the use of underground cables instead of overhead lines to final electricity consumers via the network charges. In addition to rules for UGC the Planning Programme also forces grid operators to bundle their transmission circuits by

- preferably extending existing transmission circuits, and
- conveying high and extra-high circuits on the same transmission route.

Federal Electricity Line Extension Act

In Germany (as in Ireland) new transmission circuits are a precondition for successful integration of electricity from renewable energies and development of liberalised electricity markets. But the planning and permitting processes for the construction of new transmission circuits often last up to ten years [BNETZA 2007, p. 9]. Against this background the German Federal Government – in the context of its climate and energy package presented in December 2007 – is currently working on a new law to simplify the planning and construction of new transmission circuits, the so-called “Electricity Line Extension Act”.

The Electricity Line Extension Act is expected to be developed in May 2008 and shall contain the following regulations:

- Legal statement of the necessity of prior transmission circuits and special rules for their planning and permitting process;
- Bundled approval procedure for sea cables for the connection of offshore wind farms.

In the context of the prior transmission circuit identified by the Law, an internal discussion within the German Government is currently evaluating the possibilities of a special – nationwide – regulation for UGC [HANDELSBLATT 2008].

Implications

The entry into force of the new legislation in Lower Saxony changed the legal basis for the planning of new extra-high voltage transmission circuits. Therefore, the grid operator had to re-examine the options for transmission corridors which he had presented earlier (e.g. in October 2007 for the circuit Wahle-Mecklar). An additional application forum must now be held. For the circuit Wahle-Mecklar this will be in June 2008 – about half a year after the change in legislation. Also, criticism is launched against lack of clear rules for partly undergrounding and against rational distance limits between overhead lines and residential zones.

Also the ongoing discussion on the Federal "Electricity Line Extension Act" is said to delay current planning procedures, for example in the North of Federal State Hesse [NH24 2008].

One major expected benefit of the amendments discussed above is that they accelerate planning and implementation of new transmission capacity. However, with current, limited experience it is uncertain whether this objective is really achieved. Emerging legislation and pending amendments in existing legislation, respectively, inherit an obvious risk of additionally retarding of the planning and permitting process of projects under development. But also for a final judgement on the effectiveness of the rules currently introduced, an ex-post policy evaluation is required, providing evidence only over a number of years.

3.4 Summary and conclusions

The presented overview on international UGC projects shows that up to now projects have been implemented mainly in urban areas. These cases suggest appropriateness of the technology for those applications from a technical viewpoint and indicate a stable point in the learning curve.

In recent years, the demand for UGC in rural areas, due to environmental and aesthetic considerations, is increasing. However, no case has actually resulted in the realisation of an UGC instead of an OHL of the size which may apply to future plans in Ireland. Though the UGC option may be justified with the growing number of successful cases worldwide, care is required as most existing UGC cases are not representative of transmission.

In the political discussions regarding UGC as an alternative for OHL, the extra cost for the UGC option are a dominating aspect. The wide variations in reported results (see paragraph 5.1.3) indicate differences in the characteristics of the specific projects being subject of the various assessments, uncertainties regarding market data and a lack of coherence in methodologies and basic assumptions applied. From that perspective, reference to those data requires much care until consensus is achieved in industry on those methodologies.

Up to now, in comparative studies the assessment of technical aspects was focusing on technology characteristics in general and particular projects under discussion in a narrow sense. Aspects of long term power system planning did not draw much attention, which is justified considering the negligible share and, thus, local impact of current UGC projects.

However, in a strategic perspective, the latter dimension is highly essential. This is discussed in more detail in paragraph 5.1.1 and 7.2.

4 Technology characterisation

The objective of this work package is to provide generic information related to the design characteristics of the relevant technology options. The section will provide a comparative evaluation of selected key characteristics (magnetic fields, reliability etc.) and will make and explain major choices with respect to the assumptions applied in the case studies (section 9).

4.1 State-of-the-art of AC OHL

4.1.1 *Concept*

History

Alternating current overhead lines (AC OHL) have been used from the very beginning of AC power transmission. Starting with medium voltages and relatively small dimensions, they were gradually developed further to reach high and extra-high voltages by simultaneously increasing their dimensions.

World's first 380-kV OHL was installed in 1952 in Sweden to transport a power of 460 MW over a distance of 950 km from Harspränget to Halsberg [Oswald et al 2005]. With more than 50 years of experience OHL are state-of-the-art and are the reference technology for transporting large amounts of electric power over distances of several hundreds of kilometers.

The transmission network operated by EirGrid consists of over 6,000 km of high voltage lines and cables. Table 4-1 shows the total length for the different voltage levels [EirGrid TFS 2007].

Table 4-1 Total length of existing grid circuits in Ireland as of December 2006 [EirGrid TFS 2007]

Voltage Level	Total Line Length (km)	Total Cable Length (km)
400-kV	439	0
275-kV	42	0
220-kV	1,729	100
110-kV	3,848	50

Design

The main principle of an OHL is that air is used as an insulator in between the high voltage wires (phases) and to the earth. This makes the design of an OHL very simple. As shown in Figure 4-1 an OHL consists of

- Towers and their foundations with the earthing system, and
- Conductors or bundles of conductors for each phase of the AC system attached to insulators and accessories.

The conductors or conductor bundles are attached to the towers by the use of insulators. The tower itself is on earth potential and fabricated of latticed galvanised steel pieces. Since air is a rather weak insulator, distances between the conductors and between conductors and tower and ground respectively must be large for extra-high voltage levels. Additional security clearance to both sides of an OHL is required, because of swing off effects of the conductors due to wind. The wayleave served for the line cover a 23 m ‘corridor’ outside the line (see also paragraph 6.1).
A major advantage of OHL is that they can carry multiple systems without much additional costs. However, towers as in Figure 4-1 designed by EirGrid support only one AC circuit.

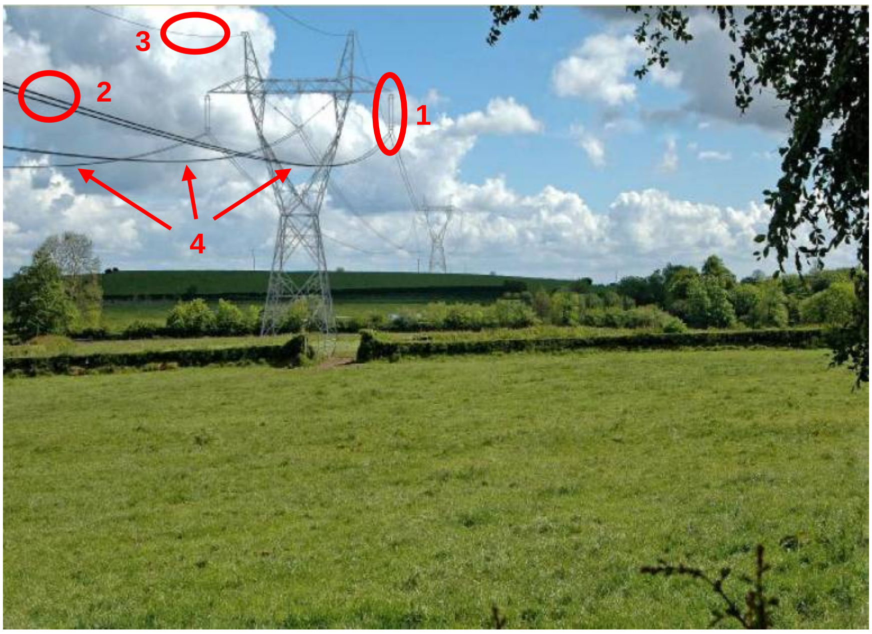

Figure 4-1 EirGrid 380 kV tower design with single circuit; 1: insulator, 2: bundle of conductors (separated by spacers), 3: earth wires (for lightning protection), 4: three conductor bundles form one AC circuit [source: EirGrid Web]

Decisive for the distance between two towers of an OHL is the ground clearance of the lowest conductor. In Ireland statuary ground clearance for OHL over agricultural land is 9 meters.
Since the conductor sag depends on the conductor's temperature as well as the height and distance between two towers, the design will be optimised for the highest expected power flow and most unfavourable air temperature. Typical span of a 400 kV OHL equals approximately 300 meters to 400 meters.
For high power transmission, conductor bundles instead of single conductors are used. Depending on the required current rating, a conductor bundle consists of two, three or four single wires.
For new transmission projects developed by EirGrid, pairs of ACSR type conductors of 600 mm² cross section are a common choice [Corcoran 2008].

4.1.2 Specific technology characteristics

Electrical parameters
The specific inductivity L' and specific capacity C' are determined by the geometry of the conductors. Due to the distance between conductors of an OHL of several meters, their specific capacity is rather low compared to the specific inductivity. Compared to UGC the specific capacity is 12-26 times lower and the inductivity 3-4 times higher for an OHL.
The above mentioned parameters influence the characteristic impedance Z_w and the natural power S_W, of a line; these values have strong effect on the electric transmission characteristic over long distances. Since the characteristic impedance of OHL is 6-10 times higher than for UGC, their natural power is equally lower at the same time.
Operating OHL beyond their natural capacity implies significant voltage drop due to line reactance. Without appropriate countermeasures this may result in violation of voltage tolerances at ends of the line.

Assembling
OHL are assembled by steel pieces that are preassembled on ground into segments; the segments are then assembled by the use of mobile cranes as shown in Figure 4-2. The foundations are either prefabricated steel tubes that are rammed into the ground; or they are built on a concrete foundation.

Figure 4-2 Assembling of preassembled steel segments by the use of a mobile crane (source: E.ON Netz website)

Only earthworks in the vicinity of the tower foundations are necessary; however, these areas have to be accessible by trucks for later maintenance or repair.

Crossings of roads, railway tracks and waters are easy for OHL as long as certain security clearance is met.

Maintenance

OHL can be easily accessed for maintenance or repair. The area of the towers has to be accessible for truck. Only in wetlands, accessibility can be restricted.

In order to prevent any vegetation (especially trees) to touch the OHL, the route must be regularly pruned.

Management of overvoltages and short circuits

OHL are exposed to all kind of external influences. Dirt or moisture can reduce the insulation and, hence, discharges or even electric arcs may occur. Lightening strikes can hit the line or insufficient clearance to close vegetation may result in electric arcs. In most cases these phenomena are non-permanent.

The insulators are specified to withstand overvoltages to a certain level. If the conductor voltage exceeds these levels (e.g. as a consequence of a lightning strike) this is controlled by an intended flash-over.

By applying a short term interruption with subsequent delayed automatic reclosing (DAR) electric arcs are cleared avoiding damage to the OHL. In that way, the line automatically returns to normal operation within a second and interruptions of supply can be avoided.

Seasonal adjustment of OHL ratings

Line ratings are based on conservative assumptions regarding environmental conditions (see European Standard EN 50182). A set of parameters applied is (example Germany):

- Ambient temperature 35°C
- Sunlight 800 W/m^2
- Wind speed at right-angles to the line 0.6 m/s.

Such a set of conditions is appropriate only in summer. EirGrid, as other European TSOs, applies line ratings varying with the season. Winter ratings of an OHL as shown in Figure 4-1 are about 20% above summer ratings.

Real time temperature monitoring

The overloading capability of OHL is restricted to a couple of minutes due to the negligible thermal inertia of the surrounding air. Still, OHL capacity changes with changing weather conditions and, for example, increases with wind speed or decreasing temperature.

Real-time measurements of the conductor temperature support a dynamic operational management of the transmission networks. Some EHV OHL are built due to the strong increase of renewable energies, mainly wind, in low load areas, and therefore the correlation between power flows and the actual wind speed is high. Under suitable conditions, this allows line loading above nominal capacity.

As an example, Figure 4-3 indicates the effects of shading of sunlight, the air temperature and a lateral wind flow on the overloading possibility of a 243-AL1/39-ST1A conductor based OHL. The capacity can be increased on windy days to around 150 % in summer and 165 % in winter.

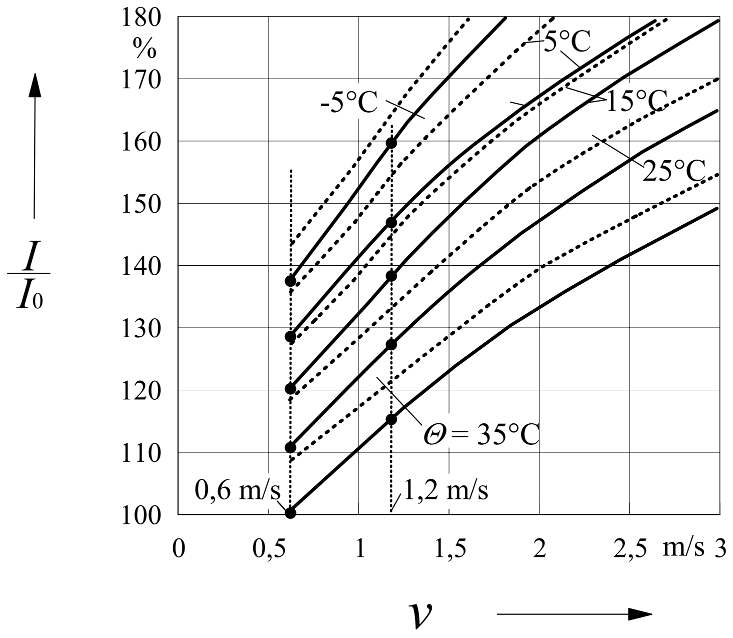

Figure 4-3 Overloading capabilities of OHL with 243-AL1/39-ST1A conductors; tolerated ampacity I compared to nominal ratings I_0 as function of wind speed in lateral direction to the conductors v for various ambient temperatures and with (dark) and without (dashed) irradiation (source: University of Duisburg Essen)

Today, a limited number of temperature monitoring systems is available [GA-B 2005]. Some measure the conductor temperature directly, others estimate the it based on measurement of different parameters. Examples are:

- conductor sag measured optically or by suspension forces at the masts;
- temperature sensors clamped on the conductors;
- transfer characteristics of optical fibers included in the conductors.

The cost for the real time monitoring system can be estimated to an additional 10% of the total investment cost of a new conventional line.

Of course other assets in the circuit (such as conductor clamps, current transformers, power transformers, circuit breaker, etc.) have to be rated to the maximum load. In case of uprating of existing lines this implies replacement of components. Also, the protection schemes may have to be adapted to the new operating strategy.

Rewiring with high-temperature conductors

The transmission capacity directly is restricted by the power line sag which in turn depends on the line temperature. Standard conductors for transmission lines can be operated up to a temperature of approx. 80° C with short excursions of up to 100°C. High temperature low sag conductors allow operation up to 120° C or even 180°C continuously with allowed short peak temperatures of well above 200°C without violating ground clearance requirements. Capacity upgrades of existing routes up to 50% are possible. Rewiring may be possible without interaction with permission procedures. Hence, the option potentially allows promising acceleration of capacity extension.
The following four different types of thermal resistant aluminium (TAL) conductors are based on an alloy of aluminium and in application in different stages [FIERS2007]:

- Gap conductors composed by a steel core that serves as the mechanical carrier and a loose TAL conductor that surrounds the steel core.
- ACSS (Aluminum Conductor Steel Supported) composed by soft glown aluminium conductors that are bound over a very solid steel core.
- ACCR (Aluminum Conductor Composite Reinforced) composed by a ceramic composite that replaces the steel core.
- Invariant conductors such as STACIR/AS, STACIR and TAL/HACIN conductors. based on an alloy of aluminium and nickel.

TAL/HACIN conductors were successfully demonstrated in 2004 by the Suisse TSO EGL Grid on their 380 kV transmission line Sils – Soazza – Forcola.
For a more detailed overview see [CIGRE 2004] and [CIGRE 2007]. In recent years such conductors have been installed worldwide on all voltage levels, also above 345 kV. In Japan alone about 40.000 km are in operation.

However, high temperature conductors have some important drawbacks too:

- naturally, increased temperatures are a consequence of increased line losses.
- the higher specific weight may affect the mechanical design of the towers.
- the magnetic field that surrounds high temperature conductors increases proportionally with conductor currents and, hence, exposure levels may increase.
- investment costs for high-temperature low sag conductors are generally about 50-100 % higher than for standard conductors depending on the technology.

4.1.3 Innovations and technology progress

New Towers

Due to the strong opposition from the public and local communities against the construction of new OHL, grid operators are seeking for improved tower design that would fit more aesthetically into the landscape.

EirGrid states on their webpage that they have not decided the tower type for the new transmission projects yet but present new tower designs as shown in Figure 4-4.

Figure 4-4 Tower Designs published by EirGrid, IVI (left), VVV (middle) and inverted delta (right) [EirGrid Web]

Also in Denmark, Energinet.dk has proposed new tower designs that are presented in Figure 4-5. [Elinfrastrukturudvalget 2008b] states

> *The towers will be 7-12 meters lower than a typical 42 m Danube tower. The new towers can also be integrated better into the landscape than the existing towers by planning the route in better harmony with the landscape, giving as much consideration as possible to landscape values.*

Figure 4-5 Conventional design (Donau-Mast) and new tower designs for improved visual impact [Energienet.dk]

4.1.4 Cost components

Given the extensive track record of OHL projects reliable information about specific costs is available. The cost for the conductors amounts to roughly one third of the total cost of a typical 2-system HV OHL.

[OSWALD 2007] indicates specific investments for an OHL (Donaumast with 2 circuits with 2300 MVA each) at k€ 930 per km. In the context of this study a value of k€ 700 per km is assumed for a single circuit design as represented by the Figure 4-1 and Figure 4-4.

4.2 State-of-the-art of 400 kV AC UGC

4.2.1 Concept

As a result of successful development and operation of XLPE-cables (XLPE = cross-linked polyethylene) during the last three decades, nowadays commercial XLPE cables are available for voltages up to 550 kV.
Before the 1990's exclusively fluid-filled paper insulated cables have been applied for EHV. Compared with these, XLPE cables show some important advantages.

- Higher maximum operational temperatures (permanently 90°C instead of 85°C)
- Lower capacitance per km and, hence, lower effort for compensation and reduced related losses and increased lengths
- Lower dielectric losses
- As a consequence of all these factors increased current ratings
- Lower thermal resistance of the insulation and, consequently, improved heat dissipation
- Low maintenance requirements
- Pre-fabricated (cable joints and sealing end compound) resulting in high quality control standards as well as easy and safe installation within short periods
- Increased section length
- The state of the insulation can be evaluated by partial discharge measurements during operation
- No pressurized oil storages, no risk of contamination of soils by oil leaking from cables
- Cost reduction of 20% to 30%
- Increased number of suppliers

Because of these advantages XLPE cables virtually completely replaced fluid filled cables in new projects but even in the replacement market. For that reason UGC is used as a synonym for XLPE technology in this study.

Figure 4-6 shows one 380-kV-XLPE-cable. For AC transmission 3 of those single core cables are required.
The electrical field associated with the EHV is controlled by the 25 to 28 mm insulation (number 3 in Figure 4-6) around the conductor. For cross sections larger than 800 mm^2, the conductor is manufactured in segments (Milliken conductor). In that way the disadvantages associated with electrical phenomena (skin effect and proximity effect) are reduced. A hermetically sealed aluminium layer (number 7) under the outer PE coating (number 8) prevents moisture entering the insulation.

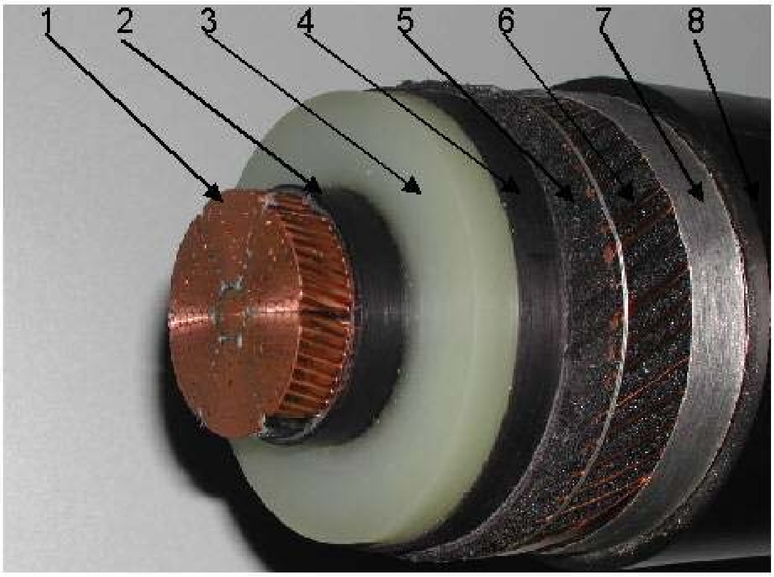

Figure 4-6 cross section of a 400 kV XLPE cable with copper Milliken conductor [source: Nexans]

This kind of cables currently is available with single core and conductor cross sections up to 3200 mm^2 and supply length of up to 1000 m. Longer sections are possible but the weight of the cable drum and its impact on logistics form the dominating restriction. One meter of such a cable with copper conductor weights about 40 kg and a 900 m cable drum (incl. drum weight) about 40 tons. As these drums have to be transported along the complete transmission route in short distances, this forms an important planning parameter. Under difficult soil conditions even shorter sections are used.
Recently the copper prices grew dramatically (factor 3 within 3 years). Hence, for moderate required transfer capacity aluminium gets attention as an attractive alternative from a cost perspective. In particular for conductor cross sections lower than 2000 mm^2 manufacturing costs are comparably low. Up to this size solid conductors can be manufactured using a simple process. Figure 4-7 illustrates the design of a 400 kV UGC with aluminium conductor.

In the course of this study both, cables with Cu Milliken conductors and Al conductors, are considered.

Figure 4-7 cross section of a 400 kV XLPE cable with 1200 mm^2 Al conductor (A2XS(FL)2Y, 3*1*1200 RE/50; source NKT Kabel)

For the connection of the cable sections pre-fabricated joints are used (Figure 4-8). These control the electrical fields at the interfaces and are fed safe and quickly on the cable ends on site (see Figure 4-9).

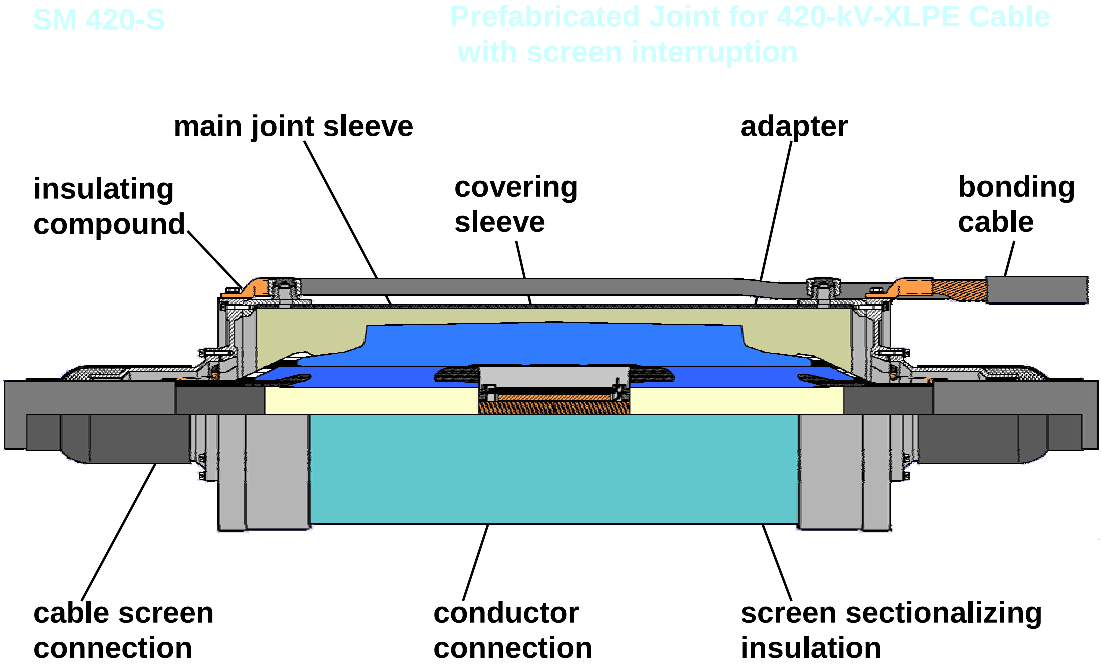

Figure 4-8 400 kV cable joint consisting of 3 parts (source Nexans)

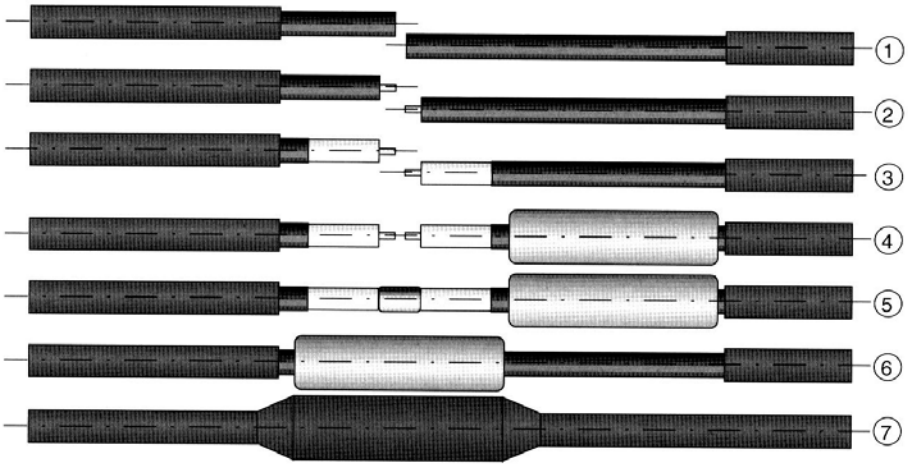

Figure 4-9 steps connecting the ends of EHV cables using prefabricated joints (source: Siemens / Pirelli)

For ease of assembly, maintenance and thermal management the distance between the cables is increased to about 1.5 m in the vicinity of the joints.

Also for termination of the cables at both ends prefabricated sealing end compounds are used. These are covered by porcelain or compound insulators for protection against environmental impacts (see Figure 4-10).

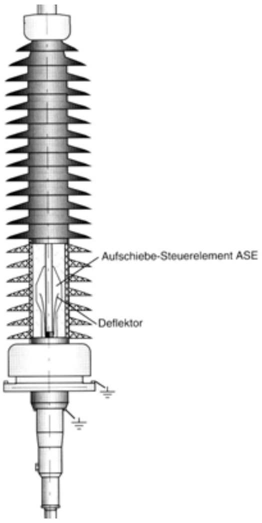

Figure 4-10 prefabricated sealing end compound for a 400 kV cable (source: Siemens / Pirelli)

Cable insulation and joints are designed in such a way that they tolerate the same voltage levels as the OHL they are connected to (stationary as well as transient peaks, for example associated to lightning strikes). The cable cross section is determined by the required transfer capacity, which in turn is influenced by the arrangement of the conductors and thermal conditions of the soil (see also paragraph 5.2 as well as Appendix 1 – Losses in AC transmission and Appendix 3 – Rating of UGC circuits).

4.2.2 Specific technology characteristics

Cross-Bonding

The currents in the conductors of single core cables induce voltages in the cable's sheath and armoring along the line. For several reasons the sheaths are connected to ground and, hence, these voltages drive currents in opposite direction to the conductor currents. These currents cause substantial losses, in the order of magnitude of the conductor losses if no appropriate mitigation measures are implemented. The losses and the associated heat generation are undesired.

In EHV cabling cross bonding is a common method to suppress these undesired sheath currents. Cross bonding means cyclic connection of the sheath or armoring of adjacent cables along cabling sections. At the ends of the section the sheaths / armoring are connected to earth. In between there are three subsections with the sheaths cross connected with so called cross-bonding joints (see Figure 4-11). By cross bonding the sheaths / armoring the resulting induced voltage along the section adds up to about zero and the sheath current is minimized.

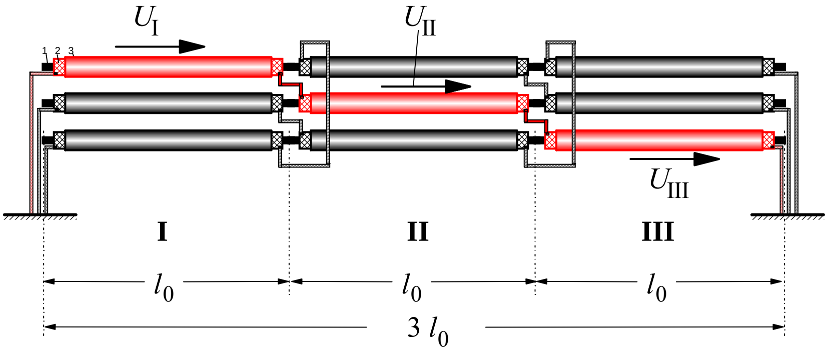

Figure 4-11 cross bonding along a cable section with sheaths earthed at both ends and cyclic cross connection of sheaths after each sub-section of identical length

Of course, cross bonding implies additional effort. The joints are more complex and the connections are made in dedicated cross bonding boxes to be placed accessibly in regular distances (each 2 to 3 km) along the route.

Reactive power compensation

Compared to OHL with a specific capacitance of 9...14 µF/km, the specific capacitance of UGC is high: 200...300 µF/km. Whereas charging currents of OHL can be neglected for distances of at least 50 km, in the case of 380 kV cables they are significant: typically about 15 A/km. These charging currents, representing reactive power do not contribute to the desired power transmission, but contribute to line loading and losses. Additionally, with long lines these charging currents become an engineering issue (energising, testing, voltage profile, etc.). For that reason, the reactive power of an UGC has to be compensated at certain distances by shunt reactors. [Oswald 2007] and [KEMA 2008] indicate UGC distances of 25 km to 40 km between compensation site.

Assuming complete and symmetrical compensation from both terminals of a 380 kV UGC, a 25 km section would require about 125 MVA reactors at both sides. Figure 4-12 gives an impression of a unit in this capacity range. A compensation site consists of the sealing end compounds for the adjacent cable sections and the reactors and would have similar dimensions as an OHL-UGC transition site.

Figure 4-12 400 kV, 160 MVA shunt reactor for reactive power compensation (source: [CIGRE_B1.07 2006])

Reactive compensation introduces permanent, voltage depending losses. Common loss values for reactors are 0.15% of the rated (reactive) capacity.
Specific costs for static reactors are in the range of k€ 10 per MVAr. Under certain conditions, from a power systems perspective dynamically controllable compensation (static var compensators – SVC) using power electronics may be desired. These devices are a factor of 4 to 8 more expensive.

Loadflow control
Because of their low impedance, compared to OHL, UGC in a meshed network tend to attract power flows. This may lead to overloading of the UGC. In order to adjust the impedance of an UGC to the surrounding network and to control power flow distribution in the system, line reactors have to be added to the UGC section. Control of power flows / increasing impedance of cables by additional reactors

Overloading capability
The thermal inertia of soil is substantial and in turn the temperature response of cables to load steps is significantly delayed. Figure 4-13 shows the temperature slope of one circuit of a double 380 kV system (XLPE cable in soil, copper cross section 2500 mm^2). At a 50% loading one of both systems becomes unavailable and the other circuit has to take over the load. It takes about one week until the conductor temperature in the remaining system achieves the tolerated maximum (90°C). The temperature distribution in soil before the contingency and after about 8 days is illustrated in Figure 4-14.

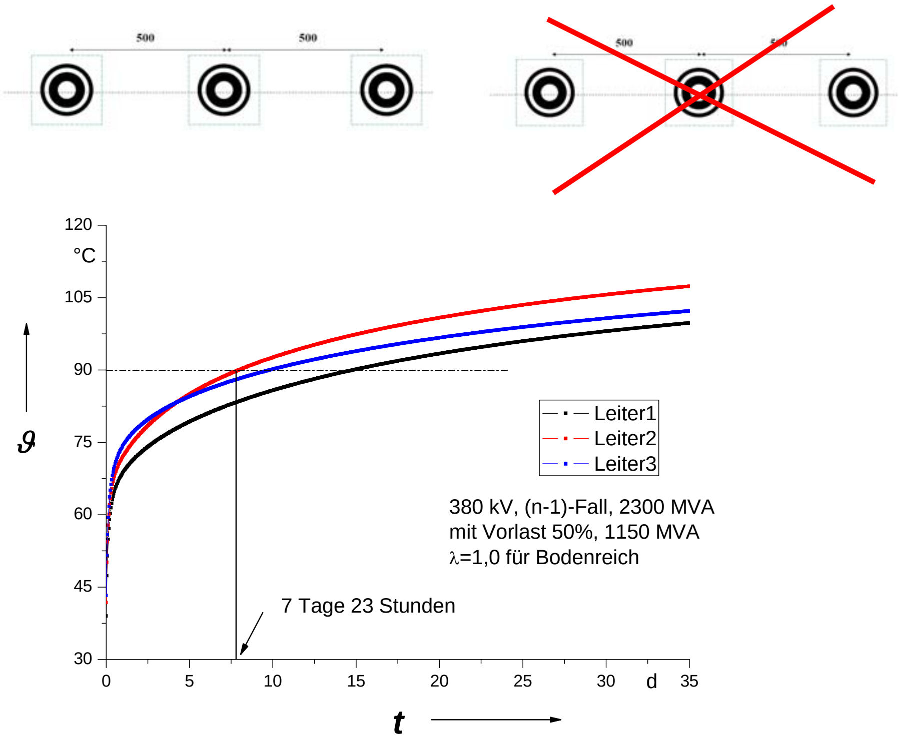

Figure 4-13 temperature response of a 380 kV XLPE cable system (two circuits with 2500 mm^2 copper conductors) after loss of one circuit preceded by 50% of nominal loading

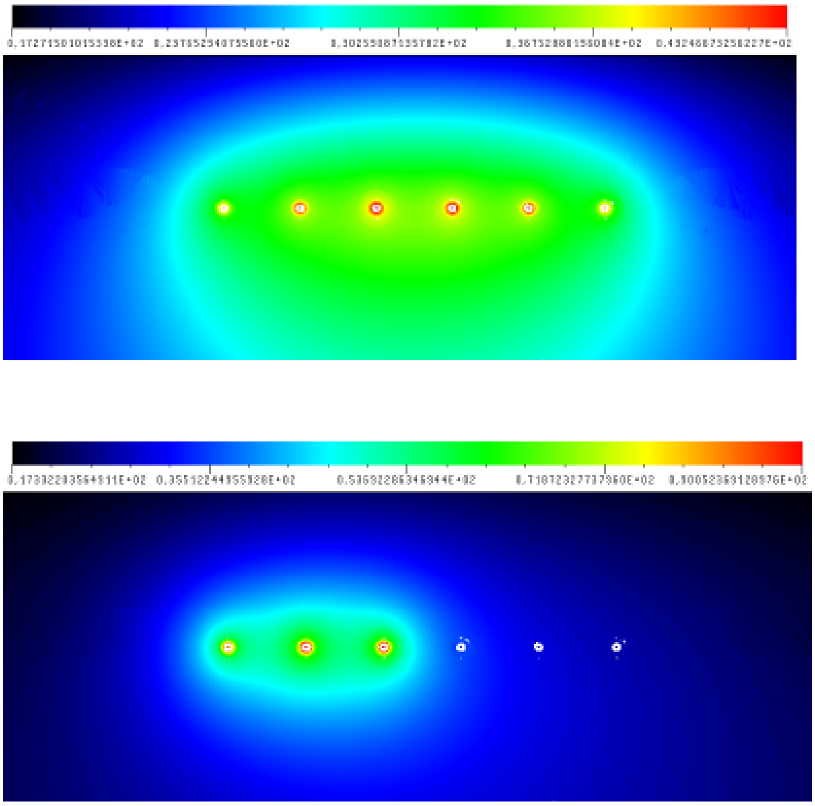

Figure 4-14 temperature fields for two instants in the process illustrated in the figure above; above starting situation, below after 8 days (at this time the conductor in the center of the system achieves the tolerated maximum temperature of 90°C)

In practice, this means that the temporary overloading capability of UGC is significant, though depending on the preceding loading. Even more, in case of a contingency this inertia gives much time for remedial measures (for example redirecting load flows, redispatch or just repair of the affected circuit). Of course, in such a case the delay has to be reflected adequately in protection schemes which in turn become more complex.

The same principle applies to UGC systems with lateral cooling (see also paragraph 5.2 and Appendix 4 - Extended AC UGC configurations).

Temperature-monitoring and real time thermal rating

Temperature monitoring systems for power cables using optical fibres, which are integrated into the copper screen of the cables, are available. During operation these systems provide information on the present sheath temperatures along a cable route up to approx. 20 km length within an uncertainty of about ± 1 K and a spatial resolution of ± 1 m.

Real time thermal rating (RTTR) means the interpretation of the incoming measured data of the sheath temperature with respect to typical questions as:

- What are the actual conductor temperatures, and where are the hot-spots?
- How long can the present current be transmitted before the condition becomes critical?
- Retaining the present load, which conductor temperature will arise at the end of a given time interval?

With existing technology these questions can be answered with sufficient accuracy in day to day operations (see Figure 4-15). This allows practical exploitation of the overloading capabilities as described in the previous paragraph.

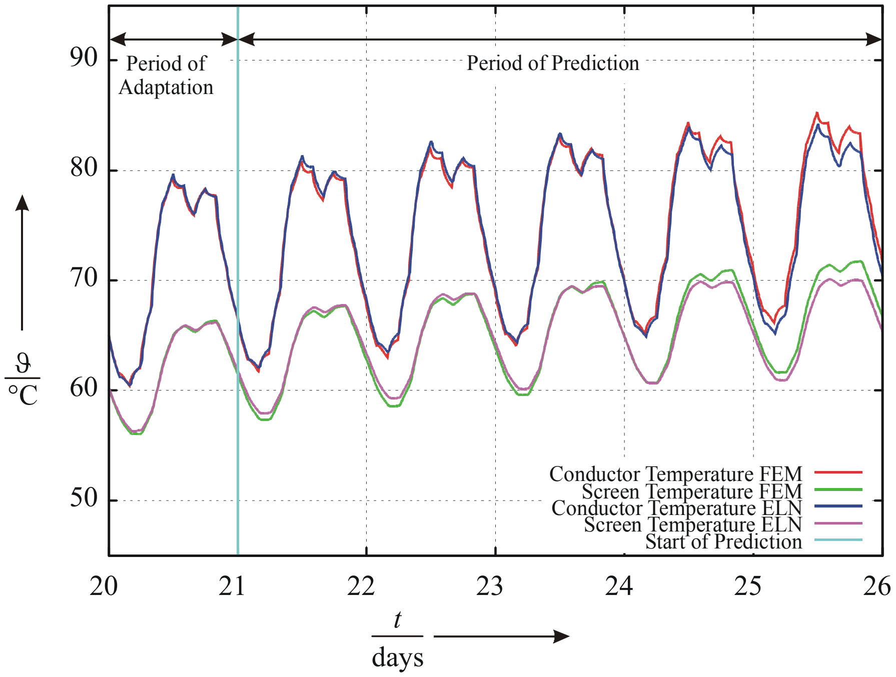

Figure 4-15 Measured (FEM) and predicted temperatures of screen and conductor by an adaptive monitoring system (source [Brakelmann et al. 2007])

Heat dissipation and temperature of soil

A matter raised regularly in relation to UGC is the heating of soils. Assuming no forced cooling, UGC systems indeed have to dissipate the heat associated with losses via the surrounding soil. A XLPE cable system operated at nominal capacity and with a conductor temperature close to 90°C dissipates about 50 W/m to 100 W/m.

In practice, under normal operational conditions transmission lines are not operated stationary at nominal capacity but mostly below 50%. In such a case the specific losses amount only 25% of the nominal value and the cable surface is not heated up to the maximum of 70°C to 80°C but only to 30°C to 35°C or less.

But even assuming stationary full load conditions, the impact on soil temperature is strictly local and very limited. Figure 4-16 illustrates the temperature rise caused by a 380 kV cable circuit in flat arrangement with cable axis distances of 0.5 m. The figure shows that the temperature rise at the surface, directly above the cable does not exceed 1 to 2 K. In a distance of 5 m a temperature change cannot be detected.

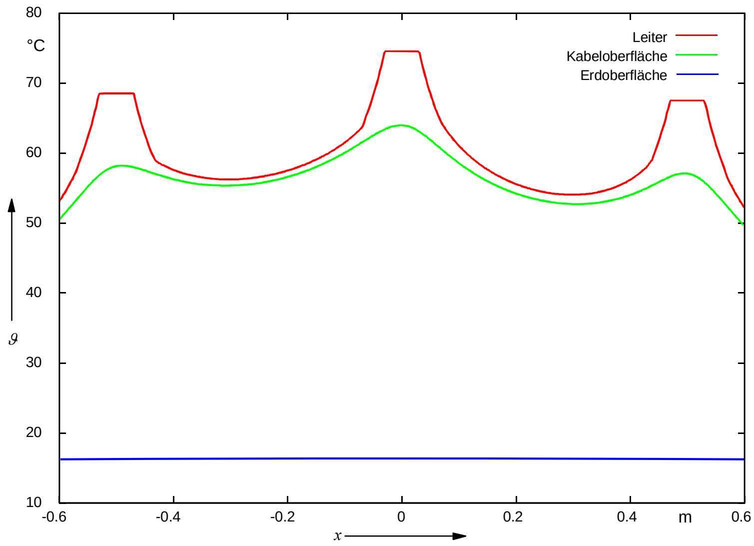

Figure 4-16 Temperature rise caused by a 380-kV-XLPE single-core cable system calculated by FEM modelling; temperatures in the conductor plane (red), in the plane directly above the cables (green) and at the soil surface (blue) (source: University of Duisburg – Essen)

Nevertheless, in a region of about 0.5 m around a highly loaded cable soil can dry out by the generated heat. This results also in a reduced heat transfer capability and is undesired. For that reason cables are often implemented in a thermally stabilised layer consisting of concrete or sand blends guaranteeing a specific heat resistance of less than 1.0 W/(K m) also when exposed permanently to increased temperatures.

Superconducting cables

Driven by the dynamic progress in the field of High Temperature Superconductors (HTS), research and development in the field of power cables has been intensified recently. Currently, worldwide a number of demonstration projects are in operation or planning stage (see Table 4-2). In practice efforts are focusing on medium voltage and the highest voltage under consideration are in the range of 138 kV.

Table 4-2: overview on high temperature superconducting (HTS) power cable projects (source [IV Supra 2008])

Consortium	Country	Year	Location	Length	Specs		Power	Phases
				[m]	[kV]	[kA]	[MVA]	
TEPCO/SEI	Japan	1997	CRIEPI	30	66	1	66	1
Southwire/IGC	USA	2000	Carrolton, GA	3 x 30	12.4	1.25	27	3 x 1
nkt Cables/NST	Denmark	2001	Copenhagen	3 x 30	30	2	104	3 x 1
Pirelli/Detroit Edison/AMSC	USA	2002	Detroit IL	120	24	2.4	100	3
TEPCO/SEI	Japan	2002	CRIEPI	100	66	1	114	3
SuperAce/Furukawa/CRIEPRI	Japan	2004	CRIEPI	500	77	1	77	1
KERI/SEI	Korea	2004	LG Cable	30	22	1.2	47	3
Innopower/Yunnan IEP	China	2004	Puji	33.5	35	2	121	3
KEPRI/SEI	Korea	2005	KEPRI (Gochang)	100	22	1.25	48	3
Tratos Cawl, AMSC	Italy	2005	Pleve Santo Stefano	50	45	2	156	3
CAS/AMSC	China	2005	Chang Tong Cable	75	15	1.5	39	3
FGS UES/VNIKP	Russia	2006	Lab Test	5	-	3	-	1
Ultera/AEP/Oak Ridge	USA	2006	Columbus OH	200	13.2	3	39	3
Superpower/SEI	USA	2006	Albany, NY	350	34.5	0.8	48	3
LS Cable	Korea	2007	KEPRI (Gochang)	100	22	1.25	48	3
ConduMex/AMSC/CFE	Mexico	2007	Queretaro	100	23	2	80	3
LIPA/AMSC/Nexans	USA	2007	Long Island, NY	650	138	2.4	573	3
Superpower/SEI	USA	2007	Albany, NY	30	34.5	0.8	48	3
Nexans/AMSC	Germany	2007	Hannover: Lab	30	138	1.8	246	1
Nexans/EHTS	Germany	2008	Hannover: Lab	30	10	1	10	1
ConEd/Southwire/AMSC	USA	2010	New York	240	13.8	4	95	3
Southwire/Ultera/Entergy	USA	2011	New Orleans	1700	13.8	2.5	60	3
LIPA/AMSC/Nexans	USA	2010	Long Island, NY	600	13.8	2.4	574	1
TEPCO/SEI	Japan	2011	Tokyo	300	66	3	340	3
LS Cable	Korea	2011	KEPRI (Gochang)	100	165	3.75	1000	3
nkt Cables/NUON	Netherlands	2012	Amsterdam	6000	60	2.9	250	3
stadtwerke Augsburg	Germany	2009	Augsburg	425	10	0.3	6	3

With the current technology status specific investments still are extremely high. Operational experience is too limited for application on a large industrial scale.

Additionally evaluating the prospects of the technology, the characteristics of the cooling equipment have to be taken into account. The availability cooling devices will directly affect the availability of the power line. The overall efficiency will be significantly influenced by the efficiency of the coolers in combination with the inevitable heat losses along the line. As a consequence, HTS development is focusing on achieving extreme power densities in space restricted applications (e.g. in urban areas) rather than substantial gains in transmission efficiency, certainly not over extended distances.

In the foreseeable future superconducting cables for 400 kV will not be available and are not discussed further in the context of this study.

4.2.3 Cost components

The specific cost components associated with UGC are:

- the cables and the accessories (joints, cross bonding joints and boxes);
- the additional amount of reactive compensation for charging currents as well as for load flow control in combination with OHL networks together with the required space;
- siting and equipment for the transition at the interface with OHL networks (sealing end compounds)
- civil works for burying the UGC circuits.

As outlined above driven by rising copper prices cable prices grew substantially during the last years. The specific costs for civil works are extremely dependent on the conditions of the route and may vary with an order of magnitude. Obstacles may prevent digging. The alternative, directional drilling is much more expensive and not always possible.

Because of these strongly varying factors, it is hard to provide generic figures for UGC costs. For a review and respective discussion of a number of references see paragraph 5.1.3.

4.3 State-of-the-art of HVDC transmission

4.3.1 Concepts

During the last decades, High-Voltage-Direct-Current (HVDC) transmission became the standard technology for power transmission over large distances (several 100 of km) and, hence, in particular for submarine connections. AC transmission over such distances implies excessive losses or is just technically unfeasible. An important advantage in the case of submarine DC connections is the significantly lighter design of the cables.
Additionally, DC concepts are applied to interconnect power systems being not part of the same synchronous control area. Direct connection of those systems with an AC connection is impossible.

HVDC technologies are distinguished by commutation principal of the converters. Converters relying on the AC network for commutation (so called Current Source converters – CSC-HVDC) use thyristor valves and have been operated successfully for decades. This technology is characterized by a substantial demand for reactive power to be provided by the AC network and by strong harmonic distortion, which in turn requires relatively extensive filters and compensation equipment.
With the evolution of semiconductors so called IGBT transistor valves in relevant power ranges became available. This allowed introduction of self commutating converters (Voltage Source converters – VSC-HVDC) in transmission systems. The AC output is created by a pulse width modulation of the DC voltage allowing independent, flexible and highly dynamical control of active and reactive power balance as well as phase angles at both sides of the connection. VSC-HVDC is capable to effectively contribute to power system stability and load flow control.

Both DC technologies allow usage of both OHL and UGC. Each system requires only two conductors and, hence, towers or cable trenches may be narrower. Insulators length for DC OHL has to be longer than in the case of AC (see Figure 4-17).

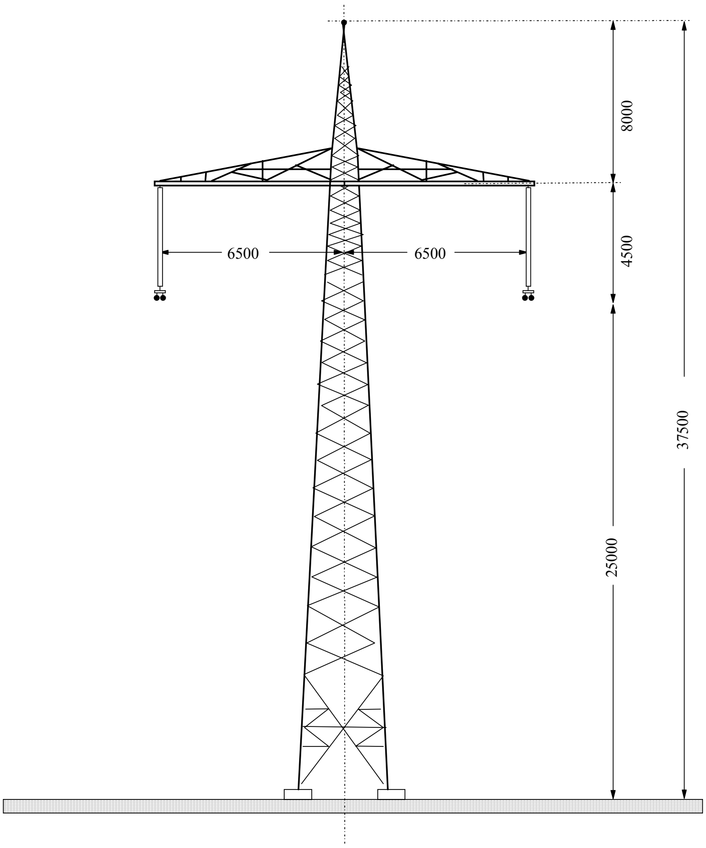

Figure 4-17 OHL tower design for ±400 kV DC transmission

In case of UGC, CSC-HVDC use fluid-filled paper insulated cables with ratings up to ±600 kV. Because of the required voltage reversal being a precondition for power flow reversal in case of CSC-HVDC, this combination implies a short term load flow disruption every time the direction of the power flow changes. Depending on the transfer profiles this may be a disadvantage. VSC-HVDC does not require voltage reversal. According to industry offerings, voltage ratings for XLPE DC cables achieve up to ±300 kV corresponding with unit sizes up to 1000 MW.

CSC-HVDC converter stations require significant space (see Figure 4-18). In particular the filters are voluminous. The resulting space requirement is indicatively 140 m^3/ MW. VSC-HVDC allows a more compact design (<70 m^3/MW, see Figure 4-19).

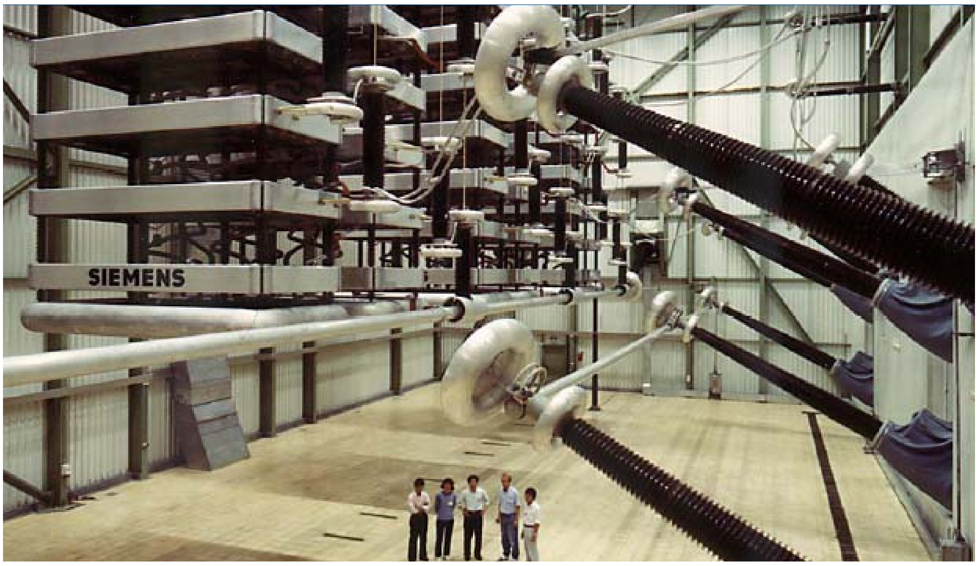

Figure 4-18 valve stack of a 500 kV / 600 MW current source HVDC converter (source Siemens)

Figure 4-19 ±150 kV / 350 MW voltage source HVDC converter station at Harku, the Estonian terminal of the Estlink interconnector (source: [Ronström 2007])

For VSC HVDC, currently, there are only two suppliers (ABB, Siemens). Up to now, only ABB implemented this technology in industrial projects (see Figure 3-6 in paragraph 3.1). This limitation will be reflected by customers in commercial considerations and negotiations.

4.3.2 Specific technology characteristics

Losses
The losses in DC transmission lines are lower than in the case of AC. No reactive power is transported and only the ohmic losses apply. However, in the case of DC transmission converter losses have to be taken into account. For a voltage source converter full load losses between 1.6% and 2% of rated capacity have been reported. As a large portion of the losses is related to current, part load losses decrease down to 0.2% of rated capacity. In standby mode (IGBT switching blocked) losses are reduced further to 0.1%.
For a ±300 kV 1000 MW HVDC link ABB indicates losses at full capacity of 4.9% (distance 200 km [ABB web 2008].

For CSC HVDC concepts similar conditions apply. In the further analysis they are neglected and only VSC concepts are considered as a representation of DC options.

Reliability / availability
Availability of HVDC OHL will not significantly differ from that of AC OHL. Availability of XLPE UGC for DC transmission may be slightly higher as the number of components (joints, crossbonding) is lower.
In practice, the availability of HVDC transmission will be dominated by that of the converter stations. These represent complex technical systems with a range of essential subsystems (valve stacks, filters, control, cooling, etc.). Key components and sub-systems are implemented in a redundant way. This increases reliability and reduces the probability of forced outages. Dedicated maintenance, service and repair strategies may allow to reduce time to repair.
For its proprietary VSC HVDC technology ABB currently offers a converter availability of 98% [ABB web 2008]. Together with communicated values for planned outages for a 300 MW converter (approximately 2 weeks each two years for stack maintenance [Stendius 2007a]) this suggests very low levels for the expected forced outage probability. This impression is supported by operational experience with existing converter stations [Stendius 2007b].

4.3.3 Cost components

Investments

Because of the limited market size generic pricing information on VSC HVDC is hardly available. [Cole 2006] quotes ABB with 55.000 € / MW installed capacity and turn key cost for a 60 km onshore UGC connection in urban areas in the Netherlands of € 163 million or € 152 million for ratings of 1100 MW and 700 MW respectively. The specific converter costs are not considered being conservative but are applied section 9 by lack of more reliable information. Because of their simplified construction specific costs of DC cables are lower than those of AC cables, certainly compared to Milliken conductors. In the course of this study, a generic figure for the specific system costs of € 400 / m (incl. accessories) for a ±1000 MW circuit using 300 kV XLPE cables is applied.

The specific investments for current source converters and respective cables are in the same order of magnitude.

Nowadays, from an investment perspective DC connections are not competitive for limited distances. Different references provide differing break even ranges for the economic viability of DC connections, most being clearly beyond 100 km. In certain cases specific system requirements (stability, load flow control, etc.) may justify the additional cost and make HVDC an option attractive at shorter distances.

Losses

As shown above the converter losses are dominating the overall system losses. They are significant and certainly have to be taken into account in any comparative assessment. The analysis in paragraph 9.3 will illustrate that not only the high investments are limiting economic application of the technology. Solely the costs associated with losses have an adverse impact on the economic viability of HVDC transmission, at least considering distances where AC technologies are not facing their technical limitations.

ABB as well as [Cole 2006] emphasise the capability of HVDC to effectively control power flows and in that way reduce overall transmission losses in the system, compensating for a part of the conversion losses. However, a generic figure for these effects would be speculative. This effect is not considered here.

5 Comparison of specific techno-economic characteristics

5.1.1 Transmission system adequacy

A reliable power supply is of vital importance for industrialised societies and a precondition for any economic activity. For knowledge intensive business (ICT) and industries with highly automated processes the reliability level of the power system is a key criterion in site selection.
For that reason, any new transmission project has to satisfy the Transmission Planning Criteria of EirGrid. The objective of transmission planning is "the maintenance of the integrity of the bulk transmission system for any eventuality. The adequacy and security of supply to any particular load or area is secondary to this primary aim. … Reliability criteria are defined and measured in terms of performance of a system under various contingencies. These criteria are based on the fundamental assumption that system integrity will be maintained for the more probable and less probable contingencies and that there is no loss of load for the common more probable contingencies."
More in detail [TPC 1998] specifies:
"… The system shall be designed to withstand the more probable contingencies without widespread system failure and instability, maintaining power quality within specified voltage and frequency fluctuation ranges and maintaining voltage and thermal loadings within operating limits.
The more probable contingencies are comprised of single contingency (N-1), overlapping single contingency and generator outage (N-G-1) and trip - maintenance (N-1-1) disturbances.
In the immediate aftermath of a disturbance, the system should reach a steady state that is within emergency limits. Then, by use of remedial actions specified in the criteria, the system should be capable of being returned to normal limits. …
For system integrity, the system should be able to withstand more severe but less probable contingencies without going into voltage collapse or uncontrolled cascading outages.
Examples of this class of contingencies are busbar faults, busbar coupler faults, breaker failures, relay misoperation, loss of double circuit, etc." [Transmission planning criteria 1998]

An appropriate assessment of system adequacy is only possible at system level. Such an assessment has to consider the contingencies defined above but also the system behaviour under normal operational conditions.

Contingencies

With respect to contingencies the system view implies that the expected portion of planned outage (voluntary outage in EirGrid terminology) associated with a technology option influences system planning, but is not necessarily restrictive for technology selection. Longer periods for maintenance with respective assets taken out of operation, e.g. as in the case of VSC HVDC may increase the required redundancy but is not automatically a prohibitive criterion as long as the planned outage range is not excessive. Some weeks of maintenance for an overhead line during the low load period do not per definition deteriorate system robustness. However, the same line being out of operation for a number of days during the winter peak because of required repair may severely affect n-1 robustness of the transmission system. Thus, for evaluation of the suitability of a technology in the perspective of contingency management, the technology specific risks associated with unplanned, forced outage are decisive. (In line with industry practice short interruptions with successful delayed automatic reclosure – DAR – are excluded from statistics.)

The forced outage rate FOR of a component or a subsystem can be calculated with the expected the failure rate λ and the mean time to repair MTTR [Billinton 1984]:

$$FOR = \frac{\lambda}{\lambda + \frac{1}{MTTR}}$$

Statistical data on forced outages of sufficient significance are unavailable for 400 kV UGC as a consequence of the very limited track record (in terms of time and volumes in operation).

Reasonable assumptions for the mean time to repair MTTR may be made based on process knowledge and experience with cable networks on lower voltage levels. Consensus exists that the MTTR for a 400 kV UGC is larger than for UGC in lower voltage levels and much longer than in the case of an OHL [Oswald 2007]. Still estimates vary form one to four weeks (and more). Obviously this assumption substantially influences the expected availability for an UGC solution.

Reliable data on failure rates λ are even more lacking. Extrapolating figures from lower voltages is speculative and, at least, introduces substantial uncertainties. The differences in technology challenge and the experience dealing with these challenges cannot be ignored.
As a consequence reported figures for the forced outage rate of UGC have to be interpreted with extreme care. The wide range in estimates is illustrated in Figure 5-1 and most of all indicates the existing uncertainties. Additionally, the FOR of an UGC is determined by the cables but also by all auxiliary equipment required for operation (sealing end terminals, monitoring and control, etc.). Most references do not specify the system boundaries in detail and differences in the scope considered may exist.

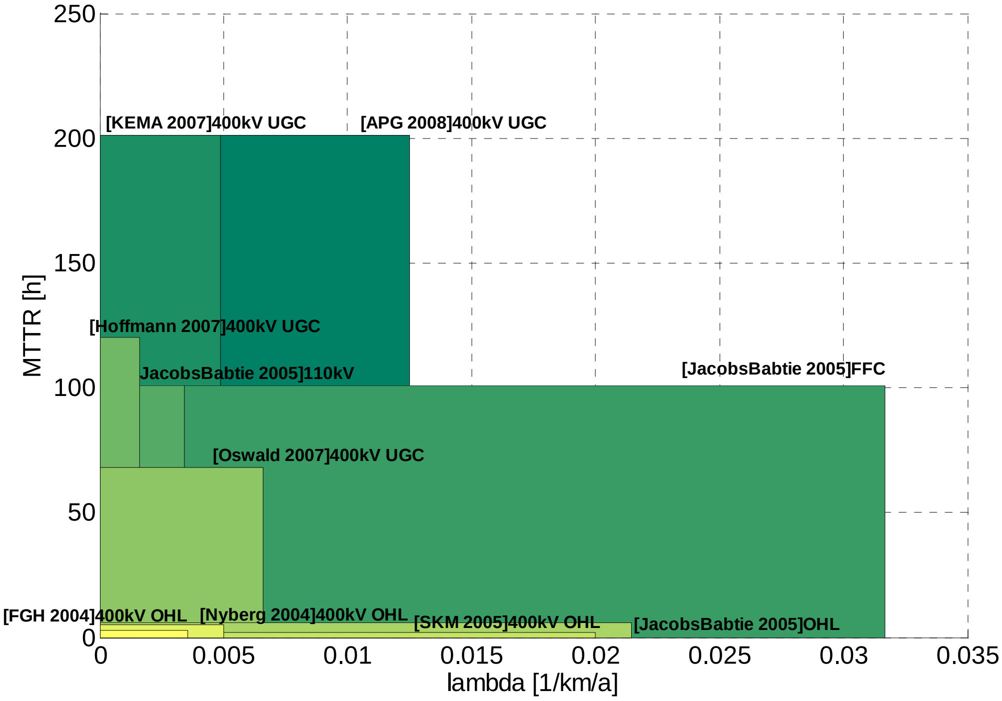

Figure 5-1 reported values for forced outage rate λ and mean time to repair MTTR for 400 kV OHL circuits (four bars in the lowest part of the graph) and UGC circuits; the area corresponding with each reference indicates the respective forced outage rate FOR

The following aspects have to be taken into account when interpreting Figure 5-1:

- The German statistics of [FGH 2004]400kV OHL intentionally ignore events related to extreme weather conditions and in that perspective are optimistic. The FOR level indicated by [Nyberg 2004] refers to Swedish 400 kV OHL statistics covering the period between 1997 and 2002 including also extreme events. Less than 15% of the events required a repair time longer than 2 hours (with one extreme value of more than 500 hours). The values derived from [Jacobs Babtie 2005] and [SKM 2005] rely on UK experience and are considered being representative for Irish conditions. ([EirGrid TSP 2006] reports that the 400 kV experienced no forced outage in 2005 and 2006.)
- The estimates for the failure rate λ in [Oswald 2007] and [Jacobs Babtie 2005]110kV are based on experience with 110 kV UGC. Both references make explicit reservations regarding applicability of the figures for 400 kV XLPE UGC. For that reason [Jacobs Babtie 2005] in the further analysis uses λ values reported for fluid filled cables.
- [APG 2008] combines external references (shown here: KEMA US “realistic guess”) in its response to [KEMA 2008] and emphasises that the cables are assumed laying in ducts resulting still in optimistic values for the failure rate λ compared to UGC directly buried in soil.

Depending on the references used for comparison, the FOR of UGC is estimated one or two orders of magnitude higher than that of OHL.

Because of their lower specific transfer capacity UGC may include more circuits than an OHL of the same capacity. As a consequence, the transfer capacity lost in case of forced outage of one UGC circuit is lower than in case of an OHL. However, in general this will not compensate for the differences indicated in Figure 5-1. Additionally, for safety reasons during repair adjacent UGC circuits in soil most likely will be disconnected too, at least during digging. This may increase the overall FOR also for those configurations.

The impact of UGC connections connecting a single load or generator to the transmission system on overall system integrity may be limited and respective projects may be viable from a transmission system adequacy perspective. However, generally concluding that UGC is as technically feasible alternative to OHL in meshed transmission networks based on those examples would be inaccurate.

Normal operational conditions

TSOs express reluctance with respect to large scale integration of extended UGC sections in the system because of the potential impact on system integrity even under normal operational conditions [Elinfrastrukturudvalget 2008]. Aspects causing concern are response to overvoltages (e.g. in case of lightning strikes in adjacent OHL sections), the impact of cable capacitance (and related reactors) on switching phenomena and short circuit response, resonance frequencies of the system, voltage stability, etc.

A range of studies dealt with respective phenomena and concluded that no fundamental problems exist preventing integration of UGC in the transmission applications considered in these studies [KEMA 2008] [Colla et al 2007] [Cigre 2008]. However, these investigations focused on individual UGC sections and assumed the surrounding system as invariant. For a comprehensive understanding of the wider system implications and the interactions further research is needed, certainly in scenarios assuming enhanced UGC shares in transmission assets [Oswald 2007]. Additionally, the existing studies can not completely compensate for the lack of practical experience and demonstrated long term performance of the required components under real world conditions. This experience has to be gained in projects of appropriate extension and with manageable impact on transmission system adequacy.

5.1.2 Operation and maintenance

Operation

UGC in a meshed OHL network increases operational complexity. Among others, load flow control, protection schemes and contingency management are affected by the mixture of technologies with different characteristics. For the exploitation of the advantages of UGC (e.g. temporary overloading capability) additional monitoring parameters have to be taken into account and the range of control actions becomes broader.

In a similar way this applies also to VSC HVDC with its enhanced operational flexibility.

Maintenance and repair

By nature, regular maintenance of UGC is very limited. If UGC are not installed in tunnels, the assets are accessible only at the interfaces with the OHL network. Just the cross bonding boxes require regular inspection. In this perspective, maintenance of OHL may be slightly more labour intensive.

The effort related to corridor clearance is similar for both options.

In case repair is required, the UGC option is significantly more time and labour intensive because of construction works. The differences in the mean time to repair may serve as an indicator (see also the previous paragraph 5.1.1). If the fault location is close to other infrastructure (e.g. roads) repair works may affect their operations too.

Testing of an UGC required before returning to normal operation involves specific equipment, specialists and additional time.

Adequate training and capacity building are a precondition for successful operation and maintenance of new transmission concepts in the existing system.

5.1.3 Costs

The cost ranges provided in literature for UGC vary dramatically. Compared to OHL, cost ratios between 2 and 30 have been reported. Many of those references insufficiently specify underlying assumptions and parameters. Additionally, various certain sources restrict the scope to the initial investments whereas others include life cycle costs (losses, O&M, etc) and even this fundamental choice is not always clearly documented.
Referring to recent studies, Figure 5-2 provides an illustrative overview of capaital costs for UGC depending on nominal transmission capacity. Only references have been included which give a minimum of transparency regarding the methodology applied and input data used. Still this does not allow judging the quality of the particular references.

The figure also indicates reasonable investment levels for OHL solutions. [Oswald et al 2005] refers to a “Donau” tower with two circuits and specific costs of about k€ 1000 per km. For a single circuit OHL as being the standard design choice of EirGrid for 400 kV transmission, a value of k€ 700 per km has been assumed (OHL reference 1 system).
For illustrative purposes, also typical 220 kV UGC capital costs reported by the CER have been included [CER 2005].

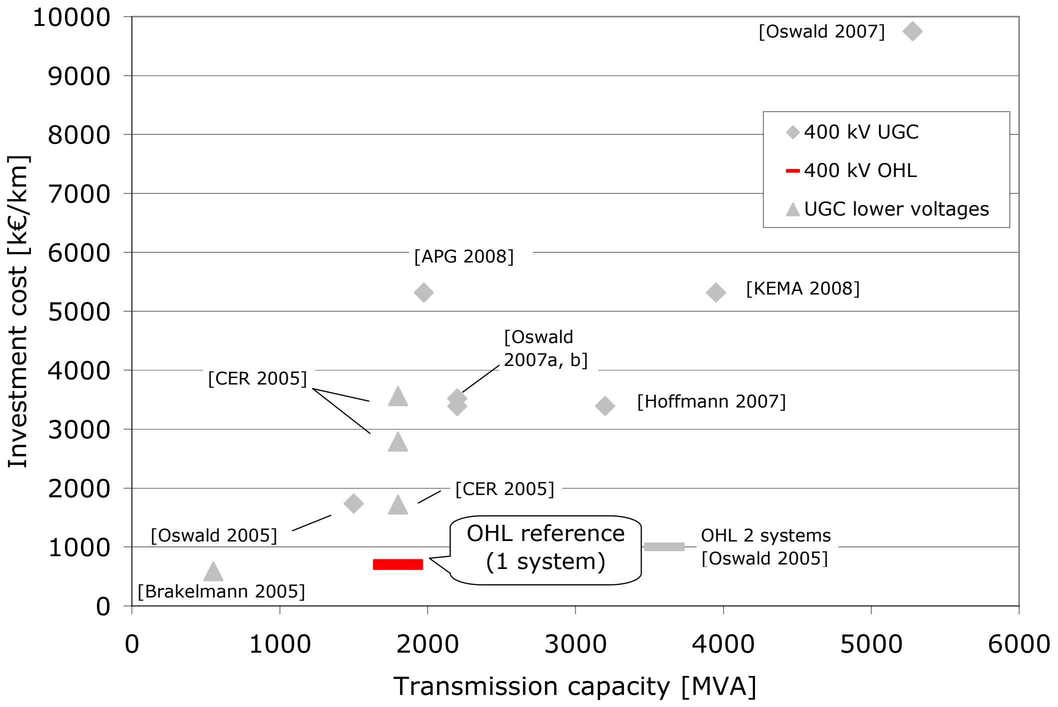

Figure 5-2 Capital costs for various UGC projects (◇ 400 kV, Δ lower voltages) in k€ per km depending on design transmission capacity and in comparison with common OHL investment levels (−)

The following aspects may help to understand the variation in the data shown:

- [Brakelmann 2005] calculated costs for UGC in a 110 kV distribution network;
- The transfer capacity calculated in [KEMA 2008] has been challenged by [APG 2008]; for illustration the figure shows the same investment for both transfer capacities;
- [Oswald 2007] discusses an UGC which is fully equivalent to a 400 kV OHL and for that reason comprises 4 circuits. This implies a trench of more than 20 m width. As the terrain is difficult (a significant share of the trench has to be prepared by blowing up rock) civil costs are relatively high.

In line with industry consensus, Figure 5-2 shows that for a given transmission capacity initial capital costs for UGC are higher. The references suggest investment ratios in a range between 2 and 9.

For a sound comparison of the economic performance of UGC in relation to OHL the operational costs, in particular the economic value of the losses has to be taken into account. This has been done for example in [PBPower 2008] and [Jacobs Babtie 2005].

The losses are strongly dependent on the operational conditions of the line and no generic figures exist. For a range of options and operational conditions a more detailed comparison is provided in section 9 analysing two case studies.

6 Comparison of Environmental Impacts

'Any economic or social development project will result in an insertion into the environment and the reduction of the impact of this insertion has a cost: Zero impact on the environment is not a realistic possibility, and a balance is the key solution' (Hammons et al. 1998)

The environmental impact issues associated with the construction of EHV transmission lines (overhead and underground) are discussed below. Considered are the potential positive and negative impacts of the installation and subsequent operation of EHV OHL and UGC under the following headings:

- Land Use
- Geology and Soils
- Water Resources
- Ground Restoration
- Ecology and Nature Conservation
- Landscape and Visual
- Cultural Resources
- Traffic and Noise
- Air Quality
- Communities
- Recreation and Tourism

The environmental issues associated with particular EHV cable and line technologies are considered where appropriate. It is assumed in this report that all new transmission lines in Ireland will be constructed, operated, maintained and decommissioned in compliance with all international and national health standards, namely, those related to EMFs. The issue of whether international or national standards related to EMFs are adequate is beyond the scope of this report.

6.1 Land Use

Impacts to land use from OHL or UGC can be categorised as either temporary or permanent. Temporary impacts include once-off construction activities.

Permanent impacts may include land sterilisation in the exclusion zones around either OHL or UGC, approximately 60 m for OHL and approximately 4 m for UGC. However most agricultural activities can continue beneath an OHL. If there is a requirement to build in proximity (23m) of an OHL then the TAO must be notified and a clear minimum clearance for construction activities established. Detailed impacts on land use can only be assessed locally as a function of the inherent, local use of the land in question, and is typically a site specific issue. The following is therefore an indicator of the general comparisons that can be made between OHL and UGC.

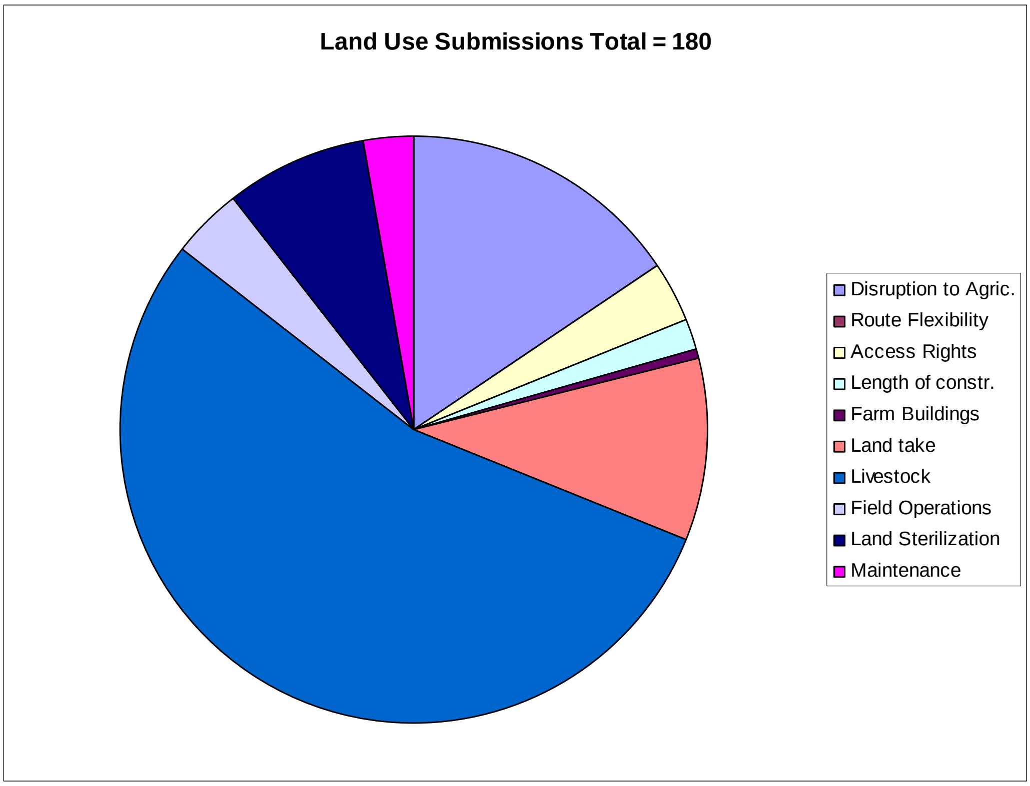

Figure 6-1 Proportions of the concerns raised in the submissions addressing Land Use

6.1.1 *Time and Flexibility of Construction*

Land use may be temporarily compromised during construction of OHL and UGC by a number factors including but not restricted to the following:

1. Construction during excessively wet or excessively dry periods can have a detrimental effect on subsequent reinstatement of vegetation along access routes. This is especially true for UGC along their entire route. Equipment for transportation and implementation of UGC is heavy – greater than 30 tons – in comparison to equipment needed for OHL. Roads have to be built along the entire route but may be removed afterwards. Impacts on OHL routes are from access routes and land take restricted to each pylon base. However forest development along the immediate **wayleave** should be restricted in order to gain access to OHL for routine maintenance and emergencies.

2. Construction during crop growth and/or harvesting season can have a detrimental effect on harvest yield. UGC would have an effect due to trenching along their entire length or at least a large portion of it. Effects on harvest yields are likely to be similar for OHL as conductors have to be rolled out with heavy equipment and spanned along the route.

3. Construction during lambing or calving season may have a detrimental effect in that livestock may have restricted access to large tracts of land especially in the case of UGC.

6.1.2 Length of Construction

Length of construction is an important consideration with regard to land use. With OHL length of construction might be two or three seasons (winter workings restricted), for a 120 km distance i.e 30 m to 80 m per day. For UGC an average of 50 m to 100 m per day could be anticipated for normal ground and 29m to 40m per day in difficult terrain [Cova, 2008 and Cesi, 2008].

6.1.3 Permanent Disruption to Agriculture

Deep rooting trees cannot be planted within the UGC exclusion zone. Tall trees may interfere with OHL and therefore must be felled if present and an appropriate exclusion zone put in place. In general, trees are removed regularly from beneath OHL, before they become tall. This would be the same over a UGC route to prevent the development of deep roots. Nevertheless, the width of a single circuit OHL route is 15 m to 21 m (depending on tower design). The width of a cable route is about 7 m (up to 21 m during construction) for a double circuit and less than 4 m for a single circuit or tunnel/duct.

Cultivation is allowed in both cases and it is only the land taken up by the pylons (OHL) or joint bays (UGC) that hinder this. Farmers should be aware of either the height of OHL or the depth of UGC. With UGC deep cultivation is not permitted along the route.

For the most part, permanent access routes are required for both OHL and UGC, especially in particularly marshy land. These access routes may impact on agriculture in the form of land take (see below).

6.1.4 Land Take

Land take for both OHL and UGC would involve permanent access routes that may be required for both as described above. In the case of OHL the pylon base would be additional land take while for UGC any necessary joint bays would also involve some degree of land take. These joint bays typically measure 16 m X 3 m and are usually rigidly restrained below ground. However the footprint each of these underground structures would require access to be restricted.

Where there is a change from OHL to UGC or vice versa significant land take would be necessary (50 m by 40 m or less). Large compounds, known as Sealing End Compounds (SECs), are needed to house the transformation of these cables or lines. These compounds would be securely fenced off.

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6.1.5 Effect on Field Boundaries

During construction of either OHL or UGC field boundaries may change or may necessitate temporary destruction in order to accommodate access or, in the case of UGC, to accommodate trench digging.

6.1.6 Effects on Farm Buildings

Construction can be limited over UGC or, in some cases, under OHL due to access requirements for maintenance and decommissioning and possible damage to the circuits during construction.

6.1.7 Effects on Drainage Patterns

Pylon bases, in the case of OHL, are likely to have little or no effect on drainage patterns. Trenches associated with UGC however may be partially backfilled (see Section 6.4 below) with differing material to the original soil and this may cause a disruption to drainage on agricultural land.

6.1.8 Catastrophic Events Implications

Implications for land use as a result of catastrophic events may mirror those associated with initial construction. In the case of OHL, major storms may result in pylon and/or line damage. If damage is severe this may require replacement of these lines. In the case of UGC major flooding poses the most significant threat although UGC are not immune to the most severe of storms [Edison Electric Institute, 2006 and references therein]. UGC also run the risk of being dug up due to construction work. Again, if the resulting damage is severe enough this may warrant the excavation of and relaying of cables.

6.1.9 Repair and Maintenance

Land use can be temporarily affected during repair and maintenance for OHL and UGC in the form of restricted access to land during repairs and maintenance. It is OHL that generally require most maintenance and repairs due to their exposure to all types of weather conditions. Similarly

recreation activities in parkland would also be curtailed for the duration of works. In case UGC repair is necessary, local impact is significant (digging works).
In general, regular maintenance of OHL is scheduled for the summer season, because system loading is lower and, hence, n-1 security is less affected when taking a connection temporarily out of operation. This would be the same for UGC.

6.1.10 Mitigation

Based upon the potential impacts associated with land use described above, the following options for mitigation have been identified:

- Careful selection of the time of year when works are carried out and the use of preformed matting systems where appropriate, which can significantly reduce tyre track damage in particularly sensitive areas;

- Use of the most up-to-date and efficient construction techniques in order to minimise construction time;

- Laying UGC in a trough in urban areas, railways or roads where concrete surfaces are already in place [Jacobs Babtie, 2005].

- Land take mitigation measures may involve remedial measures only;

- Careful route selection and due concern for field boundaries separating lands owned by different parties (ensuring the replanting of linear hedgerow features using indigenous species is very important and is considered in more detail in Section 6.5);

- Careful selection of appropriate backfill material, grading, trench drains and **soakaways** where necessary;

- Pylon design, appropriate location of pylons and careful route planning paying special attention to flood risk areas; and

- Providing as much advance warning of proposed repairs or maintenance as is reasonably possible.

6.2 Geology and Soils

Geology and soil type may often be decisive factors during the route planning phase for OHL and UGC. In general OHL are only concerned with what soils the pylon bases are constructed on. However both OHL and UGC must take account of subsurface conditions during their construction and operation. A zone may exist of weathered/fractured rock before the actual bedrock itself is encountered. Weathered/fractured rock close to the surface may significantly increase the amount of material requiring excavation. This must be taken into account when excavating OHL pylon bases and trench digging for UGC. However UGC may follow existing infrastructure e.g. roads, and this may limit additional effects.

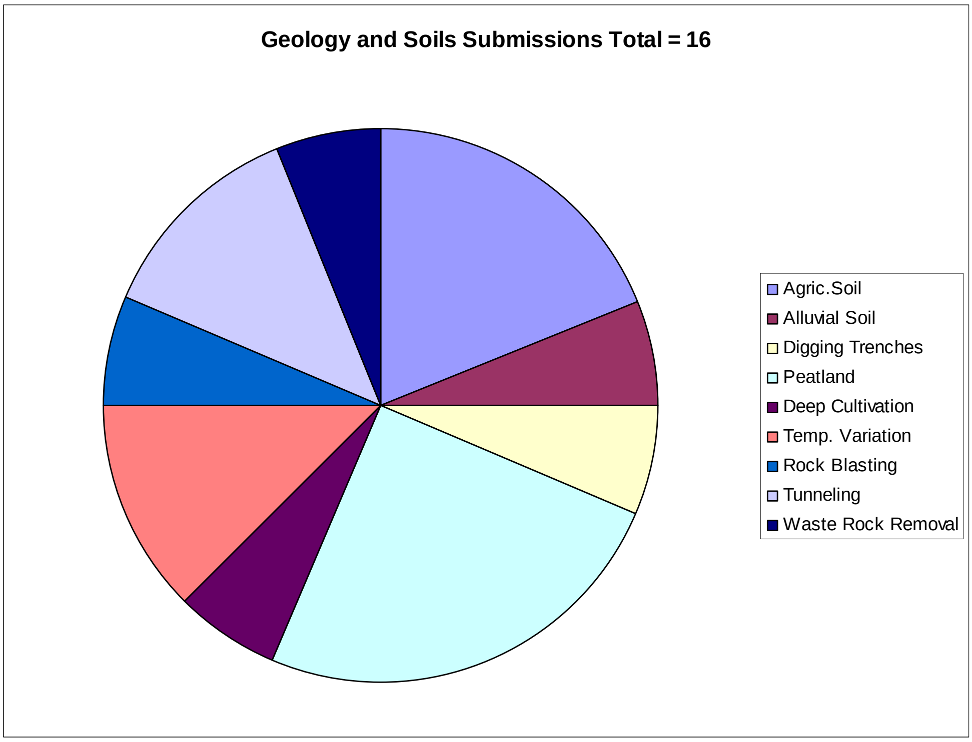

Figure 6-2 Proportions of the concerns raised in the submissions addressing Geology and Soils

6.2.1 Soil Cover

In the case of UGC, soil cover in an area governs how easy it may be to excavate and bury cables. If soil cover is relatively thin, rock cutting/blasting and/or directional drilling would play a significant role in cable laying. This in turn is dependent on geology. Limestones of Carboniferous age underlies more than half of Ireland [GSI 2004]. Many of these limestones play host to **karst** features such as caves, turloughs and sink holes. It may be extremely difficult to rock cut or tunnel in karstic areas without affecting groundwater and cable stability during operations. Karstic areas are problematic as the occurrence of voids and groundwater flow directions are often very difficult to detect. OHL are less dependent on soil cover and pylon bases can be built directly onto the rock head. Pylons and pylon bases may be an issue in karstic areas where there may be a significant risk of ground collapse due to greater forces being exerted on grounds beneath pylons and pylon bases.

6.2.2 Soil Type

Soil type concerns mainly the construction phase in OHL and UGC. With OHL soil type is only of concern where pylon bases are constructed. Soil must not be corrosive to concrete bases. Laying of UGC may be complex in relation to soil type. Its suitability as a backfill material and its thermal resistivity are important considerations when assessing cable spacing and depth of cable. Often the soil is not a suitable backfill material by itself and must be combined with specialist material from an external source e.g. for two UGC circuits directly in the ground 10.5 m^3/m and refill with $4.2m^3/m$ dedicated backfill material (i.e. permanent removal of at least 6 m^3/m) For a cable tunnel for two circuits this should be slightly more than half of this volume [Oswald, 2007]. This may have repercussions with regard to drainage patterns. This is of particular relevance in wetlands where the altering of drainage patterns, due to replacement of indigenous soils in backfill, adversely affects the ecosystem of a portion of the wetland. Rocky soils when laying UGC require heavy excavation equipment (see Section 6.1.1) which may in turn have an impact on land take and construction time. In certain cases it may not be possible to access wetlands and peatlands with this heavy equipment. These lands would then need to be avoided.

6.2.3 Excavated Material

Excavated soil and rock from both pylon bases and cable trenches would need to be disposed of in a suitable manner. In the case of OHL only volume occupied by the pylon base is of concern but should be removed, especially where bases are constructed on slopes to mitigate against any slope stability issues. The material excavated during the laying of UGC may not be suitable as a backfill material as discussed above (Section 6.2.2). In certain cases up to half of the excavated material may be re-used as backfill material [Jacobs Babtie, 2005]. Cova [2008] suggests excavated material amounting to 200 m^3 per km for OHL and 30,000 m^3 per km for UGC (assuming a cross section of $30m^2$ and partially backfilled). UGC trenches as considered in the case studies (section 9) would imply excavation of about 8000 m^3 per km, with partial backfilling. This material then impacts the amount of land affected during construction. Consideration must also be given to slope stability, especially on hillsides.

Figure 6-3 Construction route for UGC; source: [Europacable 2006]

6.2.4 Quarrying and Mining

Subsurface mining and blasting in proximity to pylon bases or joint bays may affect their structural integrity. Blasting from quarrying may also carry similar risks.

6.2.5 Mitigation

Based upon the potential impacts associated with geology and soils described above, the following options for mitigation have been identified:

- Careful route planning and careful use of standard engineering techniques;
- Detailed soil surveys and selection of suitable backfill material;
- Use of as much excavated material as possible as a backfill material and further assessment of areas where cables are to be undergrounded; and
- Close liaison with strategic plans to offset possible future quarrying or mining activity effects.

6.3 Water Resources

Environmental impact on water resources from OHL and UGC are discussed in this section. OHL generally carry some risk in the construction phase in the form of potential for increased sediment load. Operational effects on water resources are mostly visual impact on scenic water courses. UGC represent risk to water resources in the form of:

- Disruption to groundwater including wetland; and
- Disruption to surface waters during construction

Prior to any construction phase there should be close coordination with the Environmental Protection Agency (EPA) in developing method statements to help ensure least impact.

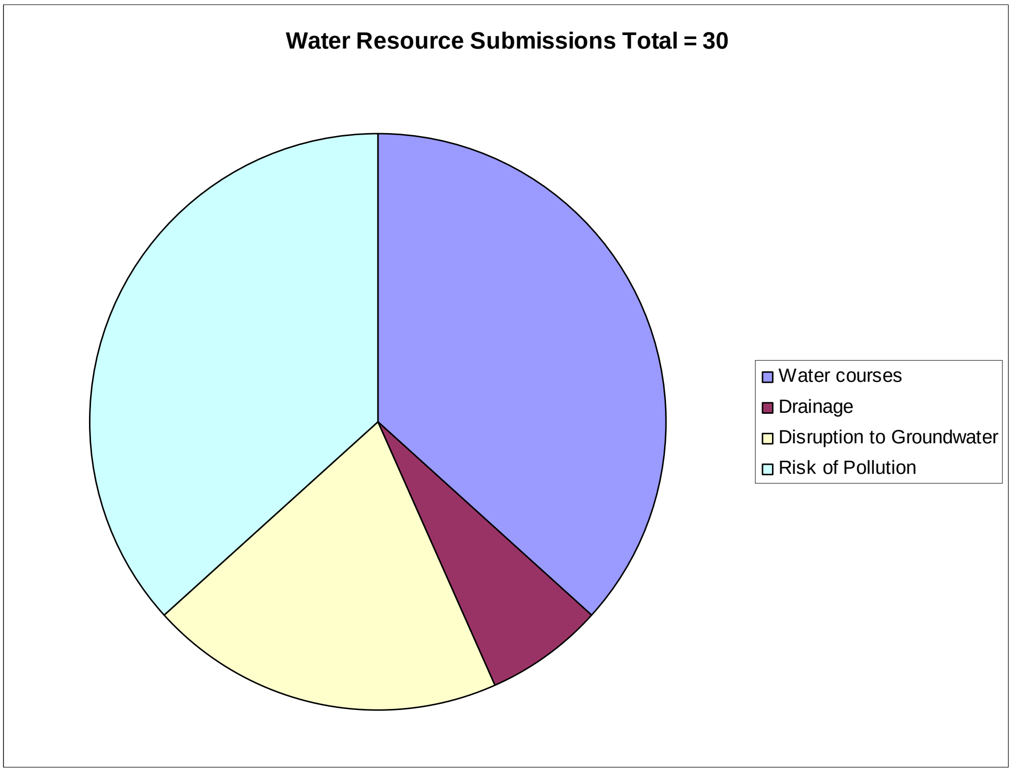

Figure 6-4 Proportions of the concerns raised in the submissions addressing OHL and their impact on Water Resources

6.3.1 Disruption to groundwater including wetland

OHL present no significant risk to groundwater either during construction or operations. However, care should be taken as both OHL and UGC construction involve the construction of haul roads and topsoil stripping. This can have an impact on shallow water resources through interception of shallow flows or production of turbid /sediment laden runoff. The impact of UGC is likely to be greater than OHL due to larger amounts of topsoil stripping. In addition the digging of trenches and the partial or complete backfill with allocthonous material may intercept shallow groundwater flow to nearby springs or wetlands. Backfill needs to be carefully selected so that backfilled trenches have similar hydraulic conductivity to in-situ material. To reduce the risk of horizontal groundwater movement along trenches, it may be appropriate to install low permeability **stanks** within the trench backfill in sensitive areas. This is of particular relevance in wetlands where the disruption of water movement may result in drying out sections of the wetland. This in turn may have a resulting adverse effect on flora and fauna.

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6.3.2 Surface Waters

Surface waters are most vulnerable during the construction phase of OHL or UGC. Although OHL present the least risk to surface waters during construction (towers are generally situated away from major water courses) it is often their visual impact on scenic waterways during operations that are of concern. Visual impacts are addressed below in Section 6.6.

Figure 6-5 Bridge used as river crossing for cables; source: [Cova 2008]

Using crossings at bridges, directional drilling under the river bed and placing the cables in ducts on the river bed are all means by which UGC can cross water courses. Placing cables in ducts on the river bed, where the river may require diversion, may pose a significant threat to aquatic life during construction e.g. otters, salmon migration.

6.3.3 Mitigation

Based upon the potential impacts associated with water resources described above, the following options for mitigation have been identified:

- Care should be taken when pylon bases are constructed where the water table is relatively shallow in order to avoid risk of pollution of groundwater due to construction activities e.g. oil spillages, fire fighting runoff. The same care should be taken with UGC.

- In the case of UGC backfill needs to be carefully selected so that backfilled trenches have similar hydraulic conductivity to in-situ material. To reduce the risk of horizontal groundwater movement along trenches, it maybe appropriate to install low permeability stanks within the trench backfill in sensitive areas.

- Use of bridge crossings where feasible, directional drilling (where geology allows), crossing major water courses out of salmon migration season and a full survey for each water course to be crossed. Diversion of water courses should be avoided where possible to minimise disruption to aquatic ecosystems.

6.4 Ground Restoration

Ground restoration for OHL is minimal and confined to the vicinity of the pylon base and access routes. Tree felling along the right of way would be necessary in order to avoid damage to lines. Continued tree trimming in proximity to lines during operation would also be necessary. Ground restoration for UGC is extensive and extends for the entire length of the UGC. Trees that demonstrate extensive and deep root systems would be prohibited from being planted along the entire wayleave, therefore leaving a noticeable strip where the final or original land use is for forestation. Where UGC are combined with existing infrastructure then the necessity for ground restoration may be reduced. Similar to OHL, access routes would require ground restoration on completion of the construction phase. In general, ground restoration for UGC on completion of construction is successful for agricultural lands and permanent markers/signs are required to draw attention to the location of the UGC. In the case of the Newby-Nunthorpe Line in Yorkshire the route was laid in mainly pastoral land and reinstated to its original condition. The ground recovered quickly [Jacobs Babtie, 2005].

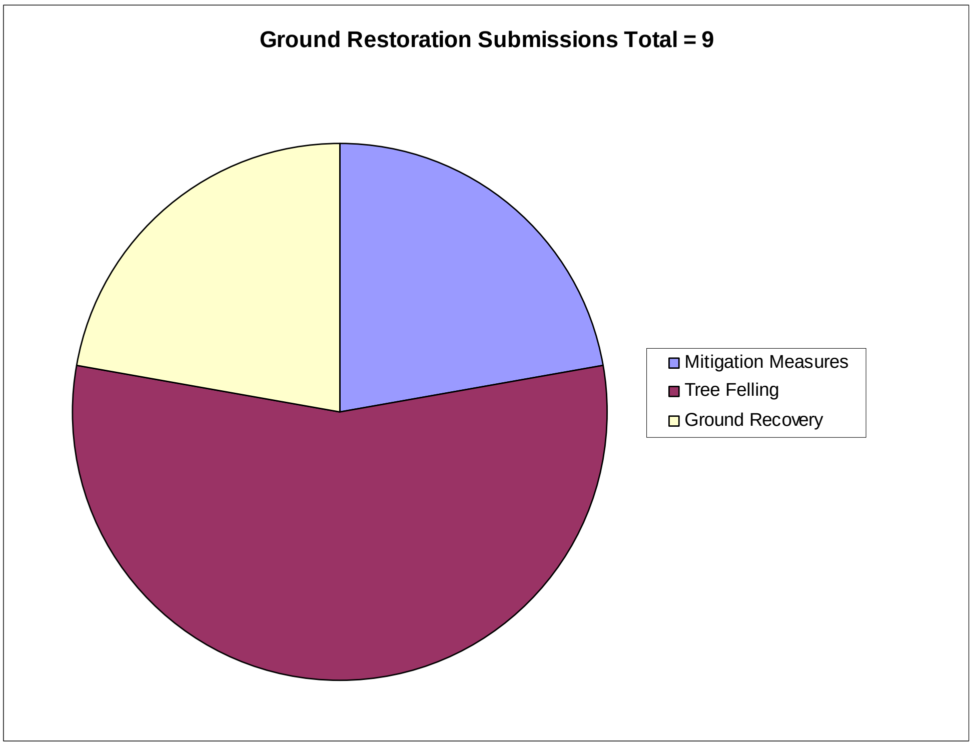

Figure 6-6 Proportions of the concerns raised in the submissions ad-dressing Ground Restoration

6.4.1 Mitigation

Potential mitigation includes careful selection of backfill material and local seeds for flora reinstatement.

6.5 Ecology and Nature Conservation

As ecological conditions are extremely variable depending on location it follows that impacts on ecology and nature conservation in association with OHL or UGC will also be extremely variable. In general, the more ground and space that is taken up (usually during construction) the greater the impact on ecological and nature conservation parameters. These parameters are discussed below.

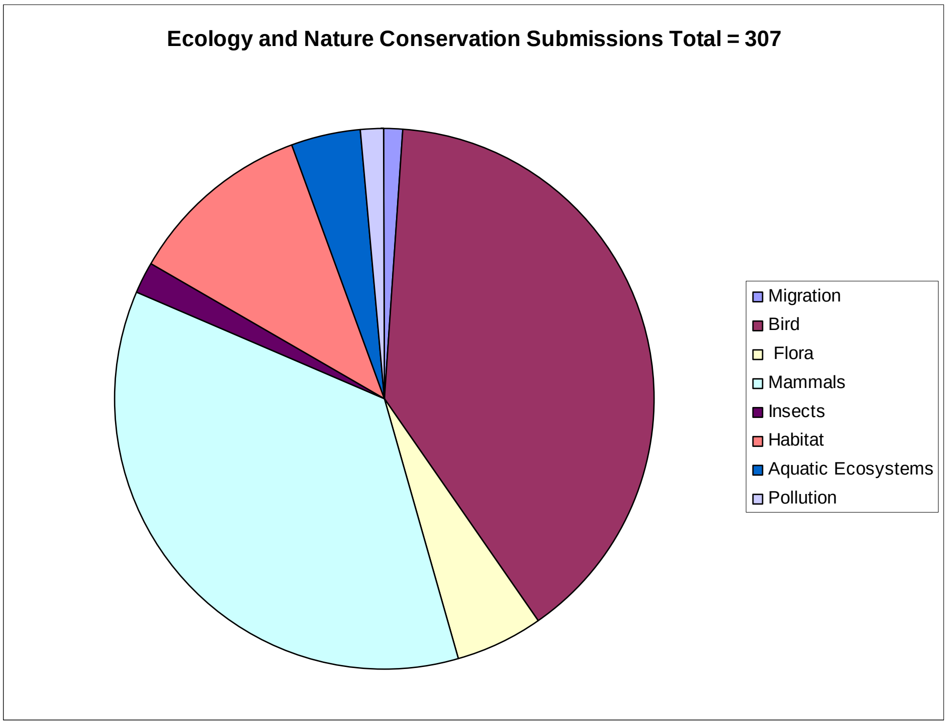

Figure 6-7 Proportions of the concerns raised in the submissions addressing Ecology and Nature Conservation

6.5.1 Bird Strike

OHL present a risk to birds in flight due to the potential for collision, especially during poor visibility. Factors such as landscape features and power line design may influence death-rate [Fernandez, 1998, Jans and Ferrer, 1998]. Alonso et al. [1994] observed a collision mortality of 5 birds/28.2km/year for the common crane while Hartman et al. [1993] estimated collision mortality at 0.5%-2.2% for waterfowl populations. Guyonne and Ferrer [2000] emphasise that the variation of estimated collision mortalities is due to a number of factors including type of bird and bird population density. Towers with red lights attached to their highest points are a particular risk as they may attract birds travelling at night. If the OHL are placed along or across migratory flight paths or between roosting and feeding areas, then the risks of strikes are greatly increased. On the other hand predatory birds may often use pylons as roosting sites [Steenhof, 1993].

6.5.2 Flora

Risk to flora is considerable for OHL and UGC mainly during the construction phase. Impact on flora is considerably less for OHL than UGC and is generally limited to the vicinity of each pylon base and access routes. UGC result in impacts along the entire linear feature, including removal of hedgerows. However, with all OHL there are ‘Limits of Approach’. These may be defined as ‘the distance a person, machine or conductive material (such as a tree) can be in relation to the energised conductors based on circuit rating, flashover distance (where an arc of electricity jumps to a nearby tree), and other attributes, such as conductor sag (where the line sags closer to the ground due to increased heat’ [British Columbia Transmission Corporation, 2005]. Therefore ‘Limits of Approach’ may require growth near to OHL to be inhibited.

UGC present more significant threats to flora in that the full length of trench for the cable may be disturbed (except in cases where directional drilling is used). Any flora would be directly affected by the clearing of flora for the right of way for the OHL or UGC. Most flora generally recover in 18 to 24 months on lowland pasture/agricultural land. However flora is often much more sensitive in other areas such as wetlands and heathland and as such may fail to fully recover e.g. in a moorland habitat full adult plant recovery may take between 5 and 10 years [Jacobs Babtie, 2005]. Heat production from UGC may also produce an ambient increase in soil temperatures in the immediate vicinity which may in turn alter biodiversity. Analysis shows that an increase of surface temperature directly above the cable of up to 2 ºK may appear during absolute calm and under full load conditions. An increase of up to 10 ºK is possible at a depth of 0.5 m below surface. Within a distance of 5 m from the cable trench no temperature change will be detected. In this context it has to be emphasised that full load conditions in practice are extremely unlikely because of the n-1 principle applied in transmission planning. Additionally, even in the case of temporary full loading as a consequence of the substantial thermal inertia of the soil the temperature rise will be delayed and not achieve stationary maximum values at all. Paragraph 4.2.2 of this report discusses temperature changes in greater detail.

6.5.3 Mammals

The greatest risk to mammals is during the construction phase where wayleaves are cleared for OHL or UGC. The impact from OHL is considerably less and is usually confined to the pylon bases and access routes. Trench digging for UGC during construction may disturb burrows and foraging areas.

6.5.4 Insects

Perceived risks to insects including risks to bee colonies are associated with OHL only [Strickler & Scriber, 1994]. No studies appear to have been undertaken into any impacts on insects in association with UGC. However, any disturbance of ground associated with trench digging may disturb ground and hedgerow dwelling insect habitats. Temperature increases, as described above, may also adversely affect these habitats but current knowledge does not allow clear evaluation.

6.5.5 Habitat Loss

Loss of habitat is of greater concern during the construction phase of OHL and UGC. The amount of habitat affected would be considerably less for OHL, being confined to pylon bases. Clearing of land to accommodate UGC would cause much greater disturbance of habitats.

6.5.6 Aquatic Ecosystems

The main risk to aquatic ecosystems is during the construction phase of OHL or UGC and is concerned mostly with increased suspended loads in water courses. Potential mitigation includes due care in excavation, development of temporary drains and settlement ponds, and the use of silt traps in nearby drainage courses. Special attention should be paid to temporary water bodies which may be vital to some aquatic species' life cycles.

6.5.7 Restoration

Restoration techniques are well established and commonly use mechanical spreaders to distribute seeds [Jacobs Babtie, 2005]. Where possible, local seeds should be used for habitat restoration and this is especially important within protected habitats. However, restoration above trenches can be difficult. Even where restoration is carried our using a mix of local plant species and every attempt has been made to ensure the restored habitat is of a similar composition and complexity to the original habitat, it is not possible to guarantee that restoration will be successful.

6.5.8 Mitigation

Based upon the potential impacts associated with ecology and nature conservation described above, the following options for mitigation have been identified:

- Potential mitigation against bird strikes includes line markers such as visibility balls and other bright line markers [Alonso et al. 1994]. However it is not currently known how effective these measures are and further research is required.

- Trench digging for UGC during construction may disturb burrows and foraging areas. Potential mitigation includes reinstatement of such features where appropriate.

- Potential mitigation is site specific and would depend on further investigations into environmental baselines, existing soil temperature fluctuations and selected technologies.

- Transplanting particularly diverse hedgerows results in the recovery of some habitats.

- Use of due care in route selection and time of construction in order to cause least disturbance to nesting birds or breeding mammals.

- Where possible, local seeds should be used for habitat restoration; this is especially important within protected habitats.

6.6 Landscape and Visual

One of the primary issues of concern identified in the public submissions related to the decision to establish a system of OHL and/or UGC is that of landscape and visual impacts. Landscape impacts relate to changes in the fabric, character and quality of the landscape. These could include direct impacts on specific landscape elements or features (such as loss of woodland or individual trees) or effects on landscape character and designated areas of landscape. Visual impacts relate to specific changes in the character of available views and the effects of those changes on visual receptors (e.g. users of footpaths, residents or users of recreational facilities).

It is generally accepted that OHL reduce landscape and visual character and quality, and that character and quality are valued by local residents and visitors to an area. This general acceptance was confirmed in the analysis of the public submissions. Therefore, it is common for local communities and businesses to respond to a proposed OHL system with a great deal of opposition, and it is thus a significant aspect to consider when planning electrical transmission infrastructure. UGC installation and operation also have an impact to landscape and visual resources. The extent of this impact is generally of less magnitude and therefore proposals for such systems are not typically faced with the same degree of public opposition. Hence, alternative route options and other mitigation measures should be considered, particularly in areas of high visual amenity or sensitivity.

Since many landscape and visual impacts associated with OHL and UGC extend to other topics covered in this report – including impacts to Communities, Land Use and Culture – they are discussed in more detail in their respective sections.

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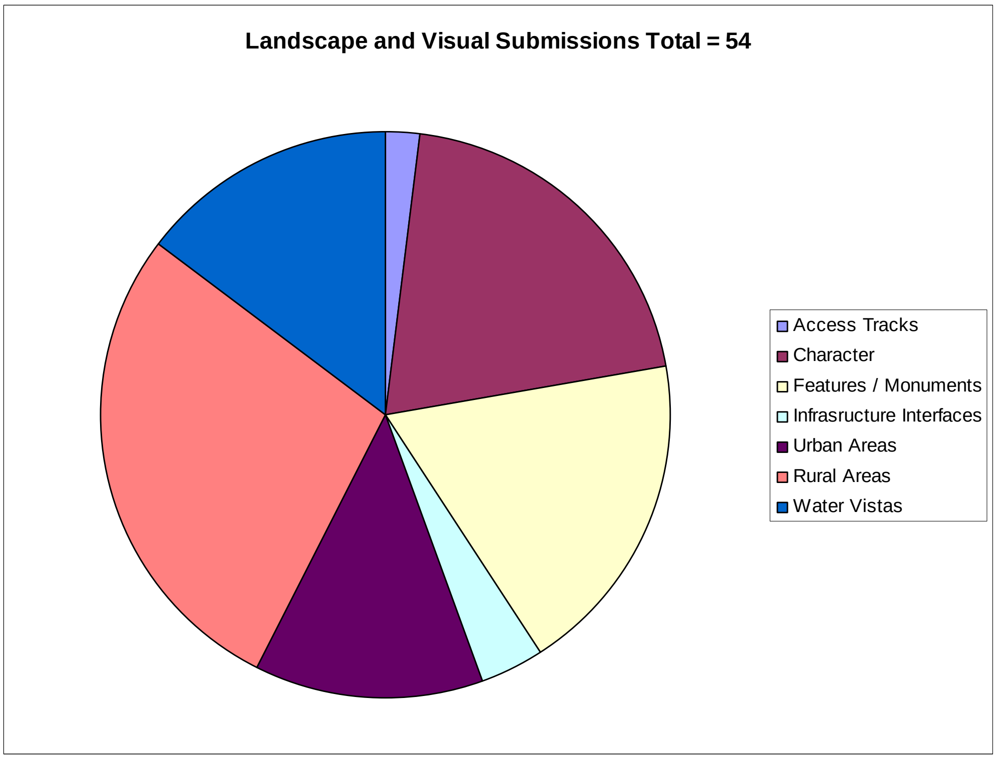

Figure 6-8 Proportions of the concerns raised in the submissions addressing Landscape and Visual Resources

6.6.1 Landscape Character and Visual Effects

Ireland's landscape is known for its undulating topography, agricultural heritage, mountainous terrain, numerous lakes and rivers, extensive coastlines, and relatively undeveloped countryside. The landscape character of the country is an aspect of great pride to Irish citizens, and is considered to be one of its most distinguishing assets. The quality of landscape is considered to be a significant driver for tourism, and is thus not only enjoyed by local residents, but also contributes to the national and local economies.

While the duration of construction for OHL and UGC do not necessarily differ significantly, the extent of earthworks required would be comparatively different. UGC construction requires substantial earthworks including trenching, the removal of excavated material and backfilling, controls on access and the restriction of traffic for prolonged periods. "These activities can have a significant effect on a landscape character as the construction would involve the removal of trees, hedges or areas of woodland to create the route. It is important to note that felling of trees and removal of other vegetation is more intense for UGC than with OHL as the width of the construction is greater" [Jacobs Babtie, 2005]. The construction of OHL does not require such extensive earthworks; however, pylon erection will also impact the local landscape character. In general, the earthworks associated with UGC will be most apparent when viewed from elevated locations, whereas the vertical nature of pylon erection will impact landscape and visual resources from ground-level. Therefore, the relative landscape and visual impacts associated with OHL and UGC will primarily be a function of local topography.

During operation, impacts to landscape and character due to UGC are anticipated to be minimal as the route may more or less eventually be restored to its original condition using the proper mitigation and restoration measures. Furthermore, the flexibility of UGC enables the route to follow existing linear infrastructure, such as motorways and railways. However, the responsible authorities (e.g. NRA) have to agree with such a combination and support is uncertain.
UGC do involve their own long-term impacts to landscape and visual resources, such as Sealing End Compounds at the end of the underground section in order to connect it to overhead transmission lines. OHL are generally more visually intrusive during operation due to the vertical nature of pylons. OHL can also be routed alongside existing linear infrastructure to minimize the relative landscape and visual impacts; however, the direction of OHL can only be changed from pylon to pylon, so this can be challenging in the case of following infrastructure which is not a relatively straight line.

Other impacts to the natural environment, such as those associated with vegetation or the crossing of water courses, could also have an indirect impact on landscape character. The potential effects on character will vary depending on the specific location. In general, the indirect landscape and visual impacts associated with these resources will be a function of the extent of ground clearance necessary for each system. An example of another impact which could have an indirect impact on landscape and visual resources is the potential soil temperature changes associated with UGC. Details on these impacts can be found in their respective sections of this report.

6.6.2 Natural Features and Historical Monuments

An important aspect of Ireland's landscape character and quality is its unique natural features and historical monuments. Natural features which characterise Ireland's landscape are drumlins, mountains, stone walls, hedgerows, water vistas and coastlines. Examples of types of historical monuments in Ireland include castles, churches and graveyards. Detailed information regarding natural features can be found in Sections 6.2 (Geology and Soils) and 6.5 (Ecology and Nature Conservation). Additional information regarding historical monuments can be found in Section 6.7 (Cultural Resources). Such natural features and historical monuments have the potential to be impacted by the installation of OHL or UGC.

Natural features and historical monuments could remain intact in the case of OHL, as OHL can be constructed to cross above them. Doing so, however, would have a negative impact on the visual nature of the feature or monument. In the case of UGC, standard trenching methods would have a higher potential to damage features and monuments, thereby having an effect on historic landscape character. However, UGC can usually be routed underneath the structure via directional drilling installation techniques. In either case, the transmission route can be diverted to avoid the feature or monument altogether. This option would increase the length of the route in both cases, although the comparative increase in length would likely be less in the case of UGC due to the flexible nature of the cables. The direction of OHL, in contrast, can only be changed from pylon to pylon. Therefore, the relative impact to these structures will be determined by method of installation.

Tree preservation is generally considered to be aesthetically beneficial. OHL require a wider girth which is devoid of trees and woodland than UGC in order to maintain the transmission route and to maintain access. “In an appropriate landscape, UGC can be a successful landscape treatment, but in others, the limitations on ground cover required for the cables may leave a line in the landscape that is impractical to integrate” [Jacobs Babtie 2005]. However, “trenching or boring required for UGC can damage tree roots which can kill trees directly, structurally weaken trees, and make trees more susceptible to disease [Infrasource, 2007].” Elevated views in particular would be impacted by the removal of trees. A more detailed discussion related to trees is included in Section 6.1 (Land Use) and 6.5 (Ecology and Nature Conservation).

6.6.3 Access Tracks / Haul Roads

Both UGC and OHL typically require access tracks and haul roads during construction. Due to the intensive nature of construction earthworks such as trenching, removal of excavated material and backfilling, the need for access tracks and haul roads is greater for UGC during the construction stage. Most of the land used for access tracks and haul roads in both scenarios can be restored post construction.

Both UGC and OHL would involve ongoing requirements for operational access, such as joint bay and tower locations. For agricultural environments, this would not normally require permanent access roads to be installed; a possible exception to this is in the case of peaty soils, where permanent access tracks may be necessary to support the weight of the vehicles. This would need to be assessed on a case-by-case basis.

6.6.4 Communities

Construction of OHL and/or UGC can have an impact on both rural and urban communities. Communities are the most sensitive visual receptors, and the potential landscape and visual effects of an electrical transmission scheme increase with the proximity of communities. A detailed description of the potential impacts to communities and how they relate to landscape and visual amenities are provided in Section 6.10 (Communities).

6.6.5 Mitigation

In general, the size of an OHL is related to the corresponding level of voltage capacity - the larger the voltage, the larger the pylon and its subsequent impact on landscape and visual resources. Therefore, careful route selection during the planning stages is critical in mitigating landscape and visual resources, particularly those attributed to high voltage pylons. It is at this route selection stage where there is maximum potential to achieve avoidance and minimal adverse landscape or visual effects.

There are basic techniques to mitigating adverse landscape and visual impacts, all of which need to be considered on a case-by-case basis. Such mitigation measures include:

- Avoiding conspicuous sky lines and horizons, particularly in visually sensitive areas;
- Avoiding, to the extent feasible, areas of high visual amenity and areas with highly sensitive visual receptors;
- Constructing lines and cables along previously established linear infrastructure such as roads and railways (co-location);
- Use of lower height towers;
- Consideration of less visually intrusive OHL pylons, particularly in sensitive areas where UGC are not feasibleö
- Agricultural uses can normally be accommodated and boundaries consisting of fence lines, stone walls and hedgerows can be installed over the buried cables;
- Offsite planting located close to visual receptors;
- Use of landscape features or creation of earthworks in order to screen sensitive views; and,
- Undergrounding cables in visually sensitive areas, where feasible.

In the case of visual impacts related to UGC, "troughs with concrete lids could be used in place of trenches. These troughs would have the appearance of a hard surface similar to a road. Appropriate aggregates can be used in the construction of the trough cover that can minimise its appearance to help to reduce its prominence where relevant. Routing of troughs parallel and adjacent to existing linear features (such as an existing road) could also help to reduce its visual impact. It is also possible to use the surface of the trough as a footpath or cycleway and they can also be specifically designed to withstand vehicular loading if required" [Jacobs Babtie, 2005].

In 1959, a series of planning guidelines were developed by Lord Holford, adviser to the then Central Electricity Generating Board (CEGB) on amenity issues. These "Holford Rules" were reviewed in the 1990's by the National Grid Company (NGC). It appears that while the rules are not published as a single work or affiliated with any particular organisation, they are referred to in a number of planning publications. The Holford Rules have generally been accepted by the electricity transmission industry as guidelines for the routing of new high voltage overhead transmission lines. In the case of landscape and visual resources, the Holford Rules are a commonly used best practice for mitigation.

- Rule 1: Avoid altogether, if possible, the major areas of high amenity value, by so planning the general route of the line in the first place, even if the total mileage is somewhat increased in consequence.

- Rule 2: Avoid smaller areas of high amenity value or scientific interest, by deviation; provided that this can be done without using too many angle towers (i.e. the more massive structures which are used when lines change direction).

- Rule 3: Other things being equal, choose the most direct line, with no sharp changes of direction and thus fewer angle towers.

- Rule 4: Choose hill and tree backgrounds in preference to sky background wherever possible and when the line has to cross a ridge, secure this opaque background as long as possible and cross obliquely when a dip in the ridge provides an opportunity. Where it does not, cross directly, preferably between belts of trees.

- Rule 5: Prefer moderately open valleys with woods, where the apparent height of the towers will be reduced and views of the line will be broken by trees.

- Rule 6: In country which is flat and sparsely planted, keep the higher voltage lines as far as possible independent of smaller lines, converging routes, distribution lines and other masts, wires and cables so as to avoid concatenation or 'wirescape'.

- Rule 7: Approach urban areas through industrial zones where they exist and where pleasant residential and recreational land intervenes between the approach line and substation, go carefully into the costs of undergrounding, for lines other than those of highest voltage.

It is recommended that the Holford Rules be taken into consideration when planning a transmission route in Ireland.

6.7 Cultural Resources

The installation of both OHL and UGC can result in potential impacts on cultural features including archaeological sites, historic monuments, historic buildings as well as national and local traditions and practices. In some instances, all of these cultural aspects can be impacted upon.

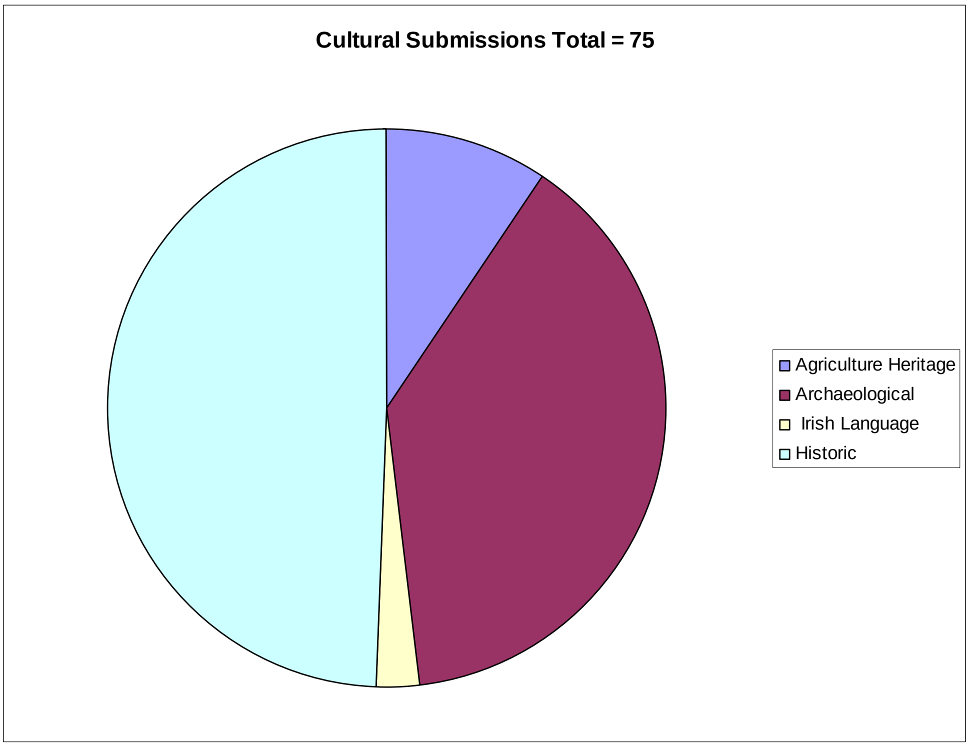

Figure 6-9 Proportions of the concerns raised in the submissions addressing Cultural Resources

6.7.1 *Archaeological*

Archaeological sites in Ireland are numerous. Some, such as Newgrange, Co. Meath are exposed, others have been exposed by accident or otherwise and still others are as yet unearthed. OHL may have an adverse effect on the setting in which these archaeological sites can be enjoyed from a visual perspective.

Because of the substantial difference in earth works, the construction of UGC has a higher potential to unearth hidden archaeological sites than construction of OHL pylon bases. Where applicable, this may cause delays and unexpected rerouting (increasing costs). Any directional drilling may also encounter subsurface archaeological features.

6.7.2 Historic Monuments and Buildings

OHL will have similar adverse effects on monuments and buildings as they would on archaeological sites mentioned above, in particular in terms of the setting in which these features can be enjoyed. UGC may be able to avail of directional drilling to run beneath historic structures. However this would depend on the sensitivity of the structure from a historical preservation perspective as drilling or trench-laying may cause site disruption during construction.

6.7.3 Language and Culture

It was suggested in several of the submissions that introduction of an electrical transmission system in close proximity to a community may deter residents from residing within the area. The degree of such an impact is unclear and would require assessment on a case-by-case basis; however, the possibility of such an impact is plausible given the level of concern related to such a system as well as the potential for decreased property values in close proximity to the system. Since the majority of concern is related to OHL as opposed to UGC, and decreasing property values are primarily related to OHL, it is likely that any impacts on community population would be in the case of OHL. In the event that a community along the route of a line were part of a minority group such as a **Gaeltacht**, then this may be perceived as a threat to the culture and language of this group.

6.7.4 Mitigation

Based upon the potential impacts associated with cultural resources described above, the primary option for mitigation involves careful route planning with due consideration given to the following:

- Known existing archaeological sites - Route planning should always be undertaken in consultation with the appropriate government bodies. Furthermore, due care in construction and careful evaluation of any sites uncovered during construction should also be undertaken.

- Historic buildings and monuments - Extended directional drilling to outside a designated buffer zone around structures. Again, consultation with appropriate government bodies is a requirement.

- Sensitive Gaeltacht communities.

6.8 Traffic and Noise

Traffic and noise are interrelated in that impact as regards OHL and UGC on noise comes from traffic associated with the construction phase.

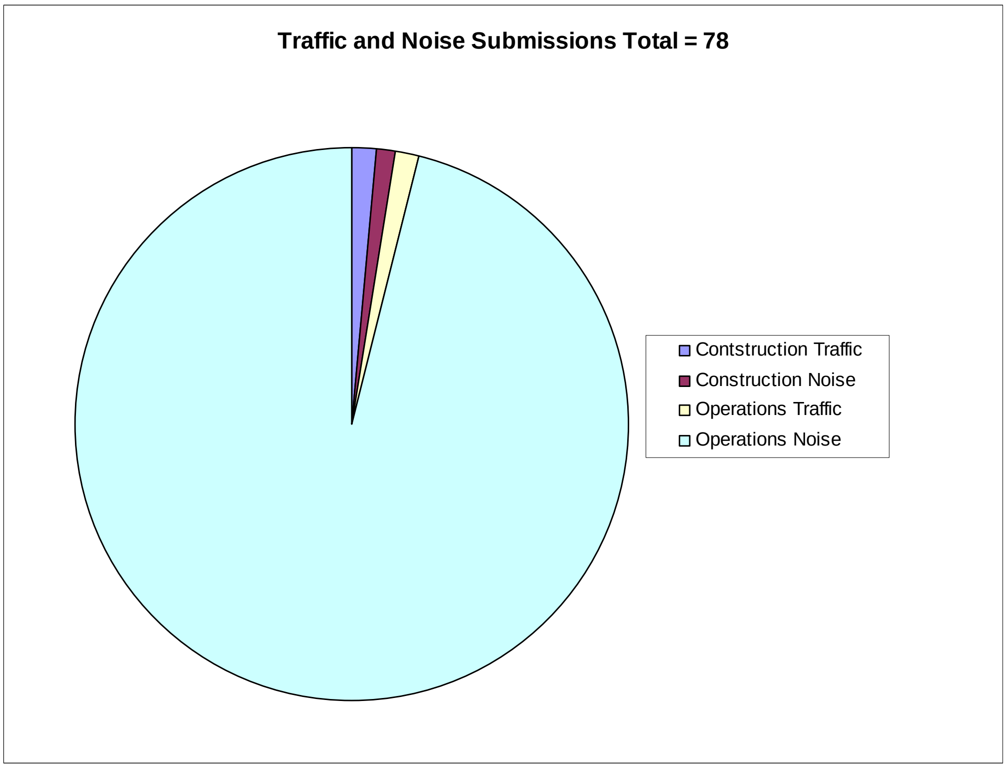

Figure 6-10 Proportions of the concerns raised in the submissions addressing Traffic and Noise

6.8.1 Traffic

Traffic movements during the construction phase are an issue for both OHL and UGC. The amount of traffic movement would depend on the amount of earth to be moved. For OHL this may be restricted to earth removed in order to accommodate pylon bases and is dependant on soils type and whether or not this has to be transported to a waste facility or can be moved to an area close by. For UGC excavated material may have to be removed along the entire route and backfill material may need to be transported in. Again this is dependant on soil type and the amount of backfill required. Construction carried out along existing roads, both major and minor routes, would require traffic management plans to minimise delays experienced by other road users. Discussions with local authorities would need to take place on the types of machinery that would be authorised to use specific routeways.

The length of construction would, in general, be longer for UGC than for OHL and this would have a knock-on effect to the amount of time traffic movements were disrupted. Jacobs Babtie [2005] refers to duration of construction phase that may amount to five times longer for UGC than for OHL. This is related not only to the amount of earth to be moved but also to sensitivity to the disturbance of nesting birds or breeding mammals at various times of the year.

On completion of construction traffic movements with regard to OHL and UGC would be kept to a minimum and would be for maintenance and emergency repair only. In this regard traffic movements post-construction may be greater for OHL as the lines and pylons themselves require more maintenance than UGC due to exposure to adverse weather.

6.8.2 Noise

Impact of OHL and UGC with regard to noise during the construction phase can be significant. As discussed above the laying of UGC would have a greater effect due to the increase in traffic during construction. In rural areas the amount of people affected by this noise would be greatly reduced. Potential mitigation includes use of ‘best practises’ with regard to construction methods during the construction phase.

The noise (Corona Effect) emitted from high voltage powerlines during operation must be taken into consideration when OHL are located in proximity to houses. During normal operation this noise can achieve levels up to 60 dB(A) below the OHL centreline [Mujcic et al., 2003]. However this can increase due to surface irregularities on the conductors due to insects, damage, raindrops or air pollution. In addition Mujcic et al. [2003] indicates other parameters that may affect the amount of noise emitted such as line length, type of connection, bundle conductor composition etc. There may be a marked increase in noise levels during adverse weather conditions

Corona discharge is not an issue with UGC except at substations and reactive compensators. Transformers may produce additional noise.

6.8.3 Mitigation

Based upon the potential impacts associated with traffic and noise described above, the following options for mitigation have been identified:

- Close coordination with local authorities and landowners, scheduling movements with due regard to existing traffic movements, and well serviced vehicles to minimise break-down.

- Situation of the OHL away from dwellings and civic amenities, and the use of UGC where reasonable. At substations and reactive compensators, acoustic enclosures and screening such as embankments may significantly reduce noise.

6.9 Air Quality

During construction, impacts to air quality would be primarily related to airborne dust and dust deposition, as well as emissions from construction vehicles (traffic is addressed in Section 6.8). Material deposited on haul roads can furthermore be re-suspended by passing traffic in dry weather. Construction traffic air quality impacts as regards vehicle emissions on-site could result from construction vehicle exhausts. It is anticipated that the relative level of traffic and earthworks associated with UGC installation would involve a greater potential to generate airborne dust, dust deposition and vehicle exhausts than OHL in most cases.

During operation, the primary impact to air quality would be related to the relative differences in operational efficiency (and correlated differences in energy demand) of OHL versus UGC. This impact is anticipated to be less in the case of UGC because cables "typically incur fewer losses during their operation to transmit electricity than overhead lines, so the amount of electricity generation required is reduced, which means less greenhouse gas emission overall" [EU, 2003]. Potential effects to soil temperature during operation could also have an indirect impact on air quality. For example, "any increase in soil temperatures is likely to encourage soil drying and oxidation during operation. In peaty soils…this could lead to the release of CO_2 which is stored in the peat. Impacts associated with this are likely to be local" [Jacobs Babtie 2005]. Impacts to soil temperature are primarily associated with UGC, and are discussed in Section 4.2.2 of this report.

Based upon the information provided above, it is anticipated that an UGC system would likely have a greater impact to air quality during construction due to the relative anticipated levels of vehicular traffic, earthworks and anticipated generation of dust. However, dust generation can be readily mitigated, as described in the following section. The comparative operational impacts would vary, as they would be a function of overall efficiency (and therefore, energy demand).

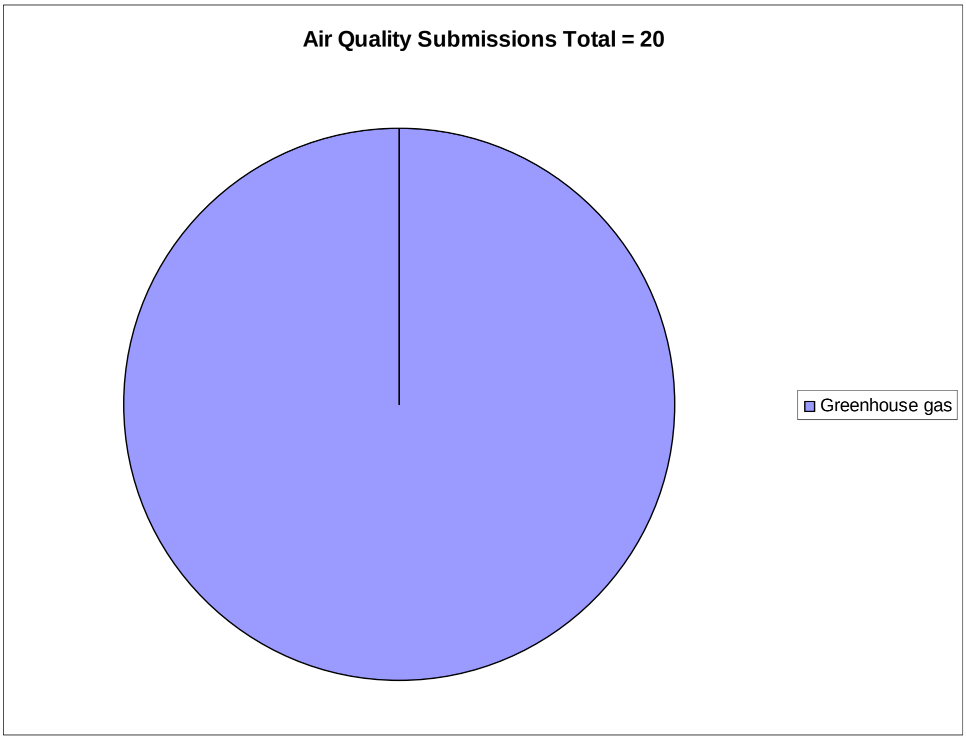

Figure 6-11 Proportions of the concerns raised in the submissions addressing Air Quality

6.9.1 Mitigation

Best practicable means to minimise site dust emissions should be employed during the construction and operation phases. A construction dust minimisation plan would minimise the potential nuisance to nearby receptors. Additional mitigation measures could include:

- Wheel wash for vehicles;
- Water suppression when necessary, to reduce dust emissions;
- A road cleaning service to be employed at critical times;
- Haul routes selected away from sensitive areas where possible;
- Regular and ongoing site inspections to identify significant dust sources; and
- Speed limits on haul roads to minimise dust generation;

To mitigate air impacts related to vehicular exhaust, construction traffic should be kept to a minimum as possible. Construction vehicles should be used which emit minimum air emissions, and should be maintained in such a manner which optimises efficiency. Furthermore, dust levels should be monitored, particularly during construction. Automatic, remote sensors can be installed to continuously monitor soil temperatures, and could be installed for UGC.

6.10 Communities

The public submission results related to this study indicate that many public concerns to communities are related to health issues and impacts to property prices. The question of whether exposure to magnetic fields can cause biological responses or health effects has been the subject of considerable research for the past three decades. It is assumed in this report that all new transmission lines in Ireland will be constructed and operated in compliance with international and national health standards, namely, those related to EMFs. The issue of whether international or national standards related to EMFs are adequate is beyond the scope of this report. However, as the mere perception of health risk often has external impacts related to topics discussed here, the topic will be addressed as appropriate in this report. Potential impacts to property prices and other concerns are also addressed in their respective sections below.

There is a lack of available studies related to the overall impact of OHL and UGC on communities. Since it is expected that the specific impacts would correlate with the perceptions of the surrounding communities, the issues and concerns expressed in the public submissions (which are representative of the perceptions of communities in Ireland) are used as the primary source of information for the assessment provided in this section.

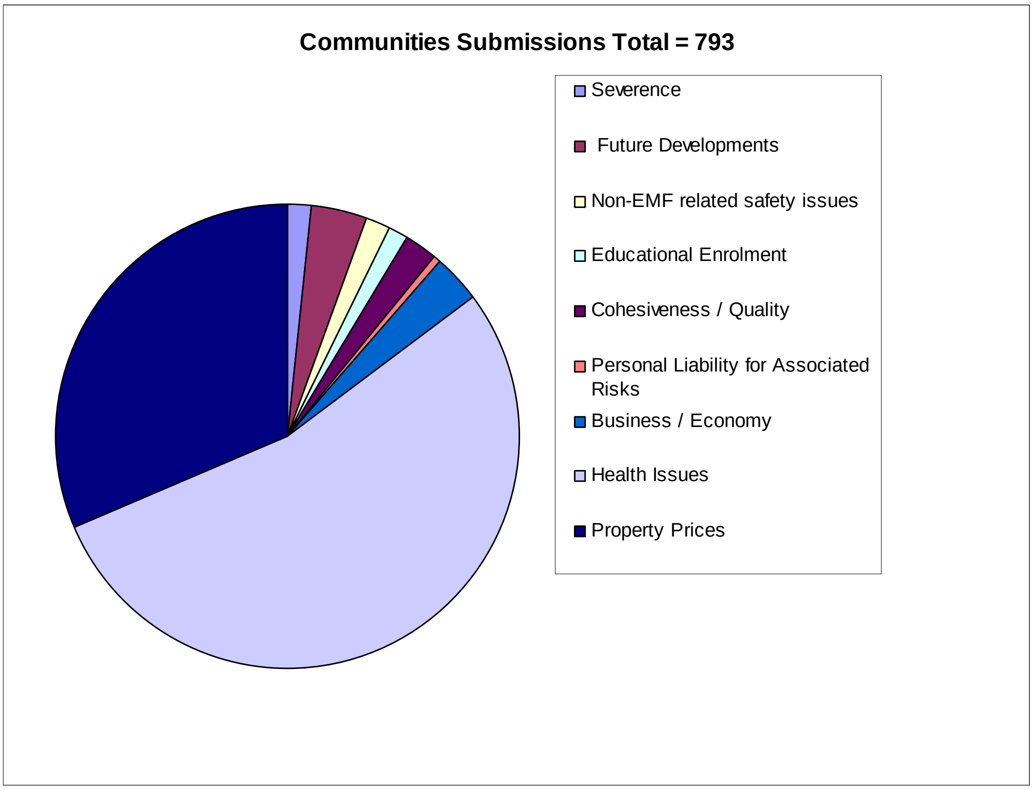

Figure 6-12 Proportions of the concerns raised in the submissions ad-dressing Communities

6.10.1 Quality and Cohesiveness

A common issue expressed in the public submissions related to community quality and cohesiveness is the general, overall enjoyment of the lands and community by area residents. The results of the public submissions analysis indicate that there is a higher degree of concern in this regard related to OHL than UGC.

It was suggested in the public submissions that perceived health risks associated with EMFs could potentially lead to an increased sense of anxiety of the community, thereby compromising the general well-being of its members. Since the results of the public submissions analysis indicate that OHL typically involve a higher degree of concern in this regard, it is anticipated that OHL would likely have a greater impact than UGC on anxiety levels of local communities. UGC could also cause a degree of concern for those communities in the direct route of the transmission system, particularly for owners of property through which the system is routed.

Analysis of the public submissions concluded that in terms of routeing and access issues, communities in proximity of either OHL or UGC transmission routes could be impacted by a diminished sense of community ownership and pride in the event that the routes are imposed upon their community. A common concern expressed in the submissions was the potential for increased tension between landowners in the case where a landowner provides route access and adjacent or nearby landowners are opposed to the project or its location. Concerns such as these are related to landscape and visual impacts, severance aspects and perceived health risks, all of which tend to be greater for OHL than UGC. However, land take (see also Section 6.1) and potential impacts to future development (Section 6.10.11) will also have a similar impact on the community.

6.10.2 Business, Economy and Employment

The public submissions indicated that impacts such as land take, land sterilisation, potential impacts to future developments and perceived health risks could have an adverse effect on business, economy and employment. Comparative land take and land sterilisation impacts are addressed in Section 6.1(Land Use), and are mainly associated with farming industries. For example, a common concern expressed in the submissions suggested that limitations to development potential could act as a deterrent to industry, which could subsequently impact the local economy – this topic is discussed in Section 5.10.11 below. Furthermore, concerns over perceived health risks could potentially influence some business owners' decision related to where to locate their business. A comparative assessment of health issues is provided in paragraph 6.10.6 below. Technology specific characteristics with respect to magnetic field exposure are also discussed in paragraph 6.10.6.

Extra high voltage transmission would help to ensure an increased security and voltage supply. A constant and reliable source of electricity is considered beneficial to communities and industry. A comparative assessment of the impact of the technology choice on transmission system adequacy is provided in paragraph 5.1.1.

6.10.3 Tourism Industry

Tourism and its related industries are a significant aspect of Ireland's economy. According to Fáilte Ireland [2006], "in 2006, out-of-state tourist expenditure, including spending by visitors from Northern Ireland, amounted to €4 billion. With a further €0.66 billion spent by overseas visitors on fares to Irish carriers, total foreign exchange earnings were €4.69 billion. Domestic tourism expenditure amounted to €1.4 billion making tourism in total a €6 billion industry in 2006Ä. Furthermore, these industries represent a significant and growing portion of Ireland's employment market, as "the estimated total number of people employed in the Irish tourism and hospitality industry in 2006 was 249,338, an increase of 1.4% on the numbers employed in 2005. The largest increases occurred in the Hotel and Restaurant sectors" [Fáilte Ireland, 2006]. Therefore, in areas with concentrated, high levels of tourism, impacts to the tourism and recreation industries could have a greater impact on employment and the local economy.

"Beauty of the scenery" and the "natural, unspoilt environment" were listed as some of the primary drivers for tourists coming to Ireland in a visitor attitudes survey conducted by Fáilte Ireland in 2006. Furthermore, "…tourism is characterised by the fact that consumption takes place where the service is available, and tourism activity is particularly concentrated in areas which lack an intensive industry base…" [Fáilte Ireland, 2006]. The existence of a transmission system, particularly OHL, would add an industrial element to the landscape. UGC would also add a degree of industrialisation to the landscape, but to a lesser extent. Based upon the results of the visitor attitudes survey conducted by Fáilte Ireland, as well as concerns raised in the public submissions, it is anticipated that impacts to the tourism and recreation industries would primarily be a function of the impacts to landscape and visual resources. A description of the comparative potential landscape and visual impacts associated with OHL and UGC is included in Section 6.6.1 of this report.

6.10.4 Filming

Several submissions suggested that it is possible that the suitability of the landscape for filming purposes could be influenced by the installation of OHL or UGC. Such impacts could include enjoyment of recreational filming as well as economic losses in the event that filmmakers were to choose to produce their films in other countries or regions with similar landscapes. Any such impact to filming is anticipated to be a function of the impact on landscape and visual resources. A description of the comparative potential landscape and visual impact associated with OHL and UGC is included in paragraph 6.6.1 of this report.

6.10.5 Animal Breeding

Some of the submissions related to this project expressed concern about the biological effects of electromagnetic fields on livestock and potential effects on animal breeding industries. It is assumed in this report that all activities related to OHL and/or UGC construction and operation would be managed in accordance with applicable health-related standards. It is beyond the scope of this report to assess the validity of the standards and thresholds set by such organisations. Therefore, the potential for biological effects on livestock is also beyond the scope of this report. However these submissions indicate that the perceived effects on livestock are of concern to members of the public. This concern could consequently have an adverse effect on the animal breeding industry. It was suggested in the submissions that farmers may be deterred from breeding their livestock due to these concerns, particularly in areas adjacent to or along the direct route of OHL or UGC. The majority of the health-related concerns expressed in the submissions were related to OHL.

6.10.6 Electromagnetic Fields (EMFs)

The term EMF refers to electric and magnetic fields that are coupled together, such as high frequency radiating fields. Voltage on any conductor produces an electric field in the area surrounding the wire. In UGC extension of this electrical field is limited to the insulation and outside the cable no electrical field will be detected. In the case of OHL the air surrounding the conductors is the insulation and, hence, electrical fields are created in the space between the conductors and between the conductors and earth. Strength of electrical fields is high in the immediate vicinity of the conductor and decreases rapidly with growing distance.

Similarly, "current passing through any conductor, including a wire, produces a magnetic field in the area around the wire. The magnetic field associated with a high voltage transmission line sur-

rounds the conductor and decreases rapidly with increasing distance from the conductor" [Xcel, 2005]. The issue of whether international or national health standards related to EMFs are adequate is beyond the scope of this report. Safety related matters, however, are discussed below.
During the planning and permit procedures of new electrical power transmission systems, aspects of EMFs become of increasing importance. Based on the limits published by the International Commission on Non-Ionising Radiation Protection (ICNIRP) [ICNIRP 1998] the WHO recommends a permanent exposure level to magnetic fields below 100 µT and this recommendation has been adopted by the EU (1999/519 EC) and many non-EU countries. Eirgrid designs and operates transmission assets according in line with these guidelines.
Field levels under OHL depend on line loading but also tower design, i.e. conductor arrangement. Maximum values only occur under full loading. As a consequence of the n-1 principle, respective loads are unlikely under normal operational conditions. Under normal operational conditions magnetic field levels are in the range of 10 to 20 µT [TenneT 2005], [Elinfrastrukturudvalget 2008b]. Average loading of 400 kV transmission lines in Ireland is below 25% of the nominal transmission capacity.

Recently, permanent exposures much below the 100 µT level have been recommended or introduced in regulation in some countries or by local authorities. Examples are 3 µT for new installations in Italy, 1 µT in Switzerland, 0.4 µT for permanent exposure in the Netherlands [TenneT 2005] as well as 0.2 µT in Tuscany (Italy).
Meeting them requires extra measures if it is possible at all with OHL in densely populated areas. [TenneT 2005] estimates additional investments in sensitive areas at a factor of 2 to 8, a similar range which is communicated for the extra cost of UGC. TenneT developed a new design for OHL towers resulting in reduced corridor width for OHL (indicatively from 300 m to 80 m) without violating the limits (see Figure 6-13). A trade off may exist between reducing magnetic fields along the line and visual impact.

Figure 6-13 Wintrack tower design for reduced magnetic field levels under 400 kV lines (source TenneT)

Furthermore, some requirements for electromagnetic compatibility with proximate technical systems may lead to special specifications for the design of the transmission system. A typical example is the limitation of the magnetic induction to 15…20 µT, due to possible interferences with pace makers. For this reason, a 380-kV cable route was realised under the restriction of 15 µT [Vavra, CIGRE 2006].

For various transmission configurations Figure 6-14 and the respective detail in Figure 6-15 show the magnetic inductions B at a height of 1 m above ground as a function of the distance from the line axis. The figures allow comparison of various OHL designs as communicated by Eirgrid (see paragraph 4.1.3) with UGC in trefoil as well as in flat formations. The magnetic inductions are related to a current of 1 kA (meaning a line loading of about 660 MW or almost 40% of nominal capacity of a single circuit OHL as considered by Eirgrid).
As the nominal capacity of UGC circuits is mostly lower than that of an OHL of the same voltage level, in practice, the same current may be distributed over two UGC circuits. With respect to the relations shown in Figure 6-14 and Figure 6-15 this difference in configuration may result in a reduction of the peak value of the magnetic field but, simultaneously, in extension of the UGC corridor.

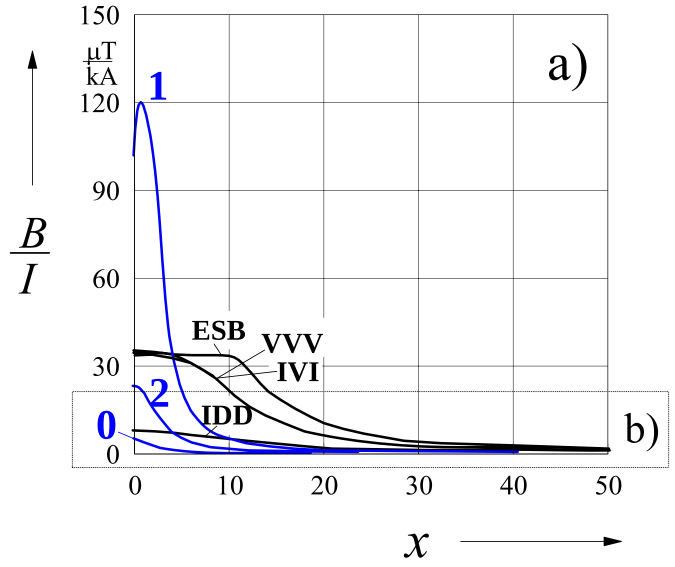

Figure 6-14 Magnetic induction B caused by transmission lines at 1 m height above ground depending on distance x from line axis; blue lines: cables in trefoil formation (0) and in flat formation with conductor distance Δs = 1 m (1) and Δs = 0.3 m (2), black lines different Eirgrid tower designs: ESB VVV and IVI, IDD, see paragraph)

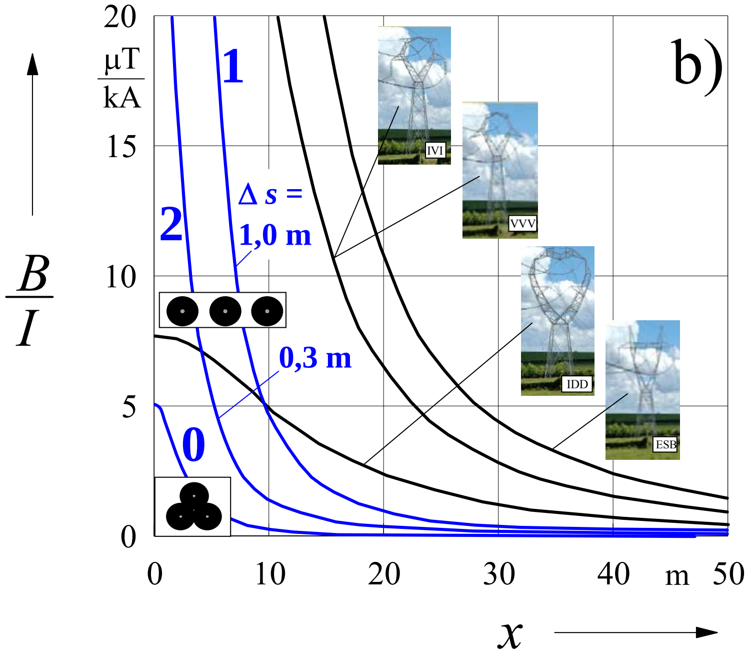

Figure 6-15 Detail of figure above showing the lower field levels

The figures clearly demonstrate that the conductor arrangement design strongly influences the magnetic field in both OHL and UGC. Eirgrids Inverted Delta Design causes much lower magnetic fields than the other towers designs. The magnetic field straight above a cable system depends in particular on the distance of the conductors.
Additionally, the figure illustrates the different field characteristics of the technologies. The magnetic field above an UGC may substantially exceed the field directly under an OHL with the same loading, in particular with higher conductor distances (e.g. 1 m). However, at distances of a few meters from the systems axis, the magnetic field of UGC very quickly diminishes, whereas the field associated with an OHL will remain at measurable levels over some meters, though still clearly below relevant limits. In highly populated areas this difference may be an important factor. Just for construction reasons no dwellings will be situated within 5…10 m of a cable route.

In the case of UGC in flat formation additional technical measures exist to substantially reduce magnetic fields. One option is the application of bipolar cable systems [Brakelmann 2008]. This arrangement allows magnetic field levels being lower than those of cables in trefoil formation. Another simple and inexpensive option is the implementation of additional compensation conductor loops (e.g. simple 1-kV-cables) above the transmission line in the cable trench (see Figure 6-16). More complex options for extremely low external fields (e.g. ≤ 0.2 μT) are:

- Steel pipes covering the cables; and
- Cable ducts with top coverage of ferromagnetic material (ferromagnetic raceway proposed by Pirelli).

In the latter three options currents of opposite direction are induced in the external structures, compensating the magnetic fields. However, this increases transmission losses reduces transfer capacity.
Currently, the subject of optimized magnetic sheathing with a minimized thermal influence to the sheathed cables is the main topic of the CIGRE Task Force B1-23.

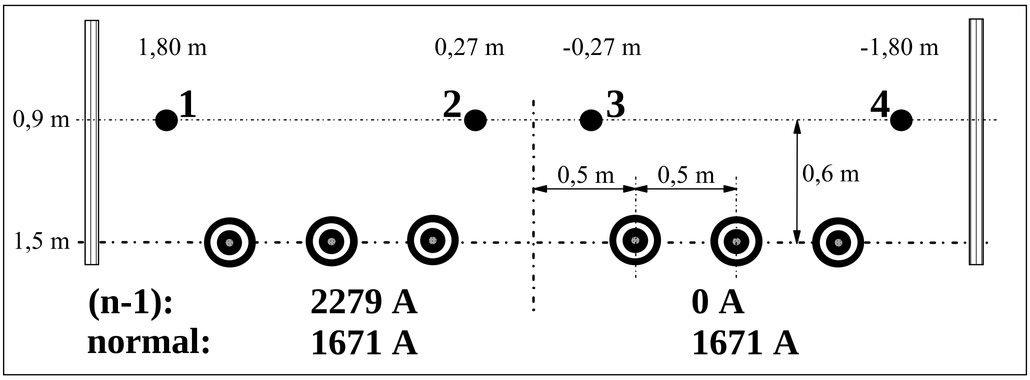

Figure 6-16 example of a 380 kV two circuit XLPE cable system with compensation loop for magnetic field reduction using aluminium conductors above the transmission cables (1 to 4)

6.10.7 Health and Safety

Electrical Contact Injuries

"OHL will occasionally "burn down" and fall to the ground. Though infrequent, a protection device under certain conditions may not open and the conductor lying on the ground may remain energised. Human contact with such a line can result in electrical contact injury. OHL are also subject to contact from tall objects such as mobile cranes and boat masts. UGC minimise this type of incident, but replaces it with the risk of electrical contact injury due to dig-in contact with the UGC" [Infrasource, 2007].

Vault Inspections

"When UGC are installed in conduit, manholes, and vaults, regular equipment inspection and maintenance must be done in the manholes and vaults. This exposes workers to potential electric contacts, arc flash burns, and vault explosions, to a higher degree than when similar equipment is examined on OHL" [Infrasource, 2007].

Dig-Ins

"UGC are more susceptible to damage from digging activities from backhoes and excavators and even hand-operated equipment like powered post-hole diggers. Underground service drops are also subject to damage from shovels and pickaxes. Not only do dig-in events constitute a reliability problem, but they also pose the risk of electric contact to the workers involved" [Infrasource, 2007].

Stray Voltage

"Stray voltage is defined as a natural phenomenon that can be found at low levels between two contact points in any animal confinement area where electricity is grounded" [Xcel 2005]. A small voltage, called Neutral-to-Earth Voltage (NEV), will inevitably develop at each point where the electrical system is grounded. "Stray voltage" occurs when a portion of this NEV between two objects is simultaneously contacted by an animal. It is important to note that stray voltage is not electrocution, ground currents, EMFs or earth currents; it only affects animals confined in areas of electrical use and does not affect humans [Xcel 2005].

Stray voltage is sometimes a concern to dairy farmers because it could potentially impact operations and milk production. Typically, problems are related to the wiring on a farm affecting farm animals that are confined in areas of electrical use or the distribution and service lines directly serving the farm. In those instances when transmission lines have been shown to contribute to stray voltage, the electric distribution system directly serving the farm or the wiring on a farm was directly under and parallel to the transmission line. These circumstances are considered in installing transmission lines and can be readily mitigated. Potential impacts related to stray voltage are primarily associated with OHL rather than UGC

Personal Liability for Safety Risks

It is possible that a person injured due to a transmission line or cable could choose to hold the landowner personally responsible for their injury. The likelihood of a landowner being held liable from a legal perspective for such an injury would have to be examined on a case-by-case basis and is beyond the scope of this report.

6.10.8 Property Prices

There is often significant concern amongst community members in close proximity to proposed electrical transmission systems that the installation of the system would adversely impact the value of their property, as improved aesthetics are commonly expected to result in improved property values. While there is growing speculation and general acceptance that property values are impacted to some degree, there is currently not a consensus on the matter. Studies which predict an impact generally conclude that the relative impacts to property values are correlated with distance from the lines themselves, and that the degree of financial impact declines rapidly as the distance from power lines increases; however, the actual monetary impacts are unclear and are expected to vary per location and property type (e.g. residences versus unoccupied land).

Properties through which OHL or UGC are routed would be the most susceptible to potential adverse impact to value, as the installation of either could limit the development potential in closest proximity of the route. However, in this case, the property owner would likely receive compensation which would assumingly offset the difference in property value. This is a well adopted procedure under existing guidelines and legislation. Severance is discussed in more detail in the section below.

Aside from the above mentioned case in which the OHL or UGC is routed directly through a property, the majority of the impacts to property values are related to visual impacts and perceived health risks. As described in the previous sections, it is generally accepted that OHL impose a greater adverse impact to landscape and visual character and quality than UGC. Also, as indicated in the sections above, OHL are generally associated with a higher degree of perceived health risk.

6.10.9 Severance

Some degree of severance is typically allocated for any land owner when either UGC or OHL are constructed within the boundaries of their property. However, there is some evidence from the public submissions related to this study that some communities maintain that all parties should receive some form of severance when an OHL passes within sight of their house or property. This feeling is directly linked to the perceived adverse effect on property values discussed above (Section 6.10.8). Any severance paid would depend on whether land has existing structures built on it or whether there is planning permission to develop on currently undeveloped land. This may require individual consultation with interested parties on a case by case basis.

6.10.10 Educational Enrolment

Analysis of the public submissions indicates that there is a common perception that children may be particularly vulnerable to health-related impacts associated with EMFs. It is expressed in several submissions that, due to this perception, parents may choose to enrol their children in schools further away from the transmission route. Perception of risk is anticipated to be correlated with degree of visual presence, and is therefore anticipated to be a function of any landscape and visual impacts. A description of the comparative potential landscape and visual impacts associated with OHL and UGC is included in Section 6.6.1 of this report.

6.10.11 Impact on Future Developments

Properties through which an electrical transmission system is routed could be impacted by a hindrance to future development, particularly within the boundaries of the wayleave. Both OHL and UGC impose limitations to development in close proximity of the route, and aspects of wayleave restrictions for both transmission types are mentioned in Section 4 of this report. Potential impacts to future infrastructure (such as roads and railways) also need to be considered in terms of routeing and when deciding to install either OHL or UGC. If supported by permissions and regulative framework UGC can typically be easily installed alongside linear infrastructure, and vice versa. OHL can also be routed alongside existing linear infrastructure; however, the direction of OHL can only be changed from pylon to pylon, so this can be challenging in the case of following infrastructure which is not a direct line. It was suggested in the public submissions that future developments could also be impacted due to location preferences related to landscape and visual disturbances, as well as perceived health risks. Descriptions of the comparative impacts for OHL and UGC are located in Sections 5.6 and 5.10.6 of this report, respectively.

6.10.12 Mitigation

Community opposition to OHL or UGC installation can, in certain instances, be attributed to perceived risk. It is important to note that even in the event that perceived risks do not represent actual risk, the mere perception of risk could potentially cause adverse effects to communities. Therefore, proactive interaction with stakeholders (such as local communities, agencies, and industry) could be an effective mitigation measure against such impacts. A key aspect of this is ensuring the community that their concerns are being recognised and addressed. Ideally, communication should be open and constant, and perception of risk can be mitigated via education and outreach in order to minimise other community-related impacts as described above. Furthermore, it is likely that a project will benefit if there are local benefits derived from a project to compensate for both real and perceived local costs and risks.

Personal injury can be mitigated in a similar manner. Possible safety risks should be assessed on a case-by-case basis and appropriate safety awareness training should be provided to all personnel working with or around OHL or UGC. It is also essential to provide education and outreach to the public about how to minimise their risk of personal injury. In addition to training and awareness, OHL and UGC should be equipped with protective devices to safeguard the public. In addition, surface structures should be fenced and access limited to authorised personnel, as appropriate.

As indicated in the sections above, landscape and visual impacts are correlated to impacts to communities. Refer to Section 6.6 (Landscape and Visual) for details about mitigation measures related to landscape and visual mitigation measures.

Prior to establishing a route and preferred transmission technology (OHL versus UGC), international, national and local development plans, strategies and applications should be reviewed in order to mitigate potential conflicts with proposed and potential future developments. Areas with high population densities should be given careful consideration and mitigated appropriately.

6.11 Recreation and Tourism

As indicated in previous sections, recreation and tourism are significant and growing aspects of Ireland's economy and culture. In 2006 alone, expenditure by visitors to Ireland was estimated to be worth €4.7 billion [Fáilte Ireland, 2006]. Tourism activity is particularly concentrated in areas which lack an intensive industry base. The existence of a transmission system, particularly OHL, would add an industrial element to the landscape. UGC would also add a degree of industrialisation to the landscape. Based upon the results of the visitor attitudes survey conducted by Failte Ireland, as well as concerns raised in the public submissions, it is anticipated that impacts to the tourism and recreation would primarily be a function of the impacts to landscape and visual resources. A description of the comparative potential landscape and visual impacts associated with OHL and UGC is included in paragraph 5.6 of this report.

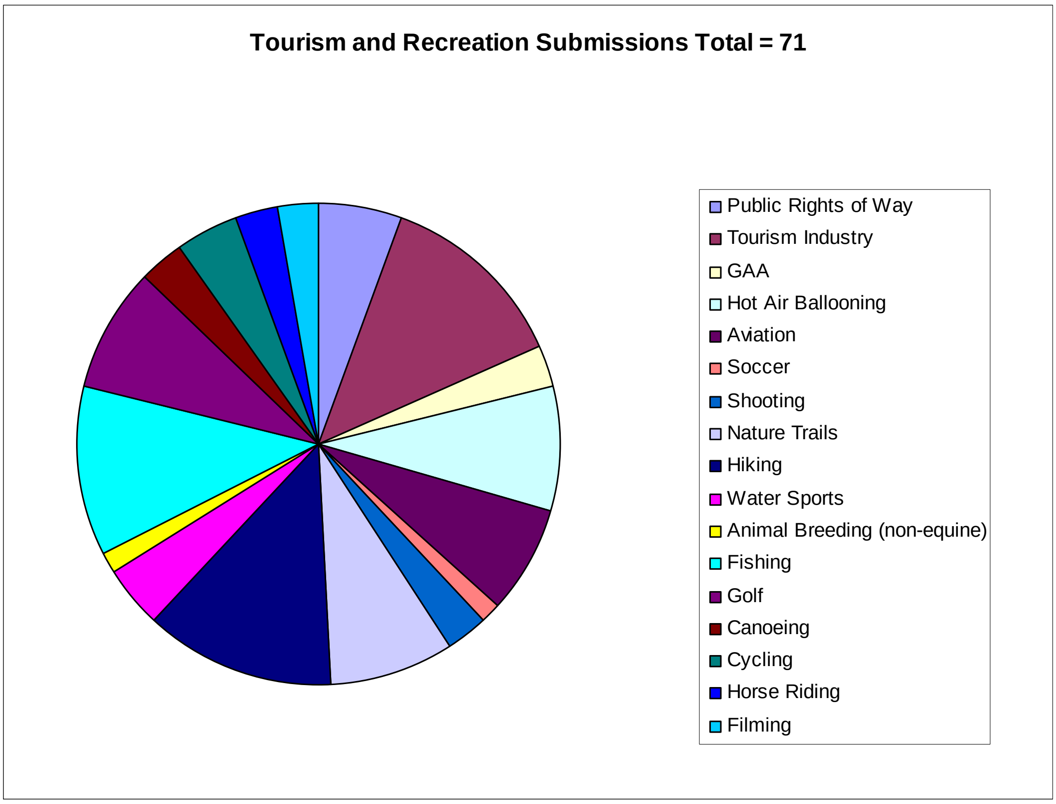

Figure 6-17 Proportions of the concerns raised in the submissions ad-dressing Recreation and Tourism

According to the Fáilte Ireland 2006 Tourism Statistics, tourists in Ireland primarily visit and engage in the following recreational activities:

- Houses and castles
- Gardens
- National Parks
- Watersports
- Heritage / Interpretive centres
- Hiking / Walking
- Golf
- Museums / Art galleries
- Angling
- Cycling
- Equestrian pursuits

In addition to the above-mentioned activities and destinations, the following were identified in the public submissions as recreational activities that could be affected by development of an extended electrical transmission grid:

- Soccer
- Shooting
- GAA
- Hot Air Ballooning
- Aviation

According to the 2006 Visitor Attitudes Survey conducted by Fáilte Ireland, the primary motivation for tourists selecting Ireland as a holiday destination was the quality of sightseeing and scenery offered. The 2006 Visitor Attitudes Survey indicated that this finding was consistent from visitor attitude surveys conducted in past years. It was also concluded in the survey that two in every three holidaymakers visited historical and cultural attractions during their stay. In fact, a recurring theme throughout the 2006 survey was the relative importance of Ireland's cultural and historical heritage as being a magnet for tourists. The 2006 survey concluded that three in every four holidaymakers overall attached a high degree of importance to the natural, unspoilt environment in considering Ireland for their holiday.

Based upon the information provided in the 2006 Visitor Attitudes Survey conducted by Failte Ireland, as well as the analysis of the public submissions, potential impacts to recreation and tourism due to the implementation of an electrical transmission system are anticipated to be a function of impacts to landscape and visual quality (Section 6.6), cultural impacts (Section 6.7) and land use (Section 6.1). Details regarding these comparative potential impacts are discussed in their respective sections of this report. In the event that recreation and tourism activities are impacted, it is reasonable to assume that there would also be an impact to the industries which rely on recreational enthusiasts and tourists. This topic is addressed in Section 6.10 (Communities). It was noted in some of the pubic submissions that aviation as a recreational activity could suffer negative impacts due to an electrical transmission system in Ireland. OHL can sometimes have an adverse impact on the use of airspace and ultimately the airport facilities if structures are located within the airport runway approach surfaces or when structures are taller than surrounding obstructions.

6.11.1 Mitigation

Measures to mitigate potential impacts to recreation and tourism include those which mitigate impacts to landscape and visual quality, cultural resources and land use. Details regarding these mitigation measures are described in their respective sections. Areas designated for conservation and recreation should be avoided as possible. Early route selection is essential to avoiding these sensitive locations.

6.12 Summary

Table 5-1 provides a summary overview of the comparative environmental implications as described in this study. It also provides an overview of the ability to mitigate the potential impacts. It is recommended that decision-makers refer to both the text and summary table of this study to gain a clearer understanding of potential environmental implications associated with OHL and UGC.

This desk-based study is not intended to provide a prescribed recommendation related to the decision to install either OHL or UGC. Rather, the purpose of this study is to provide decision-makers with an unbiased, comparative assessment of the general environmental implications of either scenario in environments typical of Ireland to enable them to make informed decisions in this regard. A site-specific Environmental Impact Statement (EIS) incorporating site surveys would be required to ensure a full understanding of the environmental issues associated with a specific area.

Table 6-1: High Voltage Transmission Systems - Overhead Lines versus Underground Cables: Environmental Impact & Ease of Potential Mitigation

	Underground Cables		Overhead Lines	
Potential for Effect	**Signif[1].**	**Ease of Mitigation**	**Signif.**	**Ease of Mitigation**
LAND USE				
Time & Flexibility of Construction	***	✸✸	**	✸✸
Length of Construction	***	✸✸	**	✸✸
Disrupt. to Agric. Operations	***	✸✸✸	**	✸✸✸
Land Take	**	✸✸	*	✸✸✸
Effect on Field Boundaries	***	✸✸	**	✸✸✸✸
Effects on Farm Buildings	**	✸	**	✸✸✸
Effects on Drainage Patterns	***	✸✸	*	✸✸✸✸
Catastrophic Event Implications	***	✸✸	**	✸✸✸
Repair & Maintenance	***	✸✸	*	✸✸✸✸
GEOLOGY and SOILS				
Soil Cover	***	✸✸✸	**	✸✸✸✸
Excavated Material	***	✸✸	**	✸✸✸✸
Quarrying and Mining	**	✸✸✸	**	✸✸✸
EFFECTS ON WATER				

	Underground Cables		Overhead Lines	
Potential for Effect	**Signif[1].**	**Ease of Mitigation**	**Signif.**	**Ease of Mitigation**
Disruption to Groundwater incl. Wetland	***	✱✱	*	✱✱✱✱
Effect on Surface Waters	***	✱✱✱	*	✱✱✱✱
GROUND RESTORATION	***	✱✱✱	**	✱✱✱
ECOLOGY and NATURE CONSERVATION				
Bird Strike	N/A	**N/A**	***	✱✱✱
Risk to Flora (construction)	***	✱✱	**	✱✱✱
Risk to Flora (operations)	**	✱✱	*	✱✱✱
Risk to Mammals	**	✱✱	*	✱✱✱
Risk to Insects	**	✱✱	*	✱✱
Loss of Habitat (construction)	***	✱✱✱	**	✱✱✱
Loss of Habitat (operations)	**	✱	**	✱
Risk to Aquatic Ecosystems	***	✱✱✱	*	✱✱✱✱
Restoration	***	✱✱✱	*	✱✱✱
LANDSCAPE AND VISUAL				
Landscape Character	*	✱✱✱	***	✱✱
Landscape Features	**	✱✱	*	✱✱✱
Visual Impact (construction)	***	✱✱	**	✱✱
Visual Impact (operations)	*	✱✱✱	***	✱✱
Access Tracks/Haul Roads	***	✱✱✱	**	✱✱✱✱
Communities	**	✱✱✱	***	✱✱
CULTURAL HERITAGE				
Archaeological Resources	***	✱✱	*	✱✱✱
Cultural/Historic Resources	**	✱✱	**	✱✱✱
Language and Culture	*	✱✱✱	***	✱✱
TRAFFIC AND NOISE				
Traffic	***	✱✱	**	✱✱
Noise (construction)	***	✱✱	**	**
Noise (operations)	*	✱✱✱✱	**	✱✱

	Underground Cables		Overhead Lines	
Potential for Effect	**Signif[1].**	**Ease of Mitigation**	**Signif.**	**Ease of Mitigation**
AIR QUALITY				
Construction	***	✹✹	**	✹✹
Operations	N/A	N/A	**	✹
COMMUNITIES				
Quality and Cohesiveness	*	✹✹✹✹	***	✹✹
Business, Economy and Employment	*	✹✹✹✹	**	✹✹
Tourism Industry	*	✹✹✹✹	**	✹✹
Fishing	*	✹✹✹✹	**	✹✹✹
Animal Breeding	*	✹✹✹✹	**	✹✹✹
Health & Safety and Electromagnetic Fields	*	✹✹✹✹	**	✹✹✹✹
Property Prices	**	✹✹	***	✹
Severance	*	✹✹✹✹	***	✹✹
Educational Enrolment	*	✹✹✹✹	***	✹✹
Future Development	**	✹✹✹	***	✹✹
RECREATION and TOURISM	*	✹✹✹	***	✹✹

Note: 1 = Significance of Impact

Significance:

***	Major: a fundamental change to a sensitive environment
**	Moderate: a material but non-fundamental change to the environment
*	Minor: a detectable but non-material change to the environment
N/A	Not applicable

Mitigation

✹	No practicable mitigation possible
✹✹	Remedial measures only
✹✹✹	Mitigation likely to reduce adverse scale of impact
✹✹✹✹	Mitigation likely to avoid adverse discernible impact
N/A	Not applicable

7 Policy Implications

7.1 Comparative review of policy implications

This section describes the implications for national policies on energy, environment and enterprise (including employment) of implementing UGC and / or OHL.

Either option requires an alignment with existing policies as well as strategic preparation for future national policies. Hence, the section describes the technology options, in terms of their alignment with existing and anticipated national policies relating to energy, the natural and social environment, and enterprise development.

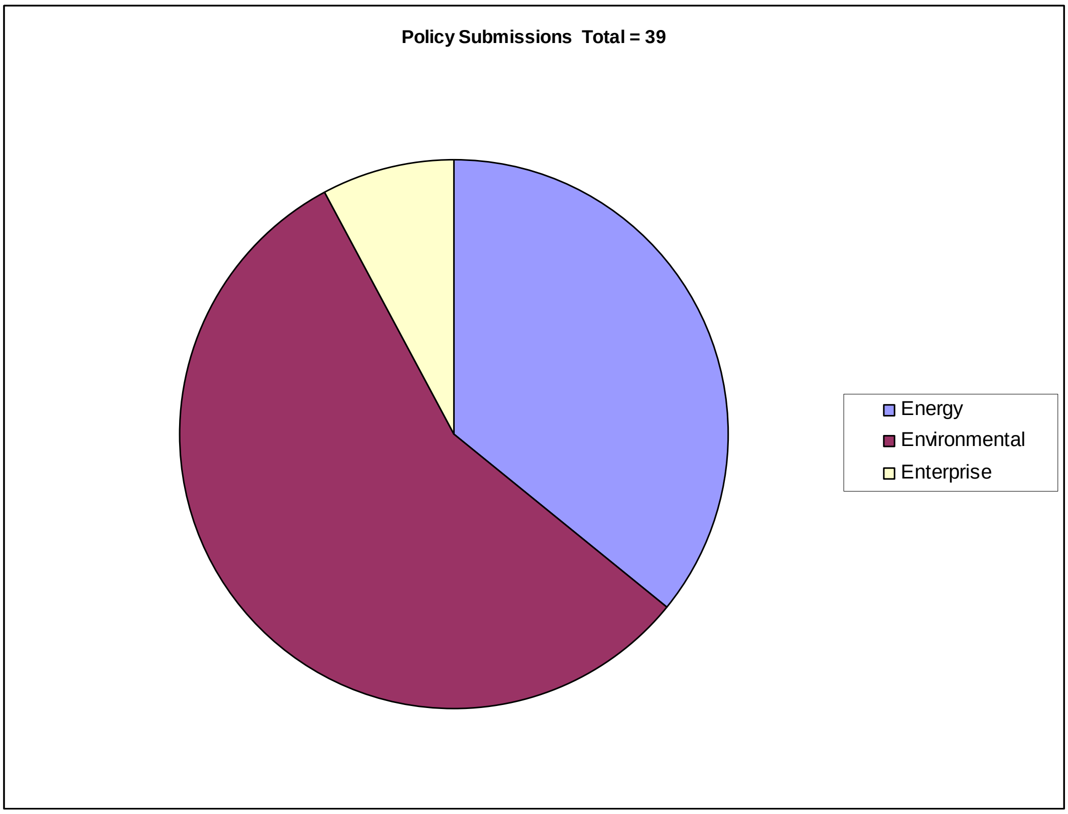

Figure 7-1 Proportions of the concerns raised in the submissions addressing policy

The following section will answer the following questions:

- Does the implementation of one of the options enhance or hamper the implementation of current national policies?
- Does a technology choice imply necessary adjustments of national policies?
- What are the likely fields of actions to be taken?

7.2 Energy policy alignment

7.2.1 Review of existing policies

Energy policy has to find a balance between the partly conflicting goals of price competitiveness, security of supply and environmental impacts.

There is no doubt that the envisaged transmission system reinforcements will contribute to the fulfilment of all aforementioned energy policy goals. Hence, the Government White Paper "Delivering a Sustainable Energy Future for Ireland – The Energy Policy Framework 2007-2020" published in March 2007 specifically committed to the delivery of the second North South electricity interconnector by 2011 to support the goals [DCMNR 2007, p.21, 50].

The All Island Grid Study, published in January 2008 anticipated the existence of both the network reinforcement as a base for their analysis. Hence, the additional required lines as identified within work stream 3 of the Grid Study are *additional* to the projects in the scope of this study [DETINI DCENR 2008].

The submissions of the consultation process preceding this study also demonstrated a broad consensus for the requirement for additional transmission capacity. Hence the following section will focus on the specific implications of both policy options with respect to the goals of energy policy.

7.2.2 Interactions with energy policy and regulation

Table 7-1 shows an overview of possible impacts of the choice of OHL versus UGC on the relevant issues for energy policy. These impacts will be discussed in the following sections.

Table 7-1: Overview of energy policy impacts

Impact category	**Explanation of impact**	**Energy policy impacts of UGC compared to OHL**		
		Price competitiveness	**Security of Supply**	**Environmental impacts of energy production**
Construction time	Possibly higher public acceptance of UGC → maybe shorter construction time	+ (temporal)	+ (temporal)	+ (temporal)
Electric Losses	UGC may have lower losses than OHL (high loading, same transmission capacity)	− / +		− / +
Investment cost		−		
Operational security	Less operational experiences with UGC, probably higher forced outage rate		−	

Legend: +: positive impact, - negative impact

Lead time

The number of submissions received in the consultation process suggest a high public awareness, and in most cases, a public opposition against OHL (see section 2). It can be expected that the public opposition will increase the required construction time for OHL and the target timeframe of 2011 can not be reached. On the other hand, the availability of high-voltage cable and related auxiliary components as well technical construction challenges may represent a risk for the schedule in the case of an UGC solution too. Figure 7-2 shows, that according to EirGrid, lead times for 400 kV overhead lines are expected to be more than 7 years, compared to a 4 year lead time when UGC are used. However, the expected lead time for UGC as indicated in Figure 7-2 and based on EirGrids experience refers to short distance connections (typically shorter than 15 km) and at lower voltage levels. In this stage of development it is uncertain whether this advantage applies identically to long distance UGC transmission as discussed in the context of this study.

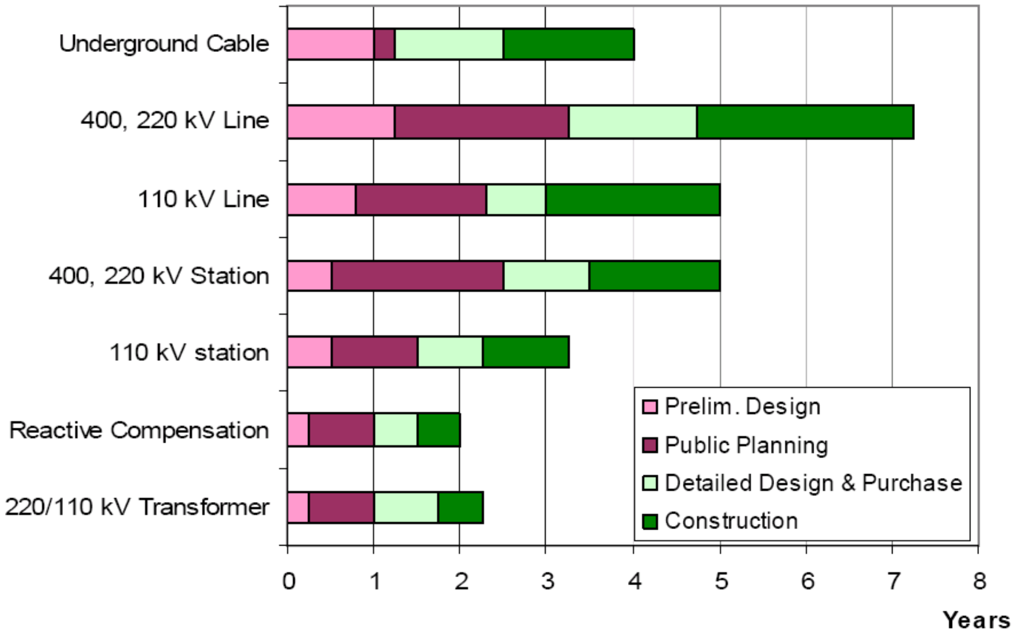

Figure 7-2 Typical lead times for Development projects, according to EirGrid [EirGrid TDP 2007]

If the use of OHL will result in higher project lead-times of this option the benefits of the transmission cannot be exploited for the period of delay. As a consequence the delay will reduce benefits in all three areas indicated in Table 7-1. However, these benefits are only of temporal character.

Electrical losses

The Transmission System losses, underlying the average transmission loss adjustment factors (TLAFs) are approximately 2.1% of the total energy requirement (TER) on an All Island basis. As discussed in section 4 and Appendix 1 – Losses in AC transmission and further illustrated in section 9.3 the losses of UGC may be lower than losses of OHL. In case of high line loading the reduced electrical losses associated with an UGC of the same transmission capacity lead to both, lower operational costs and consequently lower environmental impacts. However, with line loadings typical to the Irish transmission system this difference is negligible. Additionally, the magnitude of the cost effects of a singular project is very small, at least when compared to overall system costs.

Investment cost

Section 9.3 shows a comparison of investment cost and the resulting annuities for specific cases. As shown in section 8, the additional costs have to be born by the final customer. Hence the additional required investment of UGC is therefore opposed to the goal of a price competitive electricity supply.

Operational security

As described in Section 4, the decision to install either UGC versus OHL has implications for operational security, and depending on the applied evaluation methodology, assessments may find different results. Section 5.1.1 concluded that the operational implications of large scale UGC in the transmission system are not presently fully understood. OHL are currently considered superior to UGC with respect to the short-term security of supply. However, shorter lead times potentially achievable with UGC, as discussed before, may lead to a higher operational security for a limited period.

7.2.3 Proposed strategic future energy policy and regulation

Upon reaching a decision for network reinforcement, the energy policy implications of OHL versus UGC are limited. The most important implication results from the fact that a decision for UGC is likely to pre-determine future decisions on this question. It has to be considered, that Ireland faces the need of additional network reinforcements:

- Work stream 3 of the All Island grid Study identified a number of required reinforcements, envisaged between 2007 and 2020, mostly on the 220/275 and 110 kV level [DCENR 2008, p. 93].
- Depending on the expansion of renewable generation, an additional length of up to 647 km of transmission lines (110 and 220 kV) has to be reinforced. Although most of those lines are reinforcements of existing lines rather than new routes, permission processes are expected to be time consuming.

Reinforcements currently envisaged mostly affect existing routes. Although in many cases associated planning and permitting processes are also likely to face substantial opposition, the upgrade of lines may be less critical than the establishment of new routes.

However, realised UGC projects are regularly interpreted as proof of the general applicability of this option as an alternative to OHL. Successful UGC showcases may generically erode public acceptance of OHL. A consequent shift to UGC transmission implies a fundamental change of power systems characteristics (see Section 5.1.1). As emphasised in [Elinfrastrukturudvalget 2008a], [Elinfrastrukturudvalget 2008b] thorough technical research, demonstration, development of tools and capacity building within TSOs is an inevitable precondition for further progress in this direction. Even assuming adequate technology progress, lacking knowledge and experience cannot be neglected and may delay extended UGC application. Still, acceptance of new OHL may be difficult and, hence, development of transmission assets in general may be delayed. Of course, this is undesirable because of the adverse effects on market efficiency, security of supply and development of renewable capacity in the system.

Respective considerations should not form a barrier for application of UGC where this option is beneficial. Nevertheless, the strategic perspective has to be reflected and translated into an appropriate long term strategy.

If a decision preferring one option is made and implications for future projects are assessed, a number of transparent rules need to be defined, which establishes a clear framework for present and future decisions (see Section 3.4). These rules should clarify under which conditions UGC are an acceptable option for transmission reinforcements. These rules may take a number of factors into account such as:

- Eirgrid's transmission planning criteria
- cost differences between two options
- voltage levels
- new routes vs. existing routes
- distances to populated areas, etc.

Once a set of criteria is defined, similar regulations e.g. in the following fields of action need to be adjusted, including:

1. Regulation of planning and permitting processes.
Special regulations might be established to reduce lead times of UGC projects.

2. Re-definition of regulatory rules for the incentive regulation of TAO and TSO
As the choice for one of the options influences both losses and investment cost, the regulation of the TAO and the TSO has to be adjusted to take the increased revenue requirements into account (see section 8).

For this process, aiming at drafting new or adjusting existing regulation, experience with similar or emerging regulations in other jurisdictions (as discussed in the Sections 3 and 8) may be of use.

7.3 Environmental Policy Alignment

As a member of the European Union (EU), Ireland is required to align its policies in accordance with the policies implemented by the EU. Therefore, the legislative framework for environmental control in Ireland takes account of the relevant EU Directives. The EU has put a great deal of emphasis on implementing environmental legislation in recent times, and has established a set of priority areas on which to focus the development of their policies and programs. The current environmental priorities of the EU are:

- Combating climate change;
- Protecting biodiversity;
- Reducing the impact of pollution on health; and,
- Better use of resources.

The shaping of Ireland's recent environmental policies has been a direct reflection of the priority areas listed above, and it is reasonable to assume that they will continue to do so. "The principle agencies responsible for overseeing environmental legislation and regulation are described below:

- The Department of the Environment, Heritage and Local Government (DOEHLG) is responsible for developing environmental policy and drafting legislation;
- The Environmental Protection Agency (EPA) is responsible for issuing IPPC and most waste licences, as well as enforcing IPPC and waste legislation; and
- Local Authorities (LAs) have some degree of responsibility relating to licensing emissions below certain thresholds into water and air, granting waste recovery and some waste transport permits, and enforcement (Fanagan 2007)."

For this study, current environmental policies were assessed, and the policies which were determined to have the most relevant implications for either an OHL or UGC system in Ireland were included. However, the precise requirements for each system would need to be assessed on a case-by-case basis. To ensure compliance with environmental policies as they inevitably develop over time, the agencies listed above, and any other applicable agencies, should be consulted in the case of either OHL or UGC during project planning, construction and operation.

A brief overview of each policy is first described to provide overall context and to serve as a basis for the assessment. The comparative implications for each system are later assessed in tabular format. As the implications during project planning, construction and operation would vary, the implications for each of these stages are distinguished from one another.

7.3.1 General provisions

Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a process for anticipating the effects on the environment caused by a proposed development or project at a particular site. Where effects are unacceptable, design or other measures can be taken to avoid or reduce these to acceptable levels. The Environmental Impact Statement (EIS) is a document produced in the course of this process. EIA requirements are derived from EC Directive 85/337/EEC (as amended by Directive 97/11/EC), commonly referred to as the EIA Directive. The Directive requires that the assessment of certain projects which have a physical effect on the environment be carried out by the competent national authority. The Directive also lists the types of projects concerned, the information to be provided and the third parties to be consulted in connection with approving such a project.

Ireland has implemented the EIA Directive in primary planning legislation, namely, the Planning and Development Act 2000-2006 (the Planning Act, as amended), the Environmental Protection Agency (EPA) Act 1992 and the Planning and Development Regulations 2001 and 2006.

An EIS may be required to accompany a planning application in accordance with Section 172 or 175 of the Planning Act and must meet the requirements of Part 10 of the Planning Development Regulations 2001 and 2006 (the Planning Regulations). Article 93 of the Planning Regulations indicates that the prescribed classes of development for the purpose of Section 176 of the Planning Act are set out in Schedule 5 of the same document. The classes of development and thresholds indicated in Schedule 5 have been implemented into Irish law from the prescribed class listed in Annex I and Annex II of the EIA Directive.

The EIA Directive is anticipated to have a high, yet comparable degree of relevance to both OHL and UGC, particularly during the project planning stage. As environmental assessments of similar complexity are anticipated to be required in the case of both scenarios, no significant difference is anticipated during project planning. While the respective environmental and community impacts associated with each would differ (refer to Chapter 5), the implications for both scenarios with regard to an environmental assessment are anticipated to comparable during construction and operation as well. This is due to the fact that the primary implication associated with the environmental assessment during these stages is the consideration of any identified impacts. Such considerations include implementing appropriate management systems or mitigation measures to minimise adverse impacts associated with construction and/or operation activities.

Strategic Environmental Assessment (SEA)

The EIA Directive described above is supplemented by the SEA Directive (2001/42/EC), which requires that, prior to adoption, all proposed plans and programmes which may have significant effects on the environment be subject to an environmental assessment. The process of SEA is similar to environmental impact assessment, but it is designed to introduce the assessment at the planning stage. "The Directive applies to plans and programmes liable to have significant effects on the environment, as well as to their modifications, which are prepared and/or adopted by a competent authority or prepared by a competent authority for adoption by means of a legislative procedure; and which are required by legislative, regulatory or administrative provisions (Europa 1997-2007)." Before adopting or submitting such a plan or programme to the legislative process, the competent authority of the Member State concerned is required to conduct an SEA, consult with the competent environmental authorities and to prepare an environmental report.

The SEA process is required in the case of the development of strategic government plans and programmes. This study is not intended to address the implications of an EU or National-level plan or programme; rather, the focus of this study is on the implementation of OHL versus UGC. Therefore, it is beyond the scope of this report to assess the implications of SEA on the development of such a plan or programme.

Environmental Liability

The Environmental Liability Directive (2004/35/EC) introduced the application of the "polluter pays" principle. As such, it established a common liability framework with a view to prevent and remedy damage to animals, plants, natural habitats, water resources and land damages. Such damages to the natural environment include:

- Direct or indirect damage to the aquatic environment covered by community water management legislation;

- Direct or indirect damage to species and natural habitats protected at Community level by the 1979 "Birds" Directive or by the 1992 "Habitats" Directive (described in the following sections); and

- Direct or indirect contamination of the land which creates a significant risk to human health.

This liability scheme applies to certain specified occupational and other activities in which the operator is at fault or negligent. Further responsibility is designated to public authorities in terms of ensuring that the responsible operators themselves undertake or finance the necessary preventive or remedial measures

This report assumes compliance with environmental and community legal requirements. Appropriate mitigation measures would be implemented in order to minimise adverse impacts and maintain compliance with all permitted activities. However, there would be potential liability implications in the event that there was an unanticipated breach in permitted activities, such as those listed above. Such breaches are not anticipated during the project planning stage for either OHL or UGC. Potential breaches are more likely during construction when the majority of environmental disruption would occur, and not as likely during the relatively less disruptive operational stage. The comparative potential for breach, however, would be dependent upon the environmental resource and specific region in question. Therefore, this would need to be assessed on a case-by-case basis.

Integrated Pollution Prevention and Control (IPPC)

The IPPC Directive (96/61/EC) imposed a requirement for industrial and agricultural activities with a high pollution potential to have a permit which can only be issued if certain environmental conditions are met. The permitting requirements ensure that companies assume responsibility for preventing and reducing any pollution caused by their related activities.

The IPPC Directive was implemented as Irish law in 2003 with the enactment of the Protection of the Environment (POE) Act 2003. While Ireland's EPA Act 1992 anticipated and implemented most of the requirements of the IPCC Directive, the POE Act 2003 integrated legislative provision for the remaining elements. Although environmental auditing is not required in Ireland, all licensed IPPC activities must carry out an environmental management system. While no particular accreditation is required, the management system must be approved by the EPA, who carries out routine and regular inspections and audits.

As defined in Annex I to the IPCC Directive, the energy industry in general is considered subject to the requirements of this Directive. Therefore, it is likely that both OHL and UGC would be subject to the Directive's provisions. The primary impact is anticipated to be during planning, when an environmental management system would need to be developed and relevant permits applied for in the case of both scenarios. As indicated above, construction would involve a degree of environmental and community disruption; therefore, a moderate degree of monitoring and other similar levels and means of compliance would be required at this stage for both OHL and UGC. Operation would still require compliance with the environmental management system and permits in both cases, but the extent of effort required to maintain compliance is anticipated to be less than the construction stage. For a comparative assessment of the potential impacts associated with a specific environmental resource, refer to Chapter 5 of this report.

The Precautionary Principle

The precautionary principle, in essence, states that in the event that an action or policy could potentially cause severe or irreversible harm to the natural environment or the public, and no scientific consensus that harm would not ensue exists, then the burden of proof falls on the proponent(s) of the action or policy. "This principle has been progressively consolidated in international environmental law, and so it has since become a full-fledged and general principle of international law (Commission of the European Communities 2000)."

When and how to use the precautionary principle has been the cause of much debate both internationally and within the EU. The precautionary principle is exercised where scientific information is deemed to be insufficient, inconclusive or uncertain, and where there are indications that potential negative impacts on the environment, or human, animal or plant health may dangerous and inconsistent with the standard level of protection. According to the European Commission, the precautionary principle may be invoked only when the potentially dangerous effects of a phenomenon, product or process have been identified by a scientific and objective evaluation, and this evaluation does not allow the risk to be determined with sufficient certainty. (Europa 1997-2007)

Measures based on the precautionary principle must not be disproportionate to the desired level of protection and must not aim at zero risk, something which rarely exists. Therefore, the appropriate response in a given situation is the result of a political decision, a function of the risk level that is deemed "acceptable" to the society on which the risk is imposed. The European Community prescribes the level of protection that it considers appropriate regarding environmental protection and human, animal or plant health. The act of determining what is an "acceptable" level of risk for society is a political responsibility in a democracy. An assessment of the possible consequences of inaction should be considered and may be used as a trigger by the decision-makers. (The Toxicology Forum 2000)

Based upon the review of the submissions and the information presented above, there is some public opinion that the precautionary principle may need to be invoked in the case of an electrical transmission system in Ireland, primarily due to concerns related to EMFs. As described above, the decision whether or not to invoke the precautionary principle is the result of a political process which cannot be predicted in this report (the intent of which, furthermore, is not to assess the adequacy of EMF-related health standards).

It is assumed in this study that the precautionary principle would be invoked in the event that there was a reasonable probability of severe or irreversible harm to the community or the environment due to the installation of OHL and/or UGC, and there was insufficient scientific data to confirm that no harm would occur. However, the number of submissions which suggested invoking the precautionary principle due concerns related to EMFs indicate that there will be continuing public pressure to consider this principle, particularly during the planning stage. The vast majority of submissions addressing the precautionary principle were suggested its consideration in the case of OHL, rather than UGC.

7.3.2 Waste

The principle policy guiding the management of waste in Ireland is the Waste Management Act 1996 as amended, which was established primarily to implement the EU Waste Framework Directive (2006/12/EC). The Act identified the Minister for the Environment and Local Government as having primary responsibility for waste management and provided for the preparation of waste management plans for non-hazardous wastes. These plans are required to address all aspects of the prevention, minimisation, collection, recovery and disposal of non-hazardous waste within the local authority area and were to be reviewed on a five-year basis.

While not a key issue, there would be some waste generated during construction of either OHL or UGC. As such, it would be necessary to consider these potential implications and address them during the project planning stage. The operational stages for both scenarios would not be impacted directly by these policies.

7.3.3 Air

The EPA Act 1992 (Ambient Air Quality Assessment and Management) Regulations 1999 and the Air Quality Standards Regulations 2002 transposed the EU Air Quality Framework Directive 96/62/EC on ambient air quality assessment and management. The 2002 Regulations also transposed Directives 1999/30/EC and 2000/69/EC which introduced limit values for nitrogen dioxide, sulphur dioxide, lead, PM_{10}, benzene and carbon monoxide. The EPA designates four air quality zones for Ireland, which are as follows;

- Zone A (Greater Dublin);
- Zone B (Cork and its environs);
- Zone C (16 urban areas with population greater than 15,000); and
- Zone D (Areas in Zones A, B and C).

A transmission system should be constructed, operated and maintained in such a manner that is appropriate for the zone in which it is located. It is probable that a transmission system would be interzonal; therefore, certain lengths of such a system may require different air quality considerations than others. The comparative implications associated with these policies are directly related and are therefore based on the potential impacts described in Section 5.9 of this report.

7.3.4 Water protection and management

The EU Water Framework Directive (WFD) (2000/60/EC) rationalises and updates existing water legislation by setting common EU-wide objectives for water. This Directive provides for the management of inland surface waters, groundwater, transitional waters and coastal waters in order to prevent and reduce pollution, promote sustainable water use, protect the aquatic environment, improve the status of aquatic ecosystems and mitigate the effects of floods and droughts. "The WFD sets out that a Member State shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water, and shall protect, enhance and restore all bodies of surface water with the aim of achieving good status by 2015 (EPA 2007)."

In Ireland, in cases where the EPA Act is not applicable, the control of water pollution is exercised through the Water Pollution Acts (WPA) 1977-1990. According to the WPA, all 'trade effluents' must be licensed. The WPA 1977 defined a 'trade effluent' as an effluent "which is discharged from premises used for carrying on any trade or industry (including mining) but does not include domestic sewage or storm water (Enterprise Ireland 2006)." Water quality in Ireland is further regulated via the European Communities (Water Policy) Regulations 2003 (S.I. 722 of 2003).

The comparative implications associated with these policies are directly related and are therefore based on the potential impacts described in Section 5.3 of this report.

7.3.5 Protection of nature and biodiversity

The 1992 EU Habitats Directive (92/43/EEC), as amended, defines a common framework for the conservation of wild plants and animals and habitats of Community interest to help maintain biodiversity in Member States. The Habitats Directive lists the habitats and species whose conservation requires the designation of special areas of conservation. Closely related to the Habitats Directive is the EU Birds Directive (79/409/EEC) which established a comprehensive scheme of protection for all wild bird species naturally occurring in the EU. Central to the Birds Directive is the protection of habitats for endangered and migratory wild bird species (as listed in Annex I), which is emphasised via the establishment of a coherent network of Special Areas of Protection which comprises the most suitable territories for these species.

The Habitats Directive was transposed into National law in 1997 by the European Community's Natural Habitats Regulations (S.I. 94/1997). The Natural Habitats Regulations' provisions extend beyond EU requirements per the Habitats Directive by including National requirements relating to procedures for notification of landowners, objections, appeals, arbitration and compensation.

The Habitats and Birds Directives are implemented in Ireland primarily by the Wildlife Acts of 1976 and 2000, which are the principal National legislation for the protection of wildlife species and habitats in the country. Many mammal species and most bird species are protected under Ireland's Wildlife Act (1976), except those regarded as pest species, and those considered as game species (where they may be hunted under conditions). It is an offence to interfere with the breeding place of protected species, though there are exemptions for developments such as road construction and building works. For the generally common species, best practice provision is made to limit the season of removal of vegetation and nesting habitat.

The comparative implications associated with these policies are directly related and are therefore based on the potential impacts described in Section 5.5 of this report.

7.3.6 Noise

This Assessment and Management of Environmental Noise Directive (2002/49/EC) is aimed at controlling noise perceived by people in built-up areas, in public parks or other quiet areas in an agglomeration, in quiet areas in open country, near schools, hospitals and other noise-sensitive buildings and areas. The approach of this Directive is based on using common methods to map noise, on providing information to the public and on implementing action plans at local level.

There are no mandatory noise limits for construction noise in Ireland. In the absence of specific Irish legislation or guidance documentation relating to noise emissions from construction sites, it is necessary to refer to British Standards and other relevant planning and reference documents as appropriate. These include, but are not limited to:

- BS5228, 1997 Noise Control on Construction and Open Sites;
- BS4142, 1997 Method for rating industrial noise affecting mixed residential and industrial areas; and,
- Safety Health and Welfare at Work (Control of Noise at Work) Regulations 2006 (S.I. No. 371 of 2006).

The comparative implications associated with these policies are directly related and are therefore based on the potential impacts described in Section 5.8 of this report.

7.3.7 Soil

Although various EU policies contribute to soil protection, there are currently no EU Directives in place to specifically manage soil resources. As these policies have other aims and other scopes of action, they are not sufficient to ensure an adequate level of soil protection. Therefore, the European Commission adopted a Soil Thematic Strategy (STS) (COM(2006) 231) and a proposal for a Soil Framework Directive (COM(2006) 232) on 22 September 2006 to protect soils across the EU. The STS explains the need for further action to ensure a high level of soil protection and sets the overall objective of the Strategy and explains the type of measures that need to be taken. The STS further establishes a ten-year work program for the European Commission.

The proposal for the Soil Framework Directive sets out common principles for protecting soils across the EU. The framework provides a degree of flexibility by allowing Member States to decide how best to protect soil and how use it in a sustainable way on their own territory. Once the Soil Framework is adopted, Member States will transpose it into national legislation and start implementing it in accordance with a seven-year phased implementation.

In establishing the long-term management of an electrical transmission system in Ireland, it would be prudent to prepare for these pending changes in legislation during the planning stage. The comparative implications associated with these policies are directly related and are therefore based on the potential impacts described in Section 5.2 of this report.

7.3.8 Civil protection

The intent of the Seveso II Directive (96/82/EC) is to prevent major accidents involving dangerous substances and limit their consequences for man and the environment, with a view to ensuring high levels of protection throughout the Community. The Seveso II Directive replaced the Seveso I Directive and introduced requirements relating to safety management systems, emergency plans and land-use planning, as well as tightened up the provisions on inspections and public information. The Seveso II Directive is applicable to any establishment where dangerous substances are present, or are likely to be produced as a result of an accident, in quantities equal to or in excess of the quantities listed in the Annex. It is the responsibility of the operator to notify the competent authority if the Directive is applicable to their activities.

It will be essential to review the Annex of the Seveso II Directive in the planning and management of an electrical transmission line or cable system to determine whether the Directive and its provisions are applicable to the project. Therefore, this Directive is considered relevant to the project planning stages of both OHL and UGC, the implications of which are comparable to one another. Note that hazards created by ionising radiation are considered exempt from the Directive.

7.3.9 Summary

Table 7-2 provides a summary of the comparative environmental policy implications related to OHL and UGC. It is clear that from the perspective of EU and National level framework legislation that the comparative implications between the two options are generally similar. The difference in the comparison is primarily associated with the three distinct stages as referenced in the above sections and in Table 7-2: project planning, construction and operation. While the project planning stage does not directly involve pollution and monitoring, there are still policy implications during this stage due to the additional level of planning considerations that are required due to the provisions of the policy.

Table 7-2: Comparative environmental policy implications related to OHL and UGC

RESOURCE	**POLICY (EU / EC)**	**POLICY (IRE)**	**IMPLICATIONS**					
			UGC			**OHL**		
			Project planning	Construction	Operation	Planning	Construction	Operation
GENERAL	EIA Directive (85/337/EEC - 97/11/EC)	EPA Act (1992) Planning and Development Act 2000-2006 Planning Development Regulations 2001 and 2006	***	**	*	***	**	*
	Environmental Liability Directive (2004/35/EC)		Neg.	***	*	Neg.	***	*
	IPPC Directive (96/61/EC)	Protection of the Environment Act 2003 EPA Act (1992)	**	**	*	**	**	*
	Precautionary Principle		*	*	*	**	*	*
WASTE	EU Waste Framework Directive (2006/12/EC)	Waste Management Act 1996 as amended	*	**	Neg.	*	**	Neg.
AIR	EU Air Quality Framework Directive 96/62/EC Directive 1999/30/EC Directive 2000/69/EC	EPA Act 1992 (Ambient Air Quality Assessment and Management) Regulations 1999 Air Quality Standards Regulations 2002	*	***	Neg.	*	**	Neg.
WATER	Water Framework Directive (2000/60/EC)	EPA Act Water Pollution Acts (WPA) 1977-1990	*	**	*	*	**	*
FLORA AND FAUNA	Habitats Directive (92/43/EEC) Birds Directive (79/409/EEC)	Natural Habitats Regulations (S.I. 94/1997) Wildlife Acts of 1976 and 2000	***	**	*	***	**	*

RESOURCE	POLICY (EU / EC)	POLICY (IRE)	IMPLICATIONS					
			UGC			OHL		
			Project planning	Construction	Operation	Planning	Construction	Operation
NOISE	Assessment and Management of Environmental Noise Directive (2002/49/EC) Noise Emission by Equipment Used Outdoors Directive 2000/14/EC (amended in 2005 by 2005/88/EC)	BS5228, 1997 Noise Control on Construction and Open Sites BS4142, 1997 Method for rating industrial noise affecting mixed residential and industrial areas Safety Health and Welfare at Work (Control of Noise at Work) Regulations 2006 (S.I. No. 371 of 2006).	*	***	Neg.	*	***	Neg.
SOIL	European Commission adopted a Soil Thematic Strategy (STS) (COM(2006) 231) and a proposal for a Soil Framework Directive (COM(2006) 232)		***	**	*	***	**	Neg.
CIVIL PROTECTION	Seveso II Directive (96/82/EC)		*	Neg.	Neg.	*	Neg.	Neg.

Significance:	
***	Major: Requires extensive monitoring, reporting and consultation to maintain compliance.
**	Medium: Requires moderate monitoring and reporting with limited consultation to maintain compliance.
*	Minor: Requires simple monitoring and reporting at regular intervals to maintain compliance.
Negligible	Minimal or simple one-time measures needed to maintain compliance.

7.4 Enterprise Policy Alignment

As a member of the European Union, Ireland is required to align its policies in accordance with those implemented by the EU. Therefore, the legislative framework for enterprise and employment in Ireland is largely based upon EU priorities.

Central to EU policies on enterprise and employment is what is commonly referred to as the Lisbon Strategy, which aims to make Europe "the most competitive and most dynamic knowledge-based economy in the world, capable of sustainable economic growth accompanied by quantitative and qualitative improvement of employment and greater social cohesion" within ten years. By means of the Lisbon Strategy, the EU intends to foster a dynamic economy which encourages the generation of additional and increasingly appealing employment opportunities.

This section provides a brief overview of the EU enterprise policy priorities. With particular regard to employment, this study then focuses on the general guidelines of the Lisbon Strategy and Ireland's related National Reform Programme (NRP). The comparative implications for both OHL and UGC grid schemes are later assessed in terms of their general alignment with both the EU enterprise policy priorities and the Lisbon Strategy / Ireland NRP guidelines.

7.4.1 EU Enterprise Priorities

As indicated above, the legislative framework for enterprise and employment in Ireland is largely based upon EU priorities. The current EU priorities for enterprise policy, in no particular order, are to:

- *Promote entrepreneurship* by encouraging business creation and supporting companies, especially SMEs, during their start-up and development phase;

- Contribute to the design, implementation and improvement of a flexible regulatory framework to *provide access to the single market*;

- Open and guarantee obstacle-free, *fair access to non-EU markets*;

- *Promote European competitive performance* by encouraging businesses to adapt to structural change and maintain a high and consistent level of productivity growth;

- Ensure a proper coordination between industrial, energy and environmental policies in order to foster *consistency in policy and legislative initiatives*;

- Take into account differences in *industrial sector characteristics and needs;*

- *Promote innovation* by following up technological developments, new product designs and developing new ways of marketing products such as e-business;

- Promote *better access to funding, support networks and programmes*;

- Promote a more *simplified regulatory and administrative environment.*(Europa 2005 – 2008)

These priorities are generally described in the following sections:

Promote Entrepreneurship

To encourage and support Small and Medium Enterprises (SMEs), the EU has developed a comprehensive policy which aims to ensure that EU policies and actions are SME-friendly, as well as contribute to making Europe more conducive to establishing and running a company. The intent of this 'modern SME policy for growth and employment' is to ensure that all aspects of EU policy designed to help SMEs are appropriately coordinated, and that the needs of SMEs are more fully taken into considering when developing such policies.

Neither OHL nor UGC are anticipated to support or hinder the development of policies which encourage SMEs. Therefore, this priority has a neutral implication for both scenarios.

Access to the Single Market

The single market aims to bring down barriers and simplify existing rules to enable everyone in the EU - individuals, consumers and businesses - to make the most of the opportunities offered to them by having direct access to 27 countries and 480 million people. The single market should facilitate enterprise operation and competitiveness and provide a high level of health, safety, environmental and consumer protection without stifling technical innovation.

Electrical connection is a precondition for integration of power markets. The Irish system is connected to the British system by the 500 MW Moyle interconnector. Together with a potential additional 500 MW offshore interconnector these connections substantially contribute to an increased market size and liquidity [DETINI DCENR 2008]. The benefits, however, can be deployed only if the onshore transmission systems in Ireland allow transporting the power to the load centres and from the generation sites, respectively. There is no difference whether this functionality is implemented using OHL or UGC, provided the options offer the same performance, in terms of time to implementation and operational efficiency.

Fair Access to Non-EU Markets

There is extensive EU activity related to assessing and characterising the inherent links between the EU and non-EU countries. The intent of this activity is to strengthen the relative competitiveness of EU enterprise in support of the primary goal of the Lisbon Treaty - to become the most competitive and knowledge-based economy by 2010. In order to do so, it is critical that the EU progressively open and secure sustainable access to foreign markets. Conversely, business operators in foreign countries must in turn have open and secure access to the European market. The reciprocal nature of this system is anticipated to drive European business operators to increase their efficiency and competitiveness in order to operate effectively in a globalised economy. Neither OHL or UGC are anticipated to support nor hinder the development of policies which enable fair access to non-EU markets. Therefore, this priority has a neutral implication for both scenarios.

European Competitive Performance

In alignment with the Lisbon Strategy, competition not only drives innovation, but also delivers better products at lower prices to consumers. For this reason, the EU will continue to develop legislation which boosts competitive performance. “The opening up (deregulation) of network industries, such as electricity…should also have a positive impact on the overall economy and reduce prices for consumers (Europa 2005 - 2008).” The EU has conducted an inquiry to identify possible distortions of competition within the energy and gas sectors. The final report, which was delivered in January of 2007, concluded that consumers and businesses are losing out because of inefficient and expensive gas and electricity markets. The principle problem areas included:

- High levels of market concentration;

- Vertical integration of supply, generation and infrastructure leading to a lack of equal access to, and insufficient investment in infrastructure; and,

- Possible collusion between incumbent operators to share markets.

The final report of the inquiry was adopted together with a comprehensive package of measures to establish a new Energy Policy for Europe to combat climate change and boost the EU's energy security and competitiveness. (Europa 2005 – 2008)

The installation of both OHL and UGC equally and directly supports the development of infrastructure which is anticipated to support less expensive and accessible energy to consumers and industry. This availability will support local business, competition and therefore, competitive performance. Furthermore, any decrease in energy cost resulting from installation of either scheme is anticipated to enhance to the competitive performance of Irish businesses. Security of supply is also anticipated to encourage business, particularly in the case of Information and Communication Technology (ICT), which is directly linked with both competitive performance and supporting the development of the knowledge-based economy. Therefore, transmission system extension in general is anticipated to strongly support this priority, though possibly to a different degree depending on technology choice. The potentially lower Forced Outage Rate of OHL may be perceived as advantage by sensitive business and as such, in this stage of development, is a factor to be reflected.

For single projects, the higher life cycle costs associated with UGC will not directly affect Use of System Charges and, hence, electricity costs for final customers.

With existing knowledge, technical feasibility of extended UGC shares in the transmission system is uncertain. Nevertheless, in such a scenario the extra cost have to be taken into account. These costs may introduce a competitive disadvantage associated with UGC.

Policy and Legislative Initiative Consistency

The development of the 1992 Treaty of Maastricht, which created the European Union, defines 3 principles on which EU development policy should be based:

- Complementarity between development policies of the Member States and the EU, in order to avoid duplication and to maintain the relevance of individual programmes of the Member States;

- Co-ordination between the Member States and the EU administration at headquarters and in recipient countries to ensure effective operational implementation and avoid contradictions between different policies;

- Coherence of all Community policies so that they take account of development objectives.

The comparative alignment of an OHL and/or UGC transmission system policy consistency would be dependent upon any anticipated future policy development in Ireland due to the implementation of either scheme. It is beyond the scope of this study to make assumptions about how such a system would be implemented by decision-makers; therefore, in the context of this study, this priority has a neutral implication for both scenarios. For more information on implications for future energy policies, refer to paragraph 7.2 of this report. It is recommended during the planning stage that related policies and programmes in other EU countries be reviewed so that either system can be developed in a complementary manner. This could also further support the development of a single energy market.

Industrial Sector Characteristics and Needs

In October 2005, a new industrial policy to create better framework conditions for manufacturing industries was developed in Europe.

Neither OHL nor UGC are anticipated to significantly support or hinder the development of policies which create better framework conditions for manufacturing industries. Therefore, this priority has a neutral implication for both scenarios. Still, the differences in the degree of support provided by the technologies, as discussed above under European Competitive Performance, apply.

Innovation

Programmes such as the Competitiveness and Innovation Framework Programme (CIP) encourage the competitiveness of European enterprises. With particular support for SMEs, the programme will support innovation activities such as eco-innovation, provide better access to finance and deliver business support services in the regions. It will encourage a better take-up and use of information and communications technologies (ICT) and help to develop the information society. It will also promote the increased use of renewable energies and energy efficiency. The programme is schedule to run until 2013. The operational programme under the CIP which is anticipated to have direct implications related to an electrical transmission system in Ireland is the Intelligent Energy Europe (IEE). The key aspects of the IEE program are:

- Fostering energy efficiency and the rational use of energy sources
- Promoting new and renewable energy sources and energy diversification
- Promoting energy efficiency and new energy sources in transport (Europa 2005 – 2008)

The installation of both OHL and UGC supports the development of such programmes and policies. The grid infrastructure is anticipated to support less expensive and accessible energy to consumers and industry. Furthermore, an improved security of supply would be anticipated in both scenarios, though the degree of improvement may be different depending on the technology. Improved security of supply is anticipated to support business development in Ireland, particularly in the case of ICT. As such, this availability and security will support local business, competition and therefore, competitive performance and innovation. Therefore, the installation of either system is anticipated to support this priority.

Access to Funding, Support Networks and Programmes

Under this priority, the European Commission is focused on reducing or removing market gaps, complementing Member States' measures and working with the market to stimulate the provision of debt and equity finance to SMEs.

Neither OHL or UGC are anticipated to support nor hinder the development of such policies. Therefore, this priority has a neutral implication for both scenarios.

Simplified Regulatory and Administrative Environment

In the general context of developing better regulation, the Commission is committed to contributing to the common goal shared with European institutions and Member States by simplifying the regulatory environment for European business and citizens. The objective is to ensure that Community legislation is clear, understandable, up-to-date and user-friendly. To that purpose, the Commission launched in October 2005 a new simplification strategy which builds upon previous work in this domain. The European Commission has further reinforces the simplification programme with the addition of 43 new initiatives for the period 2006-2009. (Europa 2005 - 2008). Current activities include modification to environmental policy, accounting requirements, and sector-specific policy changes.

Neither OHL or UGC are anticipated to support nor hinder the development of such policies. Therefore, this priority has a neutral implication for both scenarios. However, this priority will require continued monitoring in the development of an electrical transmission system, as it will be a key driver in changing existing policies to which both OHL and UGC systems must comply. The modification of environmental policy and energy-sector specific policies could affect planning, construction, and/or operational activities. Since the goal of this priority is to simplify regulations, it is assumed that this implies that maintaining compliance with such policies would require less extensive effort.

7.4.2 Irish National Reform Programme

The European Employment Strategy (EES) is designed to help EU countries create more and better jobs. Objectives, priorities and targets are agreed at EU level, and Governments then coordinate their efforts to promote employment. In accordance with the EES, Ireland has developed its own National Reform Programme (NRP). Ireland's NRP brings together a broad range of policies and initiatives, the implementation of which aims to sustain Ireland's strong economic growth and employment performance as its overall contribution to the relaunched Lisbon Strategy… (DoT 2008)."

The original Irish NRP was implemented for 2005-2008; therefore, changes to the program will need to be reassessed over time. The report provides an overview of recent activities and proposed measures to act in conformance with the Lisbon Strategy, and includes updates to policies related to the Lisbon Strategy, such as macro- and micro- economic policy objectives, employment guidelines and related environmental objectives such as sustainability. Therefore, reviewing this and supporting documentation will assist in maintaining compliance with the goals, strategies, policies and programmes related to Ireland's enterprise and employment.

The NRP is based upon the EU's integrated package of macroeconomic, microeconomic and employment guidelines. These guidelines are included in Table 7-3 which assesses the comparative enterprise policy implications (including employment) for each system.

7.4.3 Summary

The comparative assessment indicates that there is little difference between the enterprise and employment policy implications when comparing OHL and UGC. As long as both scenarios offer the same technical performance, they are anticipated to have implications of the same nature and degree for each respective policy priority and NRP integrated guideline. None of the policies were determined to be adversely affected by the implementation of either scheme; therefore, the degree of implication in the table below are all considered to directly or indirectly support the policy, or have no related implications (neutral). The extra UGC costs represent a slight disadvantage. However, this cost difference to OHL becomes relevant for society only when extended portions of OHL are replaced by UGC (see [Elinfrastrukturudvalget 2008b]). At this stage of development, technical viability of such a scenario is questionable and, from that perspective, any statement regarding associated cost implications in the longer term would be speculative.

Table 7-3 below provides a summary of the comparative enterprise (including employment) policy implications related to OHL and UGC.

Table 7-3: Comparative enterprise (including employment) policy implications related to OHL and UGC

POLICY	**IMPLICATIONS**	
	UGC	**OHL**
EU ENTERPRISE PRIORITIES		
Promote Entrepreneurship	-	-
Access to the Single Market	**	*
Fair Access to Non-EU Markets	-	-
European Competitive Performance	**	**
Policy and Legislative Initiative Consistency	-	-
Industrial Sector Characteristics and Needs	-	-
Innovation	**	**
Access to Funding, Support Networks and Programmes	-	-
Simplified Regulatory and Administrative Environment	-	-
IRISH NATIONAL REFORM PROGRAMME – INTEGRATED GUIDELINES		
1. Guarantee the economic stability for sustainable growth	*	*
2. Safeguard economic and budgetary sustainability, a prerequisite for more jobs	*	*

POLICY	IMPLICATIONS	
	UGC	OHL
3. Promote an efficient allocation of resources, which is geared to growth and jobs	**	**
4. Ensure that the development of salaries contributes to macroeconomic stability and growth	-	-
5. Strengthen the consistency of macroeconomic, structural and employment policies	-	-
6. Contribute to the dynamism and smooth operation of EMU	-	-
7. Increase and improve investments in research and development, in particular in the private sector, with a view to establishing a European area of knowledge	-	-
8. Facilitate all forms of innovation	*	*
9. Facilitate the spread and effective use of ICTs and build a fully inclusive information society	-	-
10. Strengthen the competitive advantages of its industrial base	*	*
11. Encourage the sustainable use of resources and strengthen the synergies between environmental protection and growth	*	*
12. Extend and deepen the internal market	*	*
13. Ensure open and competitive markets inside and outside Europe, reap the rewards of globalisation	*	*
14. Create a more competitive business environment and encourage private initiative by improving regulations	-	-

POLICY	IMPLICATIONS	
	UGC	OHL
15. Promote a more entrepreneurial culture and create a supportive environment for SMEs	-	-
16. Expand, improve and connect European infrastructures and complete priority cross-border projects	**	**
17. Implement employment policies aiming at achieving full employment, improving quality and productivity at work, and strengthening social and territorial cohesion	-	-
18. Promote a lifecycle approach to work	-	-
19. Ensure inclusive labour markets, enhance work attractiveness, and make work pay for job-seekers, including disadvantaged people and the inactive	-	-
20. Improve matching of labour market needs	-	-
21. Promote flexibility combined with employment security and reduce labour market segmentation, having due regard to the role of social partners	-	-
22. Ensure employment-friendly labour costs developments and wage-setting mechanisms	-	-
23. Expand and improve investment in human capital	-	-
24. Adapt education and training systems in response to new skill requirements	-	-

Significance:	
**	Directly supports policy.
*	Indirectly supports policy.
-	Neutral (no) implications to policy.

7.4.4 Policy Trends

Due to a range of factors, legislation on a global scale is generally becoming more stringent and complex. Policies which were once more locally-driven and isolated are now being transformed to international framework legislation with broad, cross-cutting implications. Drivers for such legislation trends include:

- International groups of countries such as the United Nations and European Union, as well as the strengthening of international agreements such as those relating to trade help to establish international common laws and standards.

- Bretton Woods Institutions such as the World Bank and the International Monetary Fund are increasingly supportive of international aid programmes, development initiatives and criteria, and approval of such activities has indirect but critical impact on legislations.

- The Internet enables groups with common interests (NGOs, international labour organizations) and concerns to coordinate and expand their influence with greater ease.

- National and International media attention has increased awareness of various issues and has subsequently put pressure on legislative bodies and business organisations to support increasingly stringent policies related to energy, the environment and business.

Trends in legislation such as the SEA Directive, Cohesion Policy and the emergence of regionalised legislative cohesion (e.g. the European Union) demonstrate that legislation can no longer be seen in isolation. It must be looked at in the context of its broader implications to energy use, the natural environment, social equity and other stakeholder concerns. This shift in the development of policies implies that simply complying with existing policy could be a potential risk to businesses as new policies emerge. It would thus be prudent to continue to monitor legislative trends to be better prepared for changes in policy.

8 Cost allocation issues

This chapter discusses the allocation of cost differences between the OHL and UGC with respect to their impacts on different stakeholders.

Figure 8-1 gives an overview of costs and benefits and a basic structure for their allocation.

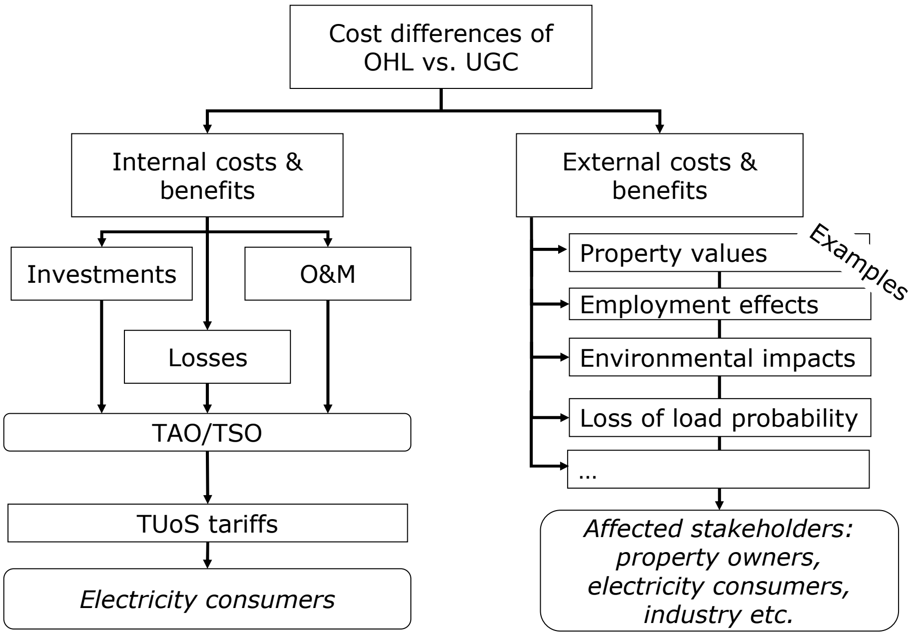

Figure 8-1 Overview of cost allocation principles

On the first level, costs and benefits are divided into two categories. For internalised cost and benefits a market price (or a price set by regulators in line with market principles) can be attributed. Examples are differences in investment cost, operation and maintenance (O&M) cost as well as the cost differences resulting from different levels of electric losses.

On the other hand, external costs are those costs which are not included in the market price of the goods and services being produced, i.e. costs not directly borne by those who create it. Examples are the different impacts on the environment, health effects or property values.

External costs can partly be internalised by compensation mechanisms. Such mechanisms have to be prescribed by jurisdiction. Internalisation is possible where costs and benefits can clearly be quantified attributed to individuals (for example, such mechanisms can be applied to impacts on property values). Indirect impacts as employment effects or the effects of loss of load can barely be attributed to individuals which makes compensations difficult. Both cost categories will be further discussed in the following chapters.

8.1 Internal costs

In the Republic of Ireland, EirGrid as the Transmission System Operator (TSO) is the responsible party to plan the future grid development. Once projects are defined, ESB as the Transmission Asset Owner (TAO) is responsible for the implementation for the projects. Both TSO and TAO are subject to revenue regulation by the CER. CER calculates the allowed revenue by analysing required operational and capital expenditures as a forecast for a regulatory period of 5 years [CER 2005]. Appropriate Transmission tariffs emerge as a result of this calculation.

As demonstrated in sections 4 and 9 the cost implications of the choice of OHL versus UGC are substantial. This is especially true if the cost categories of operational and capital cost are analysed separately. Although most of the allowed expenditure for the business is not subject to the regular annual review of allowed revenues, adjustments in the operational and capital cost budgets would have to be made to account for the decision of the TSO and the resulting expenditures of TSO and TAO. The revision of the decision would affect an adjustment of the TUoS tariffs. These charges are distributed between generators (G-component) and load (L-component). As generators will pass on charges to final customers, the cost differences will finally be borne by all electricity consumers.

The current regulatory approach followed in the 5-year price control period creates monetary incentives for the TSO to minimise losses, transmission system interruptions and voltage variations [CER 2005]. Hence further adjustments might be necessary to recognise the operational differences of OHL versus UGC.

8.2 External cost

This section lists a number of impacts that imply external costs. The quantification of these costs is typically subject to a substantial degree of uncertainty, and not within the scope of this study. The following paragraphs discuss some examples for impacts and cost allocation.

Property values

As shown in section 2 and 6, a substantial number of submissions made within the consultation process referred to consequences of new transmission lines for property values. The impact is recognized by a number of studies, but a quantification of these possible impacts would only be possible of the exact routing of the OHL is fixed.

Environmental impacts

Section 6 analyses a variety of environmental impacts of the two options. Both the economic valuation of environmental impacts and the attribution of impacts to individuals are difficult.

Employment effects

Both options will have various impacts to local employment, depending on the share of local and imported services and material for construction. Additionally, operation and maintenance has some impact on local value added. Other employment effects may emerge from the impact on tourism and the recreation industry. Again, the evaluation of these effects is difficult as it would require a detailed data basis.

Loss of load probability and valuation

As discussed in section 4 the choice of OHL versus UGC has implications for operational security. Both the quantification and valuation of loss of load implications are difficult. The quantification is hampered by the fact that the operational experience with 400 kV UGC is limited and the characteristics of unavailability differ substantially between the options, with methodologies for appropriate evaluation still under discussion. Valuation of the Value of Lost Load (VoLL) is critical as energy policy defines security of supply as a goal in itself, rather than an economic variable. The specific value of loss of load can be vary per customer. Within the process of market design for the Single Electricity Market, a value of € 10,000 per MWh was determined, but this value is not used to valuate transmission-related outages [AIP 2007].

9 Case Studies

9.1 Introduction

In order to support the generic technology comparison provided in the sections before, a more specific analysis of merits and costs of the particular options is provided for two cases in the following sections. The cases are defined in such a way that they reflect realistic conditions in Ireland. However, they do not assess the feasibility of specific projects or plans under discussion.

9.2 Assumptions and configurations

9.2.1 Description of routing and geographical conditions

Two different cases for new transmission connections are defined and analysed more in detail. They mainly differ with respect to the length of the transmission line: 100 km in case 1 and 50 km in case 2. They may be interpreted as separate projects but also as adjacent sections of one single line.

In both cases the number of km indicates the route length, rather than the geographical distance between the terminals of the line. In practice, the route length will more or less differ depending on the technology option. Planning of OHL routing may be subject to serious restrictions in populated or protected areas, resulting in detouring and thus extra route length compared to an UGC route. However, in the case of UGC, protected areas, terrain characteristics (mountains) and in particular difficult soil conditions may also require substantial deviations from the shortest route.

[Oswald 2007] estimates route savings of roughly 5% for the UGC option in the specific case of the Tauern-Salzach transmission connection in Austria. However, this figure certainly cannot be generalised. In the course of the case studies, by definition route length is assumed to be the same for OHL and UGC. Any other assumption would be speculative given the abstract character of the cases. As route length directly influences the outcomes of the economic analysis, this figure definitely requires care when comparing real world project alternatives.

Case Study 1: 100km Lowland
Land use along the proposed 100km route varies from open agricultural land to forested to industrial/urban. OHL along this route would involve planning permission for pylons all along the route. Some tree felling would also be required in the two forested areas unless existing forest breaks can be used. If no forest breaks exist or permission for tree felling is denied then the OHL may have to take a lengthy alternative route. UGC in these forested areas would not be subject to planning permission but any tree felling would be subject to permission from Coillte.

There are twenty water courses along this proposed route. This number includes three major water courses – River A, River B and River C. All three of these rivers host aquatic habitats for the otter. River B and River C are spawning rivers for wild salmon. OHL would have little or no impact on the aquatic ecosystem. UGC may use existing river crossings. However, in this analysis it is assumed that suitable bridges are not available close enough to the route. If the cables are laid through the water courses this clearly impacts on the ecosystem especially in the case of ducts which rest on the base of the rivers. The placing of these ducts may necessitate river diversion during their construction. In the analysis it is assumed that the cables are implemented using directional drilling. This option would mitigate the described impacts but in practice feasibility is dependant on the geology at each proposed river crossing.
River C is regarded as being a particularly scenic and visually attractive water course. An OHL crossing this river would have an adverse visual impact on this river. UGC would have little or no impact on this landscape.

There is one Special Area of Conservation (SAC) on the proposed route. This SAC is a semi-wetland that hosts a sensitive flora and mammal habitat. OHL would impact on this SAC during construction and careful planning of access routes and location of pylon bases would be required. Construction of UGC is considered impossible due to environmental impact, but even more because the soil in not supportive enough to allow access for equipment without excessive preparation. Consequently, routing of UGC’s has to surround respective areas.

There are two National Parks along the proposed route – NP1 and NP2. NP1 forms part of one of the forested areas already discussed. NP2 consists of a series of undulating hills known as ‘drumlins’. These are features deposited by retreating ice sheets at the end of the last ice age. They are generally made up of ‘Boulder Clay’ – a sandy, gravely clay with occasional to common cobbles and boulders. These glacial features form the basis of many walking routes and scenic drives in the National Park. OHL would therefore have an adverse visual impact in this area. Mitigation includes careful route planning such as locating pylons so that they do not impact on skylines in so far is possible. The laying of UGC in NP2 presents some major challenges. Trench excavation may prove unfeasible along some lengths of the route due to steep gradients on the sides of some drumlins. Weaving of UGC around drumlins may be difficult due to limited cable flexibility. This would also greatly increase cable length and would impact on significantly greater portions of land during construction. Directional drilling through drumlins in order to preserve as a short a route as possible may be difficult in very boulder ridden clays but this would require further investigations for each drumlin to be crossed.

There is one quarry on the proposed route. The installation of either OHL or UGC would require careful consideration of the strategic plans for this quarry. Blast monitoring information should also be gathered to ascertain any adverse impact blasting may have on potential proximal joint bays (UGC) or pylons (OHL).

The proposed route hosts three significant archaeological sites – Abbey X, Castle Y and the set of burial mounds at Location Z. The route may therefore be deemed as traversing a sensitive archaeological landscape. Although OHL would impact visually on these sites they would have little or no physical impact on them. However, UGC would cause significant adverse impact during construction. In particular, trenching may cause significant damage to the sites. Consequently, it is assumed that UGC routing surrounds these sites with sufficient distance.

The nine population centres, including one Gaeltacht village, along the proposed route require careful consideration to the communities along the route both during construction and operation of OHL or UGC. OHL would impact visually on the community in each of theses population centres. The perceived health risks associated with living in proximity to OHL must also be taken into serious consideration whilst a perceived negative impact on property prices must also be addressed. The sensitive Gaeltacht community of Village T should be carefully considered with regard to potential depopulation due to the factors described above. UGC may be better suited to these urban centres but full consideration must be given to the location of joint bays and Sealing End Compounds in relation to nearby houses. Other considerations include permanent access to UGC routes.

Traffic volumes through and around these centres of population should also be considered. Traffic and noise volumes during the installation of OHL are generally much less than for UGC. However, OHL operation noise (Corona Effect) if OHL or transformer stations are to be located close to houses must be taken into account.

There are approximately fifty roads to be negotiated by OHL or UGC along the proposed route. OHL would cause minimum disruption to traffic during construction. Temporary scaffolding would be erected on either side of the road to accommodate lines before they are supported by pylons. However, operational impact includes the visual impact of a series of pylons. UGC, whilst having little or no visual impact during operation, may cause significant disruption during their construction at infrastructural crossings. Mitigation includes directional drilling beneath the crossing (depending on geology). In either case, the length of construction would be significantly longer for UGC than for OHL at these crossings.

There is a total of 20km of peat bogs along the proposed route. OHL would have little impact on these sensitive areas except for temporary access routes during construction and the area occupied by the pylon base. As in the case of the SAC, UGC routing has to go around the peat bogs because of the weakness of the soil.

Case Study 2: 50 km Lowland and Upland

Land use along the proposed 50 km route varies from open agricultural land to forest to industrial/urban. There are 15km of upland with elevations rising to between 500m and 800m. OHL along this route would involve planning permission for pylons all along the route. Some tree felling would also be required in the two forested areas unless existing forest breaks can be used. If no forest breaks exist or permission for tree felling is denied then the OHL may have to take a lengthy alternative route. UGC in these forested areas would not be subject to planning permission but any tree felling would be subject to permission from Coillte.

There are fifteen water courses along this proposed route. This number includes three major water courses – River D, River E and River F. All three of these rivers host aquatic habitats for the otter. River E and River F are spawning rivers for wild salmon. As in case 1, directional drilling is assumed for crossing these water courses.

There is one Special Area of Conservation (SAC) on the proposed route. This SAC is a turlough that hosts a sensitive flora and mammal habitat. Additionally, there is a total of 25 km of peat bogs along the proposed route. As in case 1 it is assumed that an UGC route is able to surround these areas at the cost of extra length.

There is one National Parks along the proposed route – NP3. It forms part of one of the forested areas already discussed. The park includes many walkways and reaches a elevation of 300m. There is a viewing platform at this summit that provides commanding vistas of the surrounding landscape. The installation of OHL through this park would have an adverse visual impact. UGC would have no such visual impact but tree felling may be required that may disrupt some walkways in the forested areas during construction. Mitigation includes avoidance of impacts on skylines where possible in the case of OHL and the use of forest breaks for UGC where feasible.

There is one quarry on the proposed route. The installation of either OHL or UGC would require careful consideration of the strategic plans for this quarry. Blast monitoring information should also be gathered to attempt to ascertain any adverse impact blasting may have on potential proximal joint bays (UGC) or pylons (OHL).

There is a working mine near Village G along the proposed route. The mine is worked at approximately 200m depth. Vibration data would need to be gathered in order to ascertain potential structural threats to pylons (OHL) or joint bays (UGC). Careful consideration must also be given to the mining boundary and proposed mine developments in proximity to UGC or OHL. This may avoid possible future structural damage to joint bays or pylons.

The proposed route hosts only one significant archaeological site – Castle N and the Although OHL would impact visually on this site they would have little or no physical impact on them. However UGC would cause significant adverse impact during construction. In particular, trenching may cause significant damage to the site and UGC may not be considered feasible close to the site for this reason.

The four population centres, including one Gaeltacht village, along the proposed route require careful consideration to the communities along the route both during construction and operation of OHL or UGC. OHL would impact visually on the community in each of theses population centres. The perceived health risks associated with living in proximity to OHL must also be taken into serious consideration whilst a perceived negative impact on property prices must also be addressed. The sensitive Gaeltacht community of Village M should be carefully considered with regard to potential depopulation due to the factors described above. UGC may be better suited to these urban centres but full consideration must be given to the location of joint bays and Sealing End Compounds in relation to nearby houses. Other considerations include permanent access to UGC routes.

Traffic volumes through and around these centres of population should also be considered. Traffic and noise volumes during the installation of OHL are generally much less than for UGC. However, OHL operation noise (Corona Effect) if OHL or transformer stations are to be located close to houses must be taken into account.

There approximately thirty roads to be negotiated by OHL or UGC along the proposed route. OHL would cause minimum disruption to traffic during construction. Temporary scaffolding would be erected on either side of the road to accommodate lines before they are supported by pylons. However, operational impact includes the visual impact of a series of pylons. UGC, whilst having little or no visual impact during operation, may cause significant disruption during their construction at infrastructural crossings. Mitigation includes directional drilling beneath the crossing (depending on geology). In any case, the length of construction would be significantly longer for UGC than for OHL at these crossings.

The 15 km of upland area along the proposed route requires careful consideration. OHL would have an adverse visual impact on this area. Mitigation includes keeping pylons below skylines and using the route of the existing regional road where possible. Soil cover in this upland area consists of less than 1m (on average) blanket bog. There are large expanses of exposed rocks on the sides of some of the mountains. Installation of UGC may be difficult in this landscape due to the lack of soil to bury cables and the sensitivity of existing peat habitat to excavations. Close consultation with relevant bodies is necessary to determine the route/method that would cause least impact to the landscape in this upland area. Again, UGC may be able to follow the route of the existing regional road where conditions allow.

Table 9-1: Summary overview of case characteristics

	100 km mostly Lowland	**50 km Lowland and Upland**
Water Courses (crossed by directional drilling)	20 (includes 3 major courses)	15 (includes 3 major courses)
Roads	50	30
Centres of population **No. of inhabitants**	2 > 2000; 2 > 500; 5 > 50	1 > 2000; 1 > 500; 2 > 50
Upland area	0	15km Elevations between 500m and 800m
SAC	1	1
National Park	2	1
Airfield	1	0
Mine	0	1
Quarry	1	1
Archaeological Site	3	1
Forest	2	2
Soil Type 1 **'Boulder Clay' = Sandy, gravely CLAY**	75km	20km
Soil Type 2 **Average Thickness = 1m – 2m** **Alluvium (Silty SAND)**	5km	5km
Soil Type 3 **Average Thickness = 2m – 8m** **PEAT bog**	20km	25km
Total soils	*100km*	*50km*
Grey cells: cable route avoids crossing of these objects		

9.2.2 Technical requirements and loading

Sizing and configuration of the transmission line depends on expected loading as well as security of supply requirements, i.e. generation and transmission adequacy.
A more detailed analysis covering many additional aspects is required when planning and designing specific transmission extensions. Those additional aspects are, for example, impact on short circuit capacity at adjacent nodes, voltage stability, resonance frequencies in the system, operational complexity, etc. However, it is impossible to derive generic conclusions related to these aspects and, hence, such an analysis only makes sense for clearly specified projects. Consequently, an in-depth assessment of these aspects and their implications for the cases discussed goes beyond the scope of this study.

It is assumed that the new transmission lines considered in the two cases are integrated in an existing meshed network and as such increase the available transmission capacity. Still, in case the connection becomes unavailable, e.g. as a consequence of maintenance or faults, the existing network is capable of accepting respective load flows. Hence, n-1 security does not necessarily have to be guaranteed by designing the new transmission connection with double circuits (according to specifications n-2 security is not required).
Still, the capacity of the new connection has to be sufficient to take the complete load flow from the lines already existing because otherwise n-1 security would be compromised.

In line with EirGrid's design conventions, a transmission capacity of 1614 MVA (summer rating) to 1990 MVA (winter rating) may be assumed for a single circuit OHL equipped with twin bundles of 600 mm2 ACSR CURLEW type conductors. According to the Transmission Forecast Statements published by EirGrid [EirGrid TFS 2007], a nominal transmission capacity of 1424 MW and 1713 MW summer and winter ratings, respectively, is assumed for new 400 kV connections. The latter values are used as reference for the comparison in the following analysis. By definition, the nominal transmission capacity of any alternative option considered in the following comparative analysis should not be lower than these values.

Initially average load flow along the new transmission connections in case 1 and 2 is assumed to be 25% to 35% of the seasonal ratings, corresponding with an average load factor of $k_A = 0.12$ (for explanation see Appendix 1 – Losses in AC transmission). This loading may appear low for an investment project of such an economic, environmental and social impact. However, the development of load flows across the transmission system is subject to a variety of factors and as such, is characterized by uncertainty. Initiatives of external market players, e.g. construction of new generation capacity or demand growth in load centres in different regions of the country are out of the control of EirGrid. Taking the long lead times for transmission capacity enhancement into account, strategic planning inevitably includes certain margins. Over the lifetime of the new transmission circuits a higher loading is assumed (40% to 50% of nominal capacity, corresponding with an average loss factor of $k_A = 0.2$).

In summary, the assumed loading is in line with typical situations in Ireland [Corcoran 2008], provides n-1 security and allows coping with growing load flows in future, due to national economic developments in general and SEM evolution in particular.

In contrast with OHL, with their thermal inertia being negligible, temperature of UGC in soil responds to load steps with a delay of hours, with a change to a new stationary equilibrium taking weeks. For that reason, the thermal capacity of UGC under fluctuating load conditions is higher than their stationary limits (see paragraph 4.2.2). The exact value of the achievable thermal capacity, being the key parameter for cable rating, depends on the characteristics of the load profile.

As a simplified measure characterising the load profile, the 'daily load factor' *m* is applied (see Appendix 3 – Rating of UGC circuits). This figure is calculated as the ratio of the area under the daily load curve and permanent peak load. For 380 kV transmission lines regularly a value of *m* = 0.7 has been applied [Oswald 2007], [Oswald et al 2005], [Hoffmann et al 2007].

EirGrids Generation Adequacy Report [EirGrid GAR 2007] provides illustrative figures for typical system loading of the transmission system operated by EirGrid (see Figure 9-1). The daily load factor represented by these figures is about *m* = 0.8.

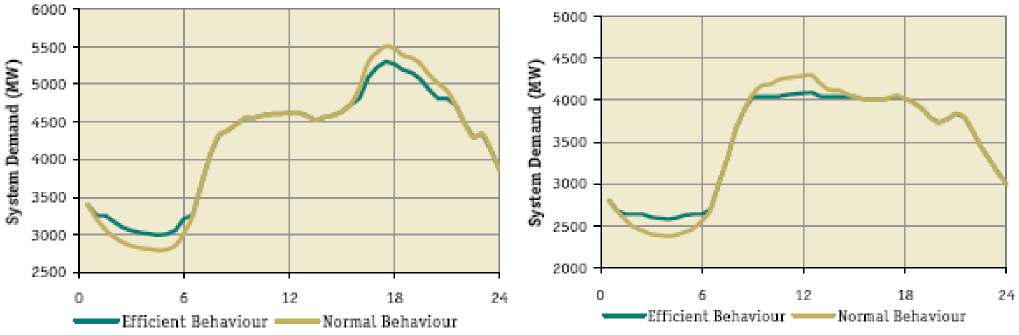

Figure 9-1: demand profile for a typical winter day (left) and summer day (right) (source: [EirGrid GAR 2007])

A transmission line being operated as an interconnector between different regions may be subject to loading patterns substantially different from demand profiles. Power plant dispatch across the country is determining load flows. In the future, in particular, fluctuating output from wind capacity may result in less regular profiles, fundamentally differing from the shapes indicated in Figure 9-1.

Nevertheless, in the further analysis *m* = 0.85 is applied as a conservative assumption for appropriate rating of an UGC connection and evaluation of respective losses.

9.2.3 Configurations

The following comparative analysis covers the configurations listed below. A detailed assessment of the transmission capacity of the various UGC configurations forming the basis for the specifications is provided in Appendix 3 – Rating of UGC circuits.

Option 1 – OHL

This option covers a conventional OHL using one of EirGrid's tower designs (single circuit, twin bundles of 600 mm2 ACSR CURLEW type conductors). The rated transmission capacity is 1424 MW (summer) and 1713 MW (winter).

Option 2 – UGC, 2 Al 3000

This option covers two transmission circuits in a flat arrangement 1.5 m below surface in one trench. The cables are equipped with segmented aluminium conductors (RMS) with 3000 mm^2 cross section and are buried directly in soil in a thermally stabilising layer. Manufacturers recently announced commercial availability of cables with such extended conductor cross sections.

The distance between cable surfaces is 0.3 m, the distance between systems 1 m, resulting in a trench width of 3.4 m (at the basement).

The nominal transmission capacity of this arrangement is 2074 MVA (assuming a daily load factor m = 0.85) and, hence, substantially higher than the capacity of the reference (OHL).

Additionally, because of the double circuit arrangement, the secured capacity of this option with one system being unavailable still is more than 1000 MVA, whereas the n-1 capacity of the OHL is zero.

As explained in paragraph 4.2, longer transmission cables require compensation of charging currents. For case 1 (100 km) two compensation sites along the route and for case 2 (50 km) one compensation site halfway is assumed.

Additional results for the following UGC AC configurations are presented.

Option 3 – UGC 1 Cu 2500 with lateral cooling

This option covers a single transmission circuit in a flat arrangement 1.5 m below the surface in one trench. The cables are equipped with segmented copper conductors (RMS) with 2500 mm2 cross section and are buried directly in soil in a thermally stabilising layer. Additionally, lateral cooling is implemented between the cables for enhancement of the transfer capacity. The distance between cable surfaces is 0.3 m resulting in a trench width of 1.5 m (at the basement).

The nominal transmission capacity of this arrangement is 1830 MVA (assuming a daily load factor m = 0.85). When the cooling is lost, a stationary transfer capacity of 1330 MVA is available. Of course, the secured capacity of the electrical circuit in case of unavailability is zero, as with the OHL.

In this case, compensation sites are also required. The occupied space per site may be less as only one circuit is involved. On the other hand, cooling sites are required each 20 km to 30 km feeding the lateral cooling pipes in two directions. Locating compensation and cooling at the same site is preferable.

Option 4 – UGC 2 Al 1600 with lateral cooling

This option is a combination of option 2 and 3. It is based on a double circuit arrangement using aluminium conductors as in option 2 with identical geometry. However, by adding lateral cooling, the conductor cross section can be reduced to 1600 mm^2.
The nominal transmission capacity of this arrangement is 1940 MVA (assuming a daily load factor m = 0.85). When the cooling is lost, a stationary transfer capacity of 1480 MVA is available, which is still more than the summer ratings of the OHL. Secured capacity of this arrangement with one system being unavailable is about 1000 MVA.
For compensation and cooling the same conditions apply as in option 3. However the space requirements per site are higher.

Option 5 – UGC 2 Al 1600 in tunnel with forced convection

In this option, a double circuit of 1600 mm^2 Al conductors is also used. However, the circuits are not buried in soil but mounted in an accessible tunnel. The tunnel allows easy access, visual inspection, fast error location and repair. In order to achieve the specified transmission capacity of 2010 MVA and 1840 MVA (winter and summer, respectively) the tunnel has to be cooled by blowers. Without forced convection the transmission capacity of the circuits is reduced to slightly more than 1400 MVA. Still this is about the summer rating of the OHL. Secured transmission capacity with one circuit being unavailable is 1000 MVA to 1100 MVA, depending on the ambient temperature.
The idea of a tunnel crossing the landscape over 50 km or 100 km is a conceptual option rather than a design proposal. The route characteristics described above include fundamental obstacles: water crossings, hilly areas and wetlands may be impassable for this tunnel. Still the technology is included in the comparison as it may be one option for partial undergrounding in sensitive areas.

The figures for options 3 to 5 are provided primarily for illustrative purposes. Feasibility of these options along such extended distances without disruption may be questionable. Obstacles such as river crossings may require a change of the concept (e.g. tunnel). Consequently, respective sections may represent bottlenecks resulting in a reduced transfer capacity for the whole line.
Further, cooling equipment introduces additional components which have to be taken into account with their characteristic failure rates in any system adequacy assessments. As indicated in the descriptions, in case of malfunction of cooling, the transfer capacity of the UGC options is temporarily reduced (for an overview see also Table 9-2). Unavailability of a single unit creates a bottleneck and reduces the transfer capacity of the whole line. Because of the limited reach of the cooling circuits, a number of units are required (about 10 for case 1). Assuming an availability of the particular cooling units of 99% (statistically independent) still the resulting availability of the total cooling system is just 90%.

Additionally, as cooling equipment relies on utility electricity supply, introduction of systematic common mode failure dependencies is a likely risk and at least requires specific attention in design of the supply infrastructure.

Option 6 – UGC 2 DC VSC

The assumed transmission line consists of two ± 300 kV DC circuits with copper conductors with a cross section of 1600 mm^2 each. Both circuits are terminated with 900 MW VSC stations at both ends, i.e. 3600 MW installed converter capacity. The two XLPE cables of one system are installed directly adjacent to each other in an underground cable trench. The system distance is 1.1 m, resulting in a width of the cable trench at the basis being approximately 1.9 m. Under these conditions the combined transfer capacity of both circuits is 1956 MW. Secured capacity of the transmission arrangement with one circuit being unavailable is about 900 MW.

Differences between case 1 (100 km circuit length) and case 2 (50 km circuit length)

Except the difference in distance, differences in configurations are only related to the number of compensation sites in case of the AC UGC options. Case 1 assumes two sites, for case 2 one compensation site half way is sufficient.

Table 9-2: Overview configurations (options)

Option	Number of systems	Nominal rating [MVA] {with cooling lost}	n-1 contingency of the option: remaining transfer capacity [MVA]
1. OHL	1	1713 (winter) / 1424 (summer)	0
2. UGC 2 Al 3000	2	2074	1180
3. UGC 1 Cu 2500 cooled soil	1	1830 {1331}	0
4. UGC 2 Al 1600 cooled soil	2	1940 {1480}	1115
5. UGC 2 Al 1600 cooled tunnel	2	2010 (winter) / 1840 (summer) {1440}	1120 (winter) / 1020 (summer)
6. DC VSC	2	1956 MW	≈1000 MW

For illustrative purposes only

9.2.4 Economic parameters

To provide a thorough and accurate comparison of the economic performance of the alternatives, investments as well as relevant cost components along the complete life cycle (losses, O&M) are considered.

Investments

By nature, cost figures provided here are characterized by substantial uncertainties, for a number of reasons.

1. Worldwide no transmission project of this size using AC UGC has ever been built. Respective cost figures are extrapolated from other studies and noncommittal industry information. AC UGC projects already realised with EHV transmission cables are representative to only a limited extent as virtually all have been implemented in quite different environments.
2. Options 3 to 5 (cooled UGC) and option 7 have never been built over distances as discussed here. Cost assumptions are just an extrapolation of figures for short distances. However, substantial additional costs may apply.
3. Assumed component prices may be subject to substantial variations. Prices of cables are strongly dependent on market prices for raw materials. During the last couple of years, for example, copper prices have been subject to a dramatic increase. As lead times for any transmission project span a number of years, this planning period implies a cost uncertainty. This should be reflected in the interpretation of this assessment. Additionally, the number of suppliers currently able to provide the equipment for UGC transmission is limited and, hence, price forming may be affected by lack of references or choice.
4. Estimating costs for civil engineering requires a thorough analysis of site specific conditions. Appropriateness of the assumptions, derived from feasibility studies and projects in other countries may be challenged. However, the scope of this study is a generic assessment and, hence, applying some generic assumptions is an inevitable part of the methodology.

In order to cope with the uncertainties adequately and to draw robust conclusions, an extensive sensitivity analysis is applied to the results.

Table 9-3 defines the cost components and quantifies the base cases for the various options.

Table 9-3: assumptions regarding required specific investment for transmission options

Option			*OHL*	**UGC AC**				**UGC DC**
			1	**2**	**3**	**4**	**5**	**6**
			2*600 ACSR	**Al 3000**	**Cu 2500 lateral c.**	**Al 1600 lateral c.**	**Al 1600 tunnel**	**DC VSC**
number of systems			*1*	2	1	2	2	2
nominal transfer capacity	MVA		*1713*	2074	1830	1940	2010	1800
conductors / cables incl. joints, implementation, testing, commissioning per system	k€ / km		*700*	1200	1600	950	950	400
total cablingcables incl. joints, implementation, testing, commissioning	k€ / km		*700*	2400	1600	1900	1900	800
compensation & termination	10	k€ / MVAr		290	178	250	250	
total electrical	*k€ / km*			*2690*	*1778*	*2150*	*2150*	*800*
planning	k€ / km			40	20	40	40	40
trench width @ trench basis	m			3.4	1.5	3.4		1.8
civil works (trenching, drilling, cable ducts etc.)	200	k€/km/m trench width @ 1.5 laying depth		680	300	680	750	360
auxiliaries, cooling equipment, tunnel		k€ / km			150	300	200	
total civil	*k€ / km*			*720*	*470*	*1020*	*990*	*400*
total specific investment in connection			***700***	**3410**	**2248**	**3170**	**3140**	**1200**
specific converter costs	[k€/MW]							100
converter costs								360000
specific investment [k€ / km]	**100**	**km**	***700***	**3410**	**2248**	**3170**	**3140**	**4800**
specific investment [k€ / km]	**50**	**km**	***700***	**3410**	**2248**	**3170**	**3140**	**8400**
investment ratio wrt	100	km		4.9	3.2	4.5	4.5	6.9
OHL (option 1)	50	km		4.9	3.2	4.5	4.5	12.0

With these assumptions, the specific investments of AC UGC options 2 and 3 are in line with figures provided by third parties (see Figure 9-2).

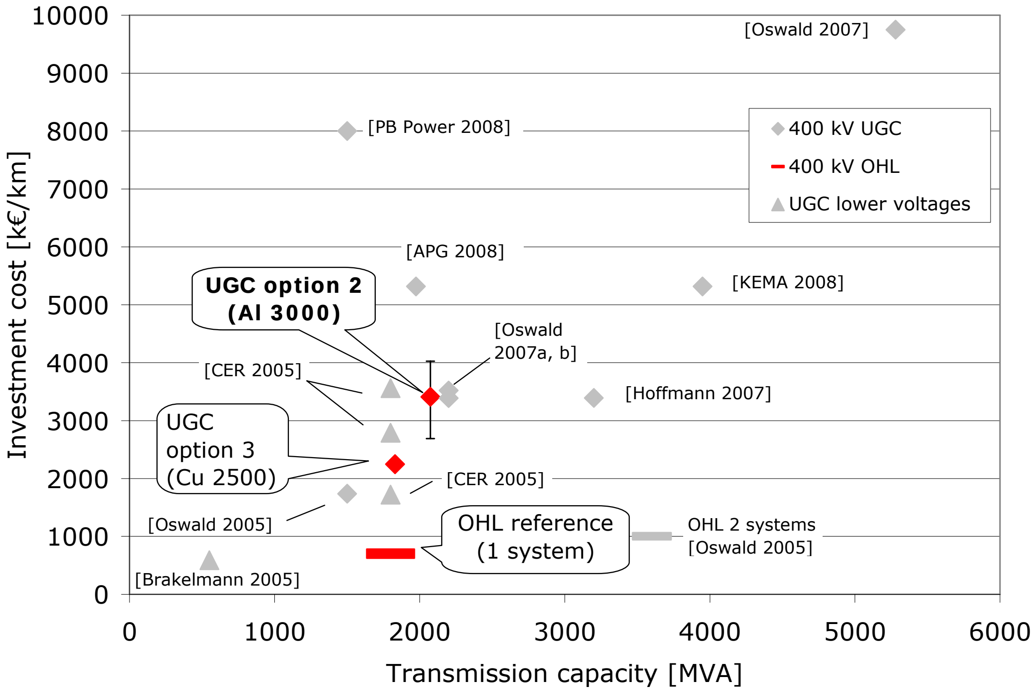

Figure 9-2 specific cost of options 2 and 3 compared to external references (for explanation see also Figure 5-2)

Operational costs

The dominating aspect of the operational costs is associated with the transmission losses. The annual losses depend on a variety of parameters and, hence, their determination is a complex exercise (see Appendix 1 – Losses in AC transmission and Appendix 2 – Losses in DC transmission). Commonly, as a measure for the annual losses the loss factor k_A is applied, defined as the ratio of the average annual losses and the peak losses.

As defined above (paragraph 9.2.2) in the first years the average loading of the transmission connection is assumed to be just 25%...35% of the seasonal ratings of an OHL which is 400 MW to 500 MW (with a daily load factor of $m = 0.85$). This corresponds with a loss factor $k_A = 1.2$, which is low compared to industry praxis. In the future, line loading may increase as a consequence of market developments. A loss factor $k_A = 0.2$ is considered as a base case for the 40 years exploitation period of the line. These load characteristics are valid for all options. The impact of line loading increase (up to $k_A = 0.3$ corresponding to an average loading of >50%) and the respective losses is assessed in the sensitivity analysis.

The O&M costs for UGC are estimated at roughly 500 €/km/a, for an OHL at 2000 €/km. Annual O&M costs for the converter stations are set at 1% of the investment. Comparing options 1 (OHL), 2 (UGC in soil) and 6 (DC) O&M costs play a minor role in the overall balance.

Operational cost may be optimistic in the case of options 3 to 5 with cooling being part of the concept. Energy costs for cooling and dedicated O&M costs for the cooling equipment have been neglected. Given the illustrative character of these options, this simplification seems to be justified but nevertheless interpretation of the results requires care.

External costs as cost of constraints or loss of load resulting from outages or devaluation of property have not been included in the analysis because of the insufficient quality of available quantitative information.

9.3 Analysis and results

Approach

The assumed economic life of all options is set at 40 years and the remaining rest value of the assets after this period is considered being negligible. In practice technical life of OHL may be longer. However, a 40 year depreciation period is a common value in energy economics. Additionally, the net present value of assets beyond this time horizon would have a marginal effect on the overall balance. Even a 40 year period implies significant uncertainties.

The internal rate of return applied to the investment costs is set at 8%. This value is in line with the assumptions applied for transmission investments in the All Island Grid Study [DETINI DCENR 2008].

For the economic evaluation of losses, EirGrid communicated two methodologies with respective values [Corcoran 2008].

One approach is based on the Commission for Energy Regulation's (CER) published "best-new-entrant" price which is intended to cover all costs of a BNE including investment and fixed costs. The most recent BNE price published was the 2007 BNE at € 86.40 per MWh which was published in 2006 for 2007.

As an alternative the system-marginal-price in the market may be used. However the new all-island market has only been operating for 5 months so there is a limited track record of SMP. SMP to date has averaged approximately €70/MWh. This is broadly in line with costs that would have been calculated from production costing programmes, subject to assumptions on fuel price, generator availability, etc. It has to be stressed that this price is an "energy-only" price. In addition a capacity payment is made to all available generation which is approximately €9/MWh.

In the long term the higher price is applied in this analysis. In fact, this value may still be considered as an optimistic assumption.

Decommissioning costs are neglected. Theoretically, they may be relatively low for OHL. However, it is reasonable to assume that at the end of the life of the assets, these are replaced rather than removed and, hence, part of the decommissioning effort may be allocated to future construction cost. Respective cost portions are speculative and the overall amounts are low. This justifies ignoring decommissioning in the comparative analysis.

Table 9-4 summarizes the general assumptions applied in the economic assessment.

Table 9-4: general economic parameters used as reference value in the analysis of life cycle cost

Economic life of all options	40 years
Internal rate of return applied by TAO	8%
Evaluation of losses	86.4 €/MWh
Rest value of assets at end of life	-
Decommissioning costs	-
Loss factor k_A	0.2 (reference, varied to 0.12 and 0.3)
Daily load factor m	0.85

Results

Because of the techno-economic limitations of options 3 to 7 the discussion focuses on the comparison of the reference (OHL) with a double UGC circuit of similar capacity directly in soil (option 2). Illustrative figures for the other options further justifying this selection are provided at the end of this section.

Figure 9-3 shows the investments and operational costs for a 50 km (case 2) OHL and the defined UGC configuration with double UGC circuit with 3000 mm^2 Al conductors directly in soil. The investment ratio between the options is about 5.

OHL losses are highly dependent on line loading. This is much less the case with UGC. In the case of realistic loading (k_A = 0.12 to 0.2), the transmission losses for both options are in the same range. With increasing line loading the difference in life cycle cost including losses and O&M decreases. For realistic line loading the resulting ratio in life cycle cost between UGC and OHL is about 2.3 … 2.9 to 1.

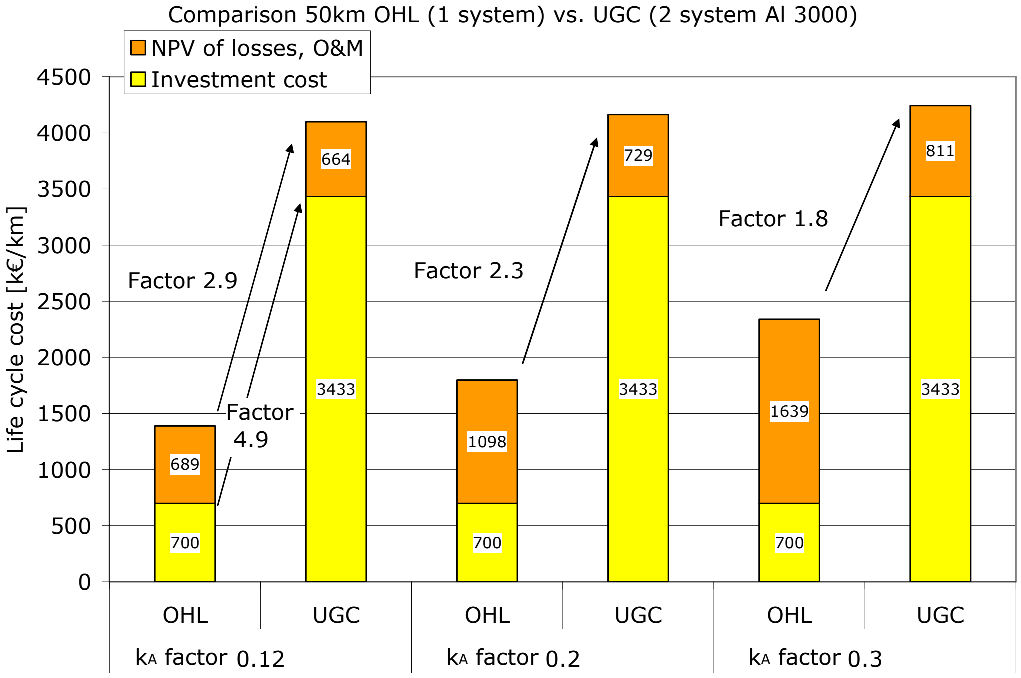

Figure 9-3 comparison of life cycle costs of reference (OHL) with AC UGC option 2 (2 circuits Al 3000 mm^2) for a distance of 50 km and various line loadings (k_A = 0.12 … k_A = 0.3)

As Figure 9-4 illustrates these relations are not sensitive to variations in distance. They hardly change for a distance of 100 km.

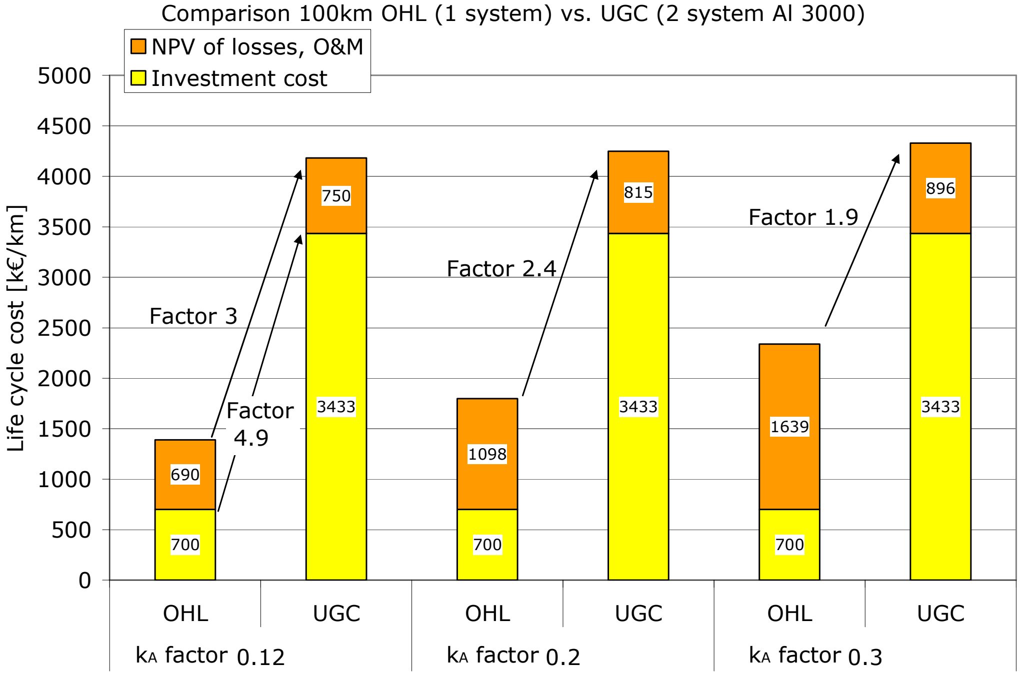

Figure 9-4 comparison of life cycle costs of reference (OHL) with AC UGC option 2 (2 circuits Al 3000 mm2) for a distance of 100 km and various line loadings (k_A = 0.12 … k_A= 0.3)

The net present value of the operating cost is influenced by the interest rate and the assumed price for electric losses. The net present value increases with higher prices for losses and lower interest rates (and vice versa). To assess the sensitivity of variables towards operating costs two cases were examined, representing "extreme" scenarios:

1. lower interest rates (6 %) combined with high energy prices (90 €/MWh)
2. Base case interest rate (8 %) combined with lower energy prices (60 €/MWh)

Scenario 1 leads to an upper bound of discounted operating costs, whereas scenario 2 results in a lower bound.

The lower bound of energy prices was chosen to account for possible future price impacts of renewable generators. The All Island Grid Study showed that expected system marginal costs are expected to be in the order of 60-70 €/MWh (without capacity charges) [DETINI DCENR 2008].

The range of operating costs for the 50km Scenario is depicted in Figure 9-5. The difference between the two alternatives decreases with higher energy prices and lower interest rates. In this case, the cable will benefit from the reduced losses more than in the second scenario. Although the range of operation costs increases considerably, the cost relationship between the two options is more or less stable, as both options are affected similarly by the examined variables.

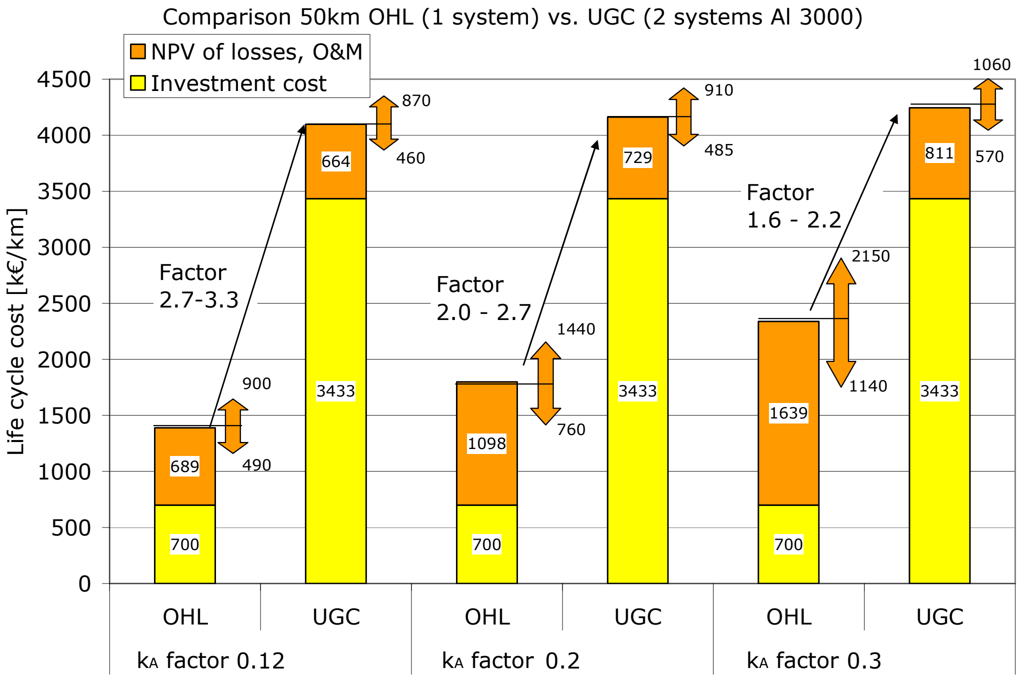

Figure 9-5 sensitivity of life cycle costs to variations in value of electricity losses and interest: high cost low interest 90€/MWh / 6% versus lower cost 60 €/MWh (k_A = 0.12 … k_A = 0.3)

As stressed above, though these figures assume similar technical performance of both options in terms of reliability, they may not be interpreted as a support to this assumption. With this approach O&M costs are assumed to cover the costs of repair and, if applicable, the costs of loss of load. Given the extreme costs associated with respective events, significant differences in performance between the options will have a dramatic impact on the figures provided above. In this perspective the discussion regarding availability and reliability of UGC needs to be reflected (see paragraph 5.1.1).

For illustrative purposes Figure 9-6 shows the annualised costs of all options under the given assumptions. Though the values related to the options with lateral cooling are characterised by high uncertainties, some general conclusions can be drawn:

- The specific life cycle costs of the cooled variants, except the option with single circuit, 2500 mm^2 copper conductor and lateral cooling, do not promise cost reduction potentials with respect to the alternative discussed above (option 2). In contrast, as the uncertainties associated with the assumptions for these variants are substantial, option 2 has to be considered being superior.
- Under the given assumptions the single circuit option 3 (2500 mm^2 copper conductor) is the cheapest alternative to an OHL with an investment ratio of about 3 and annualised cost ratio of about 1.4. However, as discussed above, the underlying assumptions must be considered as optimistic. Additionally, the option is unable to satisfy the requirements of the TSO with respect to operational reliability and hence is no realistic alternative.
- Over distances as considered in these cases, the DC options are highly uneconomical, even ignoring the substantial existing uncertainties in investment costs. Even over a distance of 100 km the VSC DC technology results in the highest life cycle cost. It has to be emphasised that this is not only a consequence of the massive investments required for the power converters but also due to the substantial converter losses. For the economic evaluation it is unimportant whether the transmission is implemented as OHL or UGC.

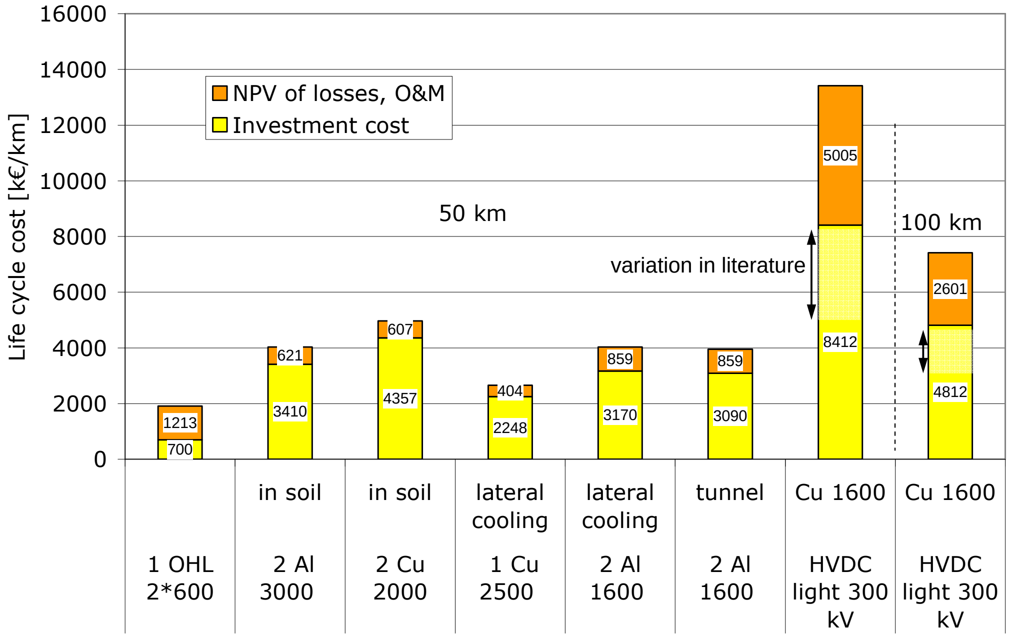

Figure 9-6 illustrative comparison of annualised costs of all options for 50 km distance (DC 100 km too) and loss factor k_A = 0.2

9.4 Case study conclusions

From a techno-economic perspective, option 2 (consisting of double circuit with 3000 mm^2 aluminium conductors in soil) is currently the only option which may be considered as a potential alternative for an OHL. With UGC investment ratios of about 5 compared to OHL and life cycle cost ratios of about 3 the cost implications however are significant.

Assuming a superior performance of UGC concepts in terms of availability, is presently not supported by experience. Hence, including cost of markets constraints or cost of loss of load would shift the balance further in the advantage of OHL. The impact may be substantial [Jacobs Babtie 2005] but insufficient data is available to derive quantitative information.

For specific projects, technical feasibility, design implications and operational behaviour have to be assessed with much more detail than in a generic perspective as drafted here. Relevant aspects include:

- routing in difficult terrain (e.g. peat and wetlands) or protected areas as well as crossings of obstacles (e.g. rivers or infrastructure);
- Transmission system adequacy with in particular:
    - Forced outage rates and their impact on contingency management,
    - operational complexity of the system under normal operational conditions (e.g. load flow control).

The environmental impact of a transmission project depends on the characteristics of the crossed area. The visual impact is clearly more dominant in the case of OHL. UGC may have significant local impact. In sensitive areas this may be prohibitive for UGC and rerouting may be required, directly adding to costs. However, though for different reasons, this also applies to OHL, and conclusions can be drawn only on a project specific basis.

Of course, in case of partial undergrounding, the per km cost as identified below will increase by the termination sites required at each OHL interface. Transition to cables in soil (e.g. directional drilling) will require additional effort in order to maintain the transfer capacity.

10 Conclusions

Technical performance of UGC

- A track record of a variety of successful UGC projects exists for more than ten years. UGC application has been growing rapidly, mainly in cases where implementation of OHL was impossible. However, size and number of existing UGC projects is limited and conditions are comparable to common transmission projects only to a limited extent.

- The track record is insufficient for deriving significant statistical data and generalising experience.

- The expected Forced Outage Rate of UGC is estimated by a variety of sources at least one order of magnitude higher than that of OHL. From a transmission adequacy perspective both technologies do not yet offer the same performance and, hence, are not equivalent.

- The Forced Outage Rate is highly influenced by design. Particular UGC configurations e.g. in accessible tunnels promise a substantial reduction and effective control of risks.

- Before UGC can be integrated in transmission assets at large scale (more than singular projects) a number of more fundamental questions at system level has to be solved.

Economical performance of UGC and OHL

- From a capital cost point of view OHL is the most attractive option. This does not change significantly when operating costs are included to give a whole life cycle analysis.

- The cost estimates for UGC, however, rely on performance assumptions derived from limited experience and provisional information from industry (e.g. technical life and reliability of assets). Hence, the estimates of UGC costs include uncertainties which may further increase the cost difference between UGC and OHL.

- For distances as discussed in Ireland, HVDC does not offer economic advantages in common transmission system projects. Still, the characteristics of the technology may justify application in specific situations.

Environmental Impact

- It is clear from this report that the construction and/or operation of either OHL or UGC will have some impact on the natural and human environment. The degree of impact on individual factors addressed in this report will vary on a case by case basis.

- When making a decision on transmission systems (OHL or UGC), particular consideration should be given to the main environmental issues raised by the public submissions. These are Communities, Land Use and Ecology & Nature Conservation. It is noted that these public submissions are generally related to the perceived adverse impacts of OHL. However, it is clear from the assessed effects of the installation and operation of OHL and UGC addressed in this report that both OHL and UGC impact the environment. The relative impact is a function of the resource in question. Therefore, both proven and perceived impacts should be taken into account when decisions are made on transmission systems.

- The comparison between OHL and UGC is complex, and impacts are often interrelated. Mitigation measures range from where no practical mitigation is possible to where mitigation is likely to avoid discernible impact. The most significant mitigation measures can be taken during the planning and construction phases.

- Exposure to electro magnetic fields (EMF) is different for OHL and UGC. Directly above an UGC field strength may be higher than under an OHL, but the corridor with relevant exposure levels is much narrower. With additional measures it is possible to decrease the magnetic fields related to UGC transmission to negligible levels. With dedicated tower design, exposure to magnetic fields can be reduced also significantly in the case of OHL, though not to such low levels. By nature no electrical fields are created outside a cable, whereas the corridor under an OHL is always characterised by an electrical field.

Policy Implications

- Implementation of OHL and/or UGC requires alignment with existing policies as well as strategic preparation for future national policies. Due to a range of factors, legislation on a global scale is generally becoming more stringent and complex. Policies which were once more locally-driven and isolated are now being transformed to international framework legislation with broad, cross-cutting implications. This shift in the development of policies implies that simply complying with existing policy could be a potential risk as new, interrelated policies emerge.

- From an energy policy perspective, anticipated advantages related to UGC (potential acceleration of planning and permitting) are of temporary nature and, additionally, might materialise to a lesser extent than expected.

- The comparative environmental policy implications of OHL and UGC as they relate to EU and National level framework legislation are generally similar. The difference in the comparison is primarily associated with three distinct stages: project planning, construction and operation.

- There is little difference between the enterprise and employment policy implications when comparing OHL and UGC. Overall, both scenarios are anticipated to have the same type and degree of implications for each policy priority and Irish National Reform Programme (NRP) integrated guideline. None of the policies were determined to be adversely affected by the implementation of either scheme, as long as the performance of the option in terms of security of supply is not compromised.

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Glossary

Alternating current - is an electrical current whose magnitude and direction vary cyclically, as opposed to direct current, whose direction remains constant. The usual waveform of an AC power circuit is a sine wave, as this results in the most efficient transmission of energy. (source: Wikipedia.org) In power transmission three phases are used with a phase angle of 120°. This results in the typical three conductors forming a conventional transmission circuit.

Direct current - is the unidirectional flow of electric charge. Direct current can be created from alternating current by electronic power converters (and vice versa).

Gaeltacht – An Irish language speaking area

Karstic – A term describing an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams, and caverns (www.thefreedictionary.com/Karstic).

Reactive power – electrical power is the complex product of voltage and current and reactive power Q is the imaginary part of this complex product. In contrast to real power P, reactive power does not represent a capability to perform work. Nevertheless is is associated with currents, which in turn cause losses and voltage drop / rise along a line. Depending on the conductor characteristics the distance over which reactive power can be transported is limited. For that reason reactive power has to be balanced along a line by suitable components (reactors, capacitors).

Soakaways - A pit filled with broken stones, or with a perforated lining of steel, concrete or plastic, below ground to take outflow from rainwater pipes, surface water gullies, land drains or small sewage disposal plants. The soakaway permits the outflow to drain away slowly into surrounding permeable ground thus minimising any negative effect on the area. Clearly to be effective, the surrounding soil must not be saturated with water. (http://www.instofasphalt.org/index.php?id=glossary).

Stank(s) – A dam or mound to stop water (http://dictionary.reference.com/browse/stank)

Synchronous control area – a transmission systems whith all generators being synchronised to the same AC frequency. AC interconnection to an adjacent control area again would require synchronuous operation of both systems. In Ireland the control areas of EirGrid and SONI are operated synchronuously.

Wayleave – permission to convey supplies, apparatus, etc. over land, etc. (The Concise Oxford Dictionary of English Etymology 1996, originally published by Oxford University Press 1996).

Abbreviations

AC – alternating current
DC – direct current
CSC – current source converter
EHV – extra high voltage, transmission voltage levels above 300 kV
EMF – electro magnetic fields
HVDC – high voltage direct current
OHL – overhead line
TAO – transmission asset owner
TSO – transmission system operator
UGC – underground cable
VSC – voltage source converter
XLPE – cross linked polyethylene, the insulator of XLPE cables

Appendices

Appendix 1 – Losses in AC transmission

The nominal current of a combination of transmission circuits I_N can be calculated from the nominal apparent power S_N to be transmitted and the nominal voltage U_N.

$$I_{\mathrm{N}} = \frac{S_{\mathrm{N}}}{\sqrt{3} \cdot U_{\mathrm{N}}} \qquad (1)$$

For a 380 kV transmission connection the resulting current for a 1500 MVA capacity is $I_{\mathrm{N}} = 2279$ A. The specific current dependent losses P_{I}' (per km) for n_P parallel transmission circuits at loading with nominal current I_{N} can be calculated as:

$$P_{\mathrm{I}}' = n_{\mathrm{P}} \cdot 3 \cdot R' \cdot \left(\frac{I_{\mathrm{N}}}{n_{\mathrm{P}}} \right)^2 = \frac{1}{n_{\mathrm{P}}} \cdot R' \cdot \left(\frac{S_{\mathrm{N}}}{U_{\mathrm{N}}} \right)^2 \qquad (2)$$

with *R'* being the specific resistance of the conductor arrangement under operational conditions.

The charging current I_{C} of the cable is calculated from the specific capacitance C', the angular frequency ω ($\omega = 2\pi f$; $f = 50$ Hz) and the physical length of the circuits l:

$$I_{\mathrm{C}} = \frac{U_{\mathrm{N}}}{\sqrt{3}} \cdot \omega \cdot C' \cdot l = I_{\mathrm{C}}' \cdot l\,. \qquad (3)$$

The charging current and the associated losses are voltage dependent. In case of OHL specific capacitance *C'* and, hence, charging currents are much lower and in fact without practical relevance for distances up to 100 km. Table 5 provides an overview of typical values for the electrical parameters for 380 kV XLPE UGC and OHL.

Table 5: Typical values for UGC and OHL parameters (source: University of Duisburg-Essen)

Parameter			**2500 Cu**	**2000 Cu**	**3000 Al**	**2500 Al**	**OHL 2*600/65 ACSR CURLEW**
Specific resistance	$\boldsymbol{R'}$	mΩ/km	8.5	10.1	10.9	12.7	29.6
Specific inductance (distance between UGC surfaces $s = 0.3$ m)	$\boldsymbol{L'}$	mH/km	0.46	0.49	0.44	0.46	0.8
Specific reactance	$\boldsymbol{X'}$	mΩ/km	121	128	116	121	251
specific conductivity of the insulation	$\boldsymbol{G'}$	nS/km	68	63	73	68	15
Specific capacitance	$\boldsymbol{C'}$	nF/km	217	201	232	217	14
Specific charging current	$\boldsymbol{I_C'}$	A/km	15.0	13.9	16.0	15.0	1.0
Specific reactive power	$\boldsymbol{Q_C'}$	MVA/km	9.8	9.1	10.5	9.8	0.635
natural load / Surge Impedance Loading (SIL)	$\boldsymbol{S_W}$	MVA	3128	2919	3292	3128	600
Wave impedance	$\boldsymbol{Z_W}$	Ω	46.2	49.5	43.9	46.2	240

Drawing the charging current from the surrounding network is undesirable. For that reason the cable capacitance should be compensated, preferably symmetrically at both ends and, hence, the reactive power of each reactor should be equal to 50% of the reactive power of the cable:

$$Q_C = n_P \cdot U_N^2 \cdot \omega \cdot C' \cdot l = Q'_C \cdot l \,. \tag{4}$$

By combining the parameters in the equation to the specific reactive power Q'_C associated with a specific circuit design, calculation of Q_C for a certain distance is simplified. Together with the active current (2279 A in the example above) the charging current geometrically adds up to the total current I_{total}:

$$I_{total} = \sqrt{I_N^2 + I_C^2} \tag{5}$$

The charging current is highest at both ends of the line and is decreasing towards the middle. Assuming symmetrical compensation, the charging current is $I_C/2$ at the lines terminals and zero half the line. The maximum current (at the cable terminals) has to be within the thermal ratings of the line configuration. Table 6 shows values for the charging current for different length and different configurations.

Table 6: charging current IC/2 and total current I_{total} (and total apparent power S_{total}, respectively) at both ends as well as required compensation capacity Q as function of line length (single 380 kV XLPE cable circuit with 2500 mm2 conductor cross section and single OHL circuit); Nominal transmission capacity is **1500 MVA**, (source: University of Duisburg-Essen)

	1 cable system				1 OHL system			
l	$I_C/2$	I_{total}	S_{total}	Q	$I_C/2$	I_{total}	S_{total}	Q_C
km	A	A	MVA	MVA	A	A	MVA	MVA
1	7.5	2279	1500	0	0.5	2279	1500	0
10	75	2280	1501	98	5	2279	1500	6.3
25	188	2287	1505	246	13	2279	1500	15.9
50	375	2310	1520	492	25	2279	1500	31.8
75	563	2347	1544	738	38	2279	1500	47.6
100	750	2390	1573	984	50	2280	1501	63.5

Another component of the voltage dependent losses are the dielectric losses associated with the insulation, determined by the nominal voltage U_N and the specific conductivity of the insulation *G*’:

$$P'_d = n_P \cdot U_N^2 \cdot G' \tag{6}$$

According to Table 5 above, the value for G’ is about 17 nS/km in case of a 380 kV OHL. For cables the dielectric losses are calculated using the loss angle δ or the dielectric loss factor tan δ, respectively:

$$P'_d = n_P \cdot U_N^2 \cdot \omega \cdot C' \cdot \tan\delta = Q'_C \cdot \tan\delta \tag{7}$$

Assuming symmetrical, complete compensation the charging current creates permanent and voltage dependent losses:

$$P'_C = n_P \cdot \frac{1}{4} \cdot R' \cdot I'^2_C \cdot l^3 = n_P \cdot \frac{1}{12} \cdot Q'_C \cdot R' \cdot \omega C' \cdot l^3 \tag{8}$$

Additionally, there are ohmic losses in the reactors:

$$P_{Comp} = Q_C \cdot k_V \tag{9}$$

A typical value for the loss parameter k_V of the reactors is $k_V = 0.15\%$.

Under nominal load, the total transmission losses add up to:

$$P_{\text{ges}} = P_{\text{I}} + P_{\text{d}} + P_{\text{Comp}} + P_{\text{C}} = \frac{1}{n_{\text{P}}} \cdot R' \cdot \left(\frac{S_{\text{N}}}{U_{\text{N}}} \right)^2 \cdot l + n_{\text{P}} \cdot Q'_{\text{C}} \cdot \left[(\tan\delta + k_{\text{V}}) \cdot l + \frac{R' \cdot \omega C'}{12} \cdot l^3 \right] \tag{10}$$

The first part in the equation P_{I} depends on current and, hence, decreases with the number of circuits. Simultaneously, the other three, voltage dependent parts P_{d}, P_{Comp} and P_{C} increase with the number of circuits. With a typical dielectric loss factor of $\tan\delta \approx 0.001$ the dielectric losses in the cable together with the compensation losses are about 0.0025. These losses are proportional to the route length. The ohmic losses associated with charging currents grow with a power of three of with route length. However, in practice this last part in the equation represented by P_{C} is relevant only for cable lengths > 100 km, as illustrated in the following example of a double circuit 380 kV XLPE UGC:

- 2 systems ($n_{\text{P}} = 2$);
- 380 kV XLPE cable, copper (Milliken-) conductor with 2500 mm^2 conductor cross section ($R' = 8.5$ mΩ/km; $C' = 0.217$ µF/km; $\tan\delta = 0.001$; $k_{\text{V}} = 0.0015$).

In this case the losses for any value of the instantaneous current I are:

$$P_{\text{ges}} = 66.2\ \text{kW} \cdot \frac{l}{\text{km}} \cdot \left(\frac{I}{I_{\text{N}}} \right)^2 + 52.6\ \text{kW} \cdot \frac{l}{\text{km}} + 1.0 \cdot 10^{-3}\ \text{kW} \cdot \left(\frac{l}{\text{km}} \right)^3 \tag{11}$$

Average loss factor k_{A}

For an assessment of average losses (and respective monetary values) the instantaneous losses have to be integrated over time. As a simplified measure the average loss factor k_{A} is defined. He indicates the ratio of the annual average of the current depending losses with respect to their peak value. As the equation above indicates the current dependent losses are proportional to the square of the current. Hence, a value for $k_{\text{A}} = 0.3$ corresponds with an average line loading of about 55%. A value of $k_{\text{A}} = 0.2$, corresponding with an average line loading of about 45% annually is considered being realistic for a 400 kV transmission line. This value is applied as the reference value in the cases studies in the main part of the report. A value for $k_{\text{A}} = 0.12$ corresponds with an average line loading of 35% and, hence, would be appropriate for the expected initial loading of the North South interconnector after implementation.

For an assumed value of $k_{\text{A}} = 0.30$ the average losses for the cable configuration introduced above can be calculated as:

$$P_{\text{ges}} = 19.9\ \text{kW} \cdot \frac{l}{\text{km}} + 52.6\ \text{kW} \cdot \frac{l}{\text{km}} + 1.0 \cdot 10^{-3}\ \text{kW} \cdot \left(\frac{l}{\text{km}} \right)^3 \tag{12}$$

This example illustrates that the voltage dependent losses, in particular the dielectric and compensation losses, are dominating the total losses associated with a double circuit 380 kV XLPE UGC as introduced above.

For a single circuit 380 kV transmission line Table 7 compares the current dependent losses P_I at nominal load (1500 MVA), the voltage dependent losses P_U (for cable inclusive compensation losses) as well as the average of the total losses $\overline{P}$ for an average loss factor of $k_A = 0.3$ for an UGC and OHL, depending on the distance. The UGC is completely compensated, however, at both cable ends only.

Table 7: comparison of losses for a 380 kV **single circuit** UGC (copper conductor, cross section 2500 mm2) and OHL (4*265/35); current dependent losses P_I at nominal load (1500 MVA), voltage dependent losses P_U (in case of UGC incl. compensation) and total average losses $\overline{P}$ for an average loss factor of $k_A = 0.3$, depending on route length (source: University of Duisburg-Essen)

	1 cable system			1 OHL system		
l	P_I	P_U	$\overline{P}$	P_I	P_U	$\overline{P}$
km	kW	kW	kW	kW	kW	kW
1	132	26	66	466	3	142
10	1324	264	661	4663	25	1424
25	3310	658	1651	10908	63	3335
50	6620	1316	3302	21815	125	6670
75	9930	1973	4952	32723	188	8357
100	13240	2631	6603	46630	250	14239

Table 8: comparison of losses as in Table above for **double circuit** UGC and OHL, depending on route length (source: University of Duisburg-Essen)

	2 cable systems (2500 mm^2)			2 OHL systems (4*265/35)		
L	P_I	P_U	$\overline{P}$	P_I	P_U	$\overline{P}$
km	kW	kW	kW	kW	kW	kW
1	66	53	73	218	5	70
10	662	527	726	2181	49	703
25	1655	1331	1827	5453	123	1759
50	3310	2755	3748	10905	245	3517
75	4965	4367	5856	16358	368	5275
100	6620	6260	8246	21810	490	7033

The following key conclusions can be drawn from the figures in the tables:
With the given loading the transmission losses of the single circuit UGC are clearly lower than those of a single circuit OHL, because of the dominating role of the current dependent losses.
However, if two circuits are implemented, current dependent losses are reduced to 25% compared to the single circuit arrangement for both options and the (doubled) voltage dependent losses become dominating. Hence, the overall losses of the OHL are lower.

The figures in Table 7 and Table 8 are illustrated in Figure 7 (single circuit, varying length) and Figure 8 (single and double circuit, 50 km), respectively.

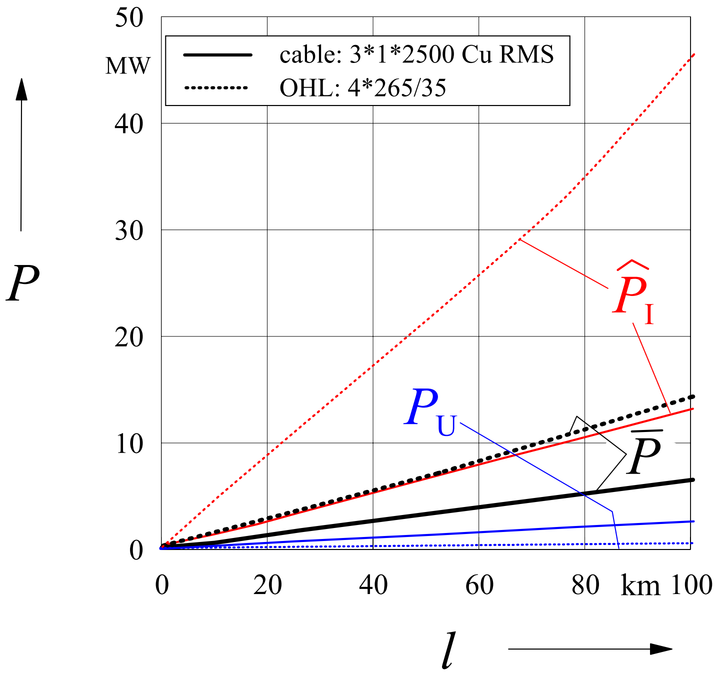

Figure 7 comparison of transmission losses of a 380 kV transmission line, **single circuit**: UGC (XLPE UGC 2500 mm^2, solid lines) versus OHL (2*600/65; dashed lines), depending on length l, peak values of current dependent losses P_I (red), voltage dependent losses P_U (blue, incl. compensation) and annual average of current dependent losses $\overline{P}$ (black) for an average loss factor of k_A = 0.3 (source: University of Duisburg-Essen)

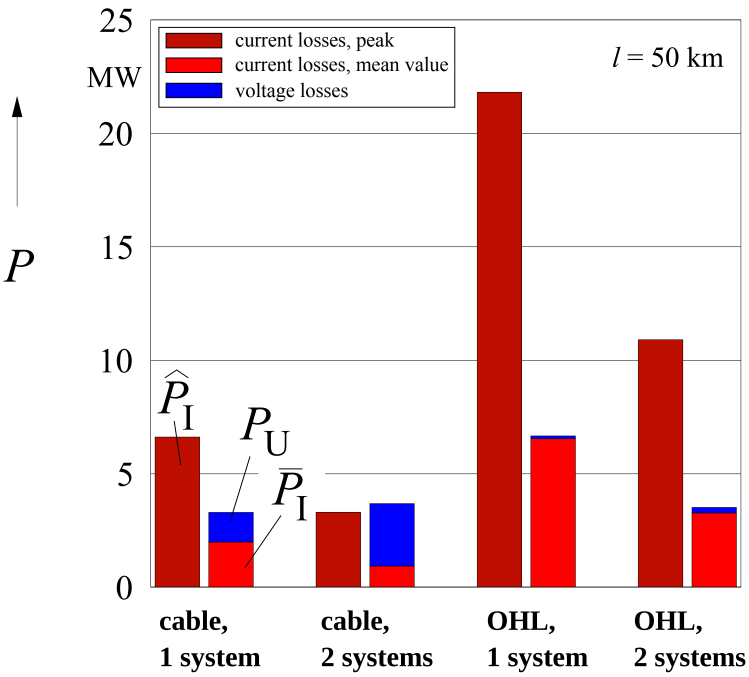

Figure 8 comparison of transmission losses of a 50 km 380 kV transmission line, **single and double circuit**: UGC (XLPE UGC 2500 mm^2, left) versus OHL (2*600/65; right); peak values of current dependent losses P_I (dark red), voltage dependent losses P_U (blue, incl. compensation) and annual average of current dependent losses $\overline{P}$ (light); for an average loss factor of k_A = 0.3 (source: University of Duisburg-Essen)

Appendix 2 – Losses in DC transmission

In case of DC transmission, no reactive power is transported and only the ohmic losses in the conductors apply.
Two systems of 300 kV XLPE cables with copper conductors with a cross section of 1600 mm^2 and 1.1 m clearance distance between the circuits can be buried in a trench of about 2 m width. The combined transmission capacity of such a double circuit system is about 1960 MW (with a daily load factor m = 0.85, see Appendix 3 – Rating of UGC circuits). With a loading of 1500 MW (4*1250 A) the specific losses per cable of about 37 W/m will result in maximum conductor temperatures of 44°C. The cumulated transmission losses for a 50 km line are 3.7 MW, i.e. 0.25%. Compared to the AC technology alternatives this is very low.

However, in case of DC transmission additional converter losses have to be taken into account. Under full load conditions these losses are 1.7 to 2% (per converter) [Cole 2006], [Stendius 2006]. Under low partial load these decrease down to 0.2%.
For a line loading as assumed in the course of this study ($k_A \le 0.2$) the resulting converter losses are estimated at about 1.8%. With these figures the total average losses of a 1500 MW HVDC VSC configuration depending on distance and peak load can be calculated as

.

$$p = 1.8\,\% + 0.25\,\% \cdot k_A \cdot \frac{l}{50\text{ km}} \cdot \left(\frac{S_\text{N}}{1500\text{ MVA}} \right)^2$$

The first number in the equation represents the average converter losses, the second part indicates the average cable losses as function of length and loading.

For transmission distances up to 100 km the total losses are dominated by the converter losses. For that reason the transmission technology choice (OHL or UGC) is without relevant impact on the operational losses. Similarly, this applies to the operational costs of this technology – these are dominated by the converter losses too.

For current source converters identical considerations apply with a very similar outcome.

Appendix 3 – Rating of UGC circuits

Maximum conductor temperature is a major design parameter for UGC rating. Hence, heat transfer characteristics of soil influence the achievable UGC capacity. But because of the thermal inertia of soil, also load profiles and transient phenomena are of importance.

The methodology applied below for calculation of losses and thermal behaviour of cable components is in line with internationally acknowledged IEC publications [IEC60287 1995], [IEC 60853 1989] and [Heinhold 1987], [Brakelmann 1985], [Brakelmann 1989], [Anders 1997]. A dedicated software tool was used (KATRAS) for analysis of stationary and transient temperature fields as well as a powerful software applying a finite element method (FEM) [Stammen 2001].

Compliant with internationally agreed assumptions, the following parameters are applied to the thermal characteristics of soil:

- Specific heat transfer rate of moist soil: 1.0 K m/W,
- Specific heat transfer rate of dry soil: 2.5 K m/W,
- Characteristic temperature increase for drying of soil: 15 K and
- ambient soil temperature at cable level 15°C.

In case the cables are surrounded with thermally stabilised material (concrete / sand blends) the specific heat transfer rate is assumed being 1.0 K m/W

Daily load factor *m*

In opposite to OHL, with their thermal inertia being negligible, temperature of UGC in soil responds to load steps with a delay of hours, with a change to a new stationary equilibrium taking weeks. For that reason, the thermal capacity of UGC under fluctuating load conditions is higher than their stationary limits (see also paragraph 4.2.2). The exact value of the achievable thermal capacity, being the key parameter for cable rating, depends on the characteristics of the load profile.

As a simplified measure characterizing the load profile, the 'daily load factor' m is applied. By definition, the daily load factor m is the area under a typical daily load curve normalized with permanent full load. Hence, stationary full load (continuous load) corresponds with $m = 1.0$. In distribution networks typical load curves correspond wit values for $m = 0.7$ („utility load“) [VWEW 2001]. Also for 380 kV transmission lines regularly a value of $m = 0.7$ has been applied [Oswald 2007], [Oswald et al 2005], [Hoffmann et al 2007].

Table 9 provides an overview of the transmission capacity of various UGC arrangements. Trefoil as well as flat arrangements are considered. For the latter typical dimensions for a single circuit arrangement and parameters used are illustrated in Figure 9.

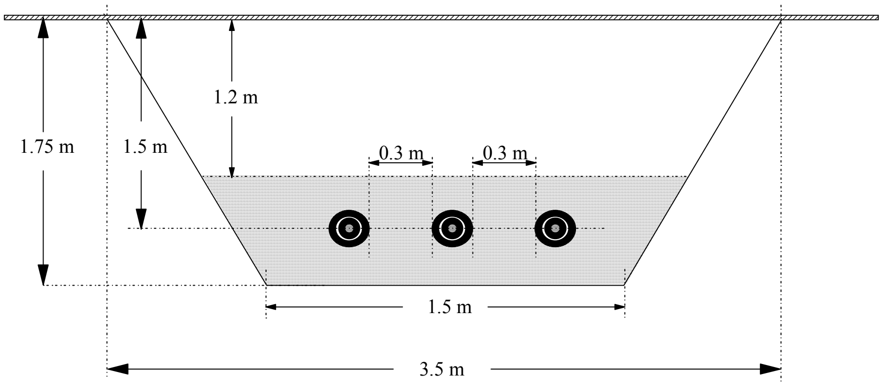

Figure 9 typical cable trench for single circuit UGC in flat arrangement with indicated distances

Table 9 covers one to three systems and various conductor types with the daily load factor *m* as parameter (ranging from 0.7 to 1.0). In all cases the UGC circuits are assumed to be implemented in a thermically stabilised layer (about 0.2 m below to 0.25 m above the cables).

Table 9: Transmission capacity S in MVA of 380 kV XLPE cable configurations in soil; 1, 2 or 3 systems with clear distance between cable surfaces Δs and 1.0 m clear distance between adjacent circuits, thermically stabilised trench, laying depths h = 1,5 m; varying parameter: daily load factor *m* (source: University of Duisburg-Essen)

			2500 Cu RMS			**3000 Al RMS**			**1600 Al RMS**		
	n_S	***B***	**0.7**	**0.85**	**1.0**	**0.7**	**0.85**	**1.0**	**0.7**	**0.85**	**1.0**
arrangement		m	MVA	MVA	MVA	MVA	MVA	MVA	MVA	MVA	MVA
trefoil	1	1,0	1320	1156	982	1175	1028	875	830	730	624
$\Delta s = 0$ m	2	2,0	2290	1830	1672	2032	1635	1480	1415	1235	1040
	3	3,3	2940	2450	2115	2610	2190	1860	1965	1655	1425
flat	1	1,5	1496	1331	1123	1339	1180	1004	934	834	717
$\Delta s = 0.3$ m	2	2,6	2716	2340	2012	2406	2074	1778	1698	1480	1260
	3	5,2	3750	3240	2760	3315	2850	2430	2370	2040	1740
flat	1	1,7	1558	1382	1183	1390	1226	1048	968	864	745
$\Delta s = 0.5$ m	2	3,8	2850	2475	2122	2506	2190	1876	1770	1556	1330
	3	6,5	3900	3480	2955	3555	3060	2610	2520	2180	1860
flat	1	2,5	1670	1485	1286	1489	1318	1140	1024	925	802
$\Delta s = 1.0$ m	2	5,8	3078	2702	2330	2732	2395	2062	1906	1690	1453
	3	9,5	4470	3900	3315	3975	3480	3000	2800	2445	2115

Figure 10 shows the results for 380 kV XLPE UGCE configurations. The graph indicates the transmission capacity for 2500 mm^2 copper and 3000 mm^2 aluminium Milliken conductors. The cables are laid in trefoil or in flat arrangement with varying distance Δ*s*. Figure 11 shows the same in a similar way, also including aluminium cables with a conductor cross section of 1600 mm^2, which may be of particular interest in case of two or more parallel circuits.

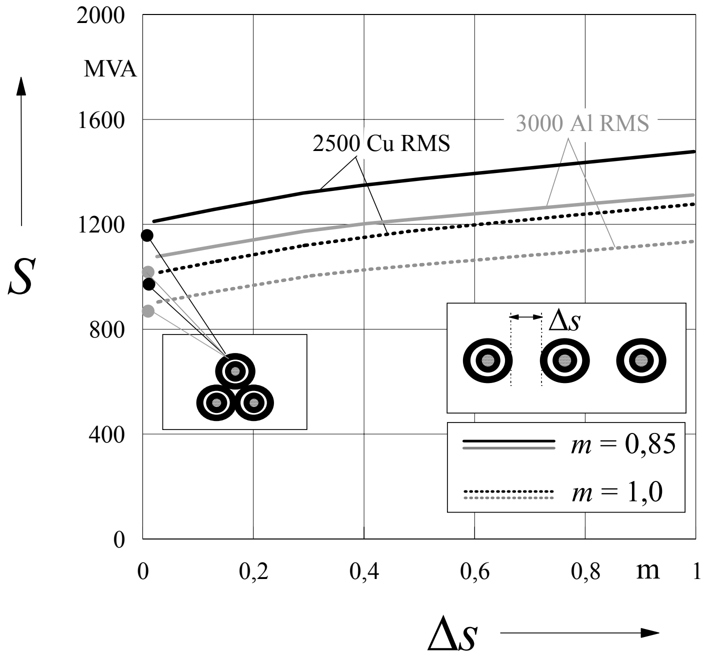

Figure 10 Transmission capacity of naturally cooled 380 kV XLPE cables (**single system**) directly in soil with thermal stabilization and copper (black) and aluminium- (gray) Milliken conductors depending on cable distance Δs; *h* = 1,5 m; parameter: daily load factor *m* (source: University of Duisburg-Essen)

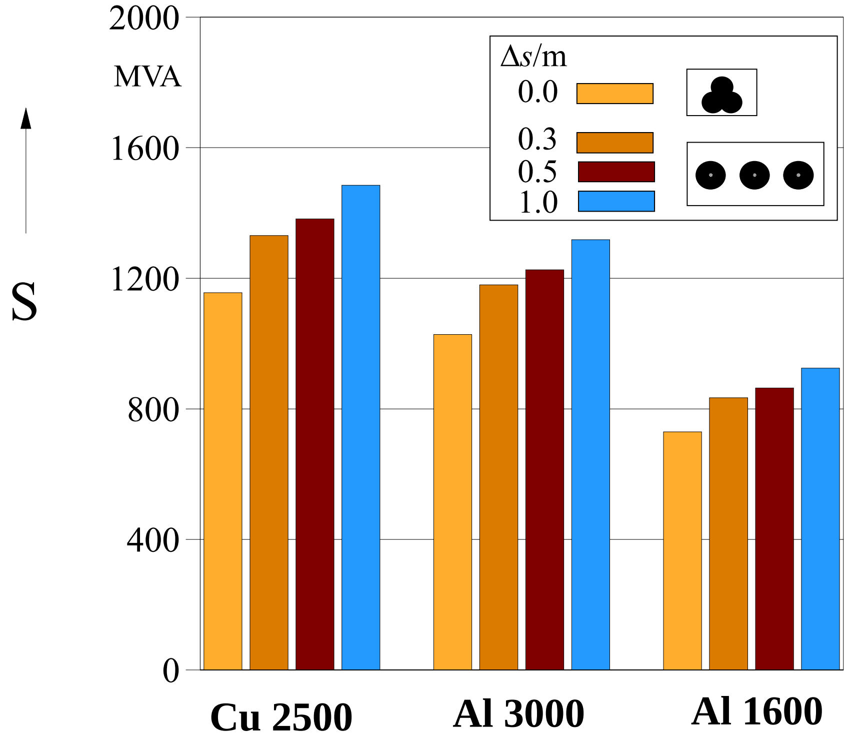

Figure 11 Transmission capacity of naturally cooled 380 kV XLPE cables (**single system**) directly in soil with thermal stabilization and copper and aluminium Milliken conductors; *h* = 1,5 m; daily load factor *m* = 0.85; parameter: cable distance Δs (source: University of Duisburg-Essen)

In double circuit arrangements the capacities indicated in Figure 10 and Figure 11 represent the secured capacities with one circuit being unavailable. However, none of the single circuit UGC arrangements presented here provides a transmission capacity being equivalent of a single OHL circuit (about 1700 MVA).

The same relations are shown in Figure 12 and Figure 13 for double circuit UGC configurations. Figure 12 illustrates that two UGC systems using 2500 mm2 copper Milliken conductors, laid in trefoil with a circuit distance of 1 m are capable to transport more than 1800 MVA. The magnetic fields caused by such an arrangement are very low, even very close to the cable route.

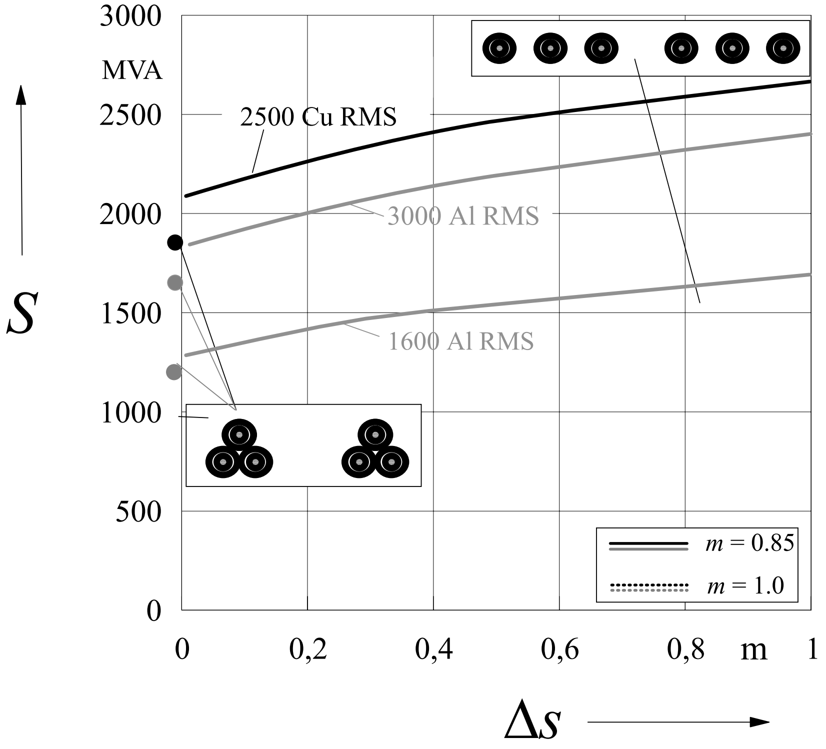

Figure 12 Transmission capacity of naturally cooled 380 kV XLPE cables (**double system**) directly in soil with thermal stabilization and copper (black) and aluminium- (gray) Milliken conductors depending on cable distance Δs; h = 1,5 m; parameter: daily load factor *m* (source: University of Duisburg-Essen)

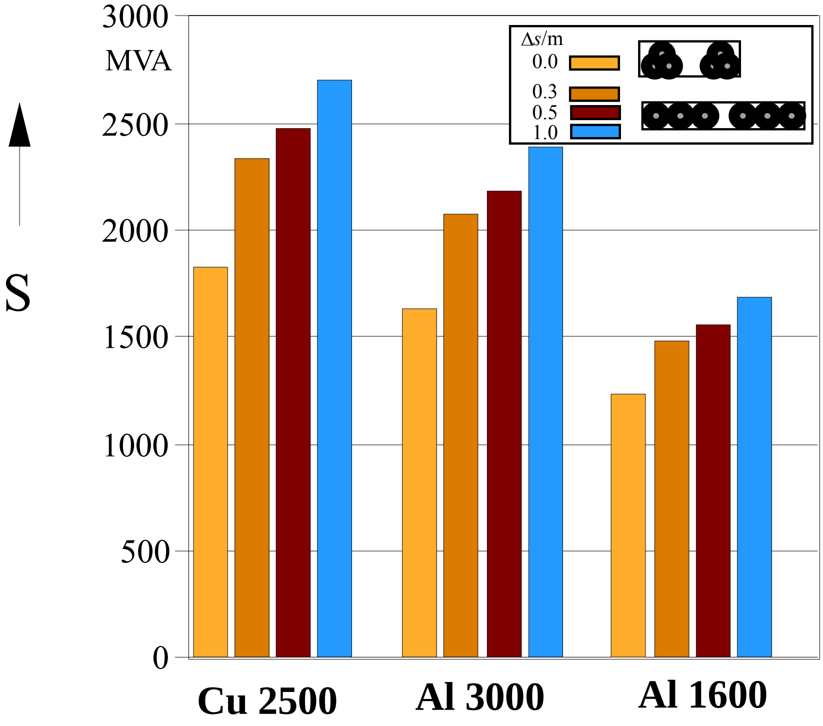

Figure 13 Transmission capacity of naturally cooled 380 kV XLPE cables (**double system**) directly in soil with thermal stabilization and copper and aluminium Milliken conductors; h = 1,5 m; daily load factor m = 0.85; parameter: cable distance Δs (source: University of Duisburg-Essen)

Implementing two UGC circuits using 3000 mm^2 aluminium Milliken conductors with a clearance between cable surfaces of Δs = 0.3 m and a distance between the edges of the two circuits of 1.0 m is a transmission capacity of more than 2000 MVA is achieved. With 1600 mm^2 aluminium-conductors transmission capacities larger than 1700 MW cannot be achieved with a double circuit UGC. At least three circuits are required for these capacity levels.

Transmission capacities of double circuit UGC arrangements as shown in Figure 12 and Figure 13 above represent the secured capacities of three circuits UGC with one circuit being unavailable.

Table 10 summarises key indicators including trench width for selected UGC configurations of with transmission capacity being at least 1800 MVA, directly in soil. The table also lists the remaining secured n-1 and n-2 contingency capacities in case one or two circuits of the UGC are lost.

Table 10: Three UGC configurations with transmission capacity of at least 1800 MVA with differing conductor types, number of systems n_S, conductor arrangement; clear distance between conductor surfaces Δs, trench width at UGC level B, resulting nominal transmission capacity and remaining secured capacity in case of (n-1)- and (n-2)-contingencies affecting the UGC (source: University of Duisburg-Essen)

380 kV XLPE UGC, Conductor type	Number of systems n_S	Conductor arrangement	Δs	B	rating	(n-1)-rating	(n-2)-rating
			m	m	MVA	MVA	MVA
Cu 2500 RMS	2	Trefoil	0	2.0	1830	1156	0
Al 3000 RMS	2	Flat	0.3	3.4	2074	1180	0
Al 1600 RE	3	Flat	0.3	5.5	2040	1480	834

Appendix 4 - Extended AC UGC configurations

A variety of UGC configurations exist with the cables not simply buried in soil. Those configurations and their potential advantages are discussed more in detail in this appendix. The adequacy of the configurations for long distance transmission may be questionable. Still, they may offer benefits for UGC projects of limited extension or partial undergrounding of extended transmission lines.

UGC in soil with lateral cooling

Forced cooling of UGC circuits increases the achievable transmission capacity of a certain arrangement. The cooling is provided by plastic pipes which are buried together with the cables and are supplied by cooled water.

Forced cooling is not a preferable option for achieving the design capacity. The forced outage rate of cooling equipment is much higher than that of UGC. This effect becomes even more prominent if a number of cooling units is required along a UGC route and unavailability of any unit creates a bottleneck.

UGC rating, however, may rely on cooling only in case of a contingency. This increases termporary overloading capabilities and, hence, creates time for repair without compromising the performance of the transmission system.

Additionally, forced cooling provides further flexibility in operation. Cable and soil temperature can be decreased. The proportional decrease of losses (partially) offsets the energy demand of the cooling equipment. The lower temperatures reduce cable ageing. As drying out of soil can be prevented thermal stabilisation may even be obsolete.

Forced cooling allows compact UGC arrangements. Figure 14 to Figure 16 show examples of narrow trenches combined with high transmission capacity.

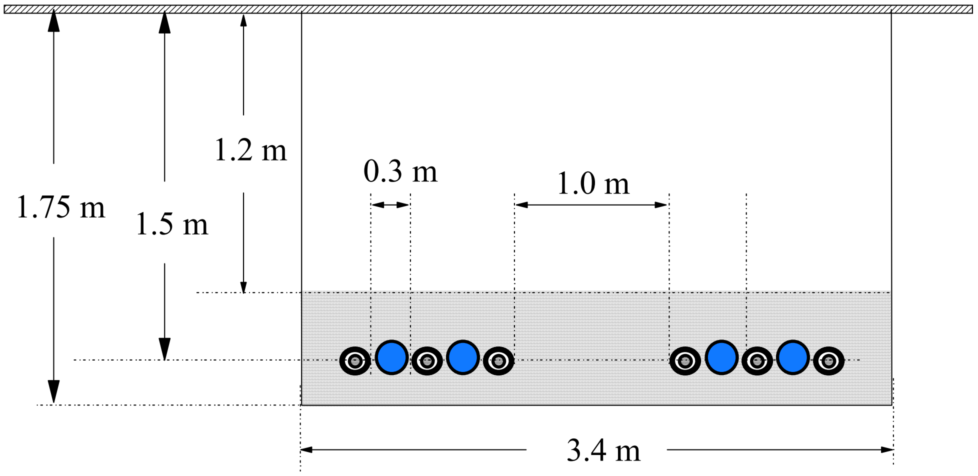

Figure 14 double UGC circuit in flat arrangement with lateral cooling (two cooling pipes between cables)

A trefoil arrangement of the cables allows the most compact trench design. The total width is just 2.2 m (see Figure 67).

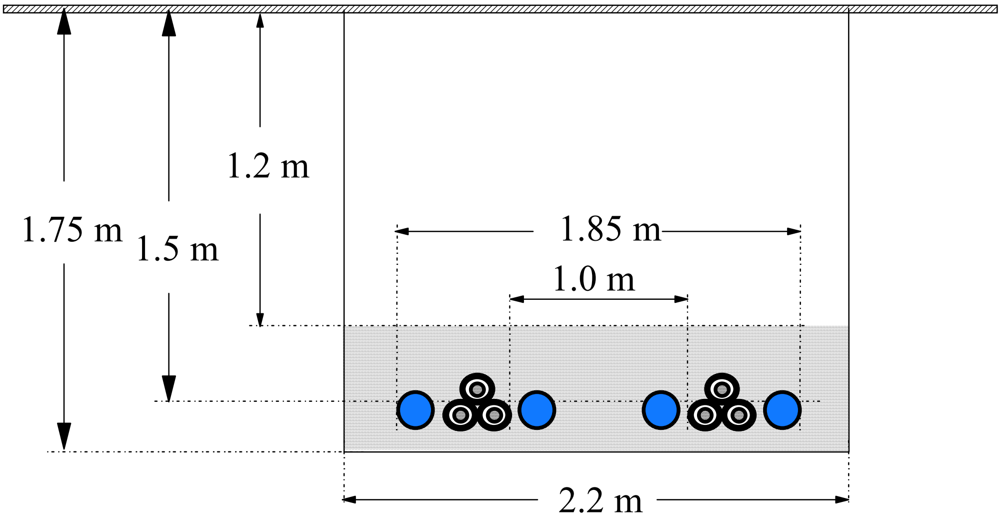

Figure 67 double UGC circuit in trefoil arrangement with lateral cooling (cooling pipes adjacent to cables)

For very high transmission capacities but also for redundancy of the cooling circuits four cooling pipes per UGC circuit can be implemented (see Figure 16). In this case the total required trench width is 4.1 m.

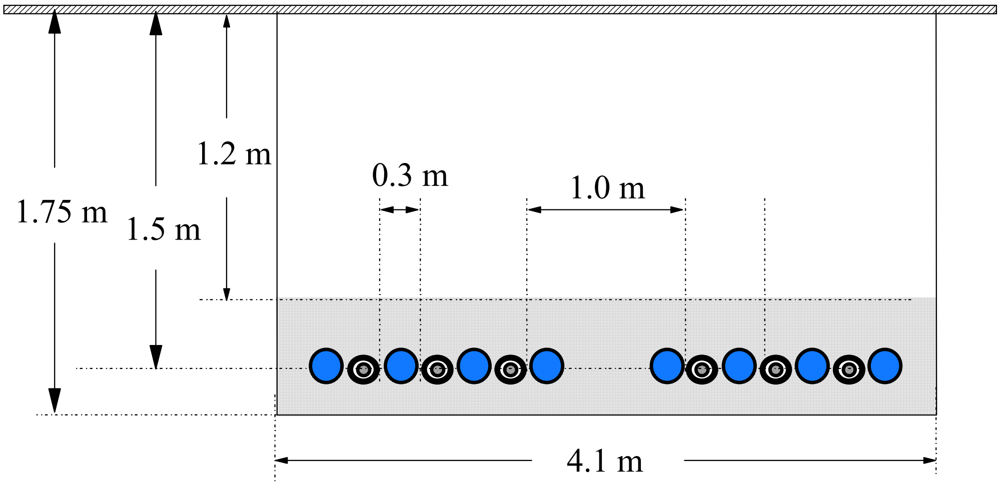

Figure 16 double UGC circuit in flat arrangement with lateral cooling (four cooling pipes between cables)

An alternative arrangement of cables and cooling pipes – a so called „U-arrangement“ has been implemented in the 380 kV UGC in Vienna. In this example the cables are in a flat arrangement. Between the cables and above the outer cables the four cooling pipes have been buried.

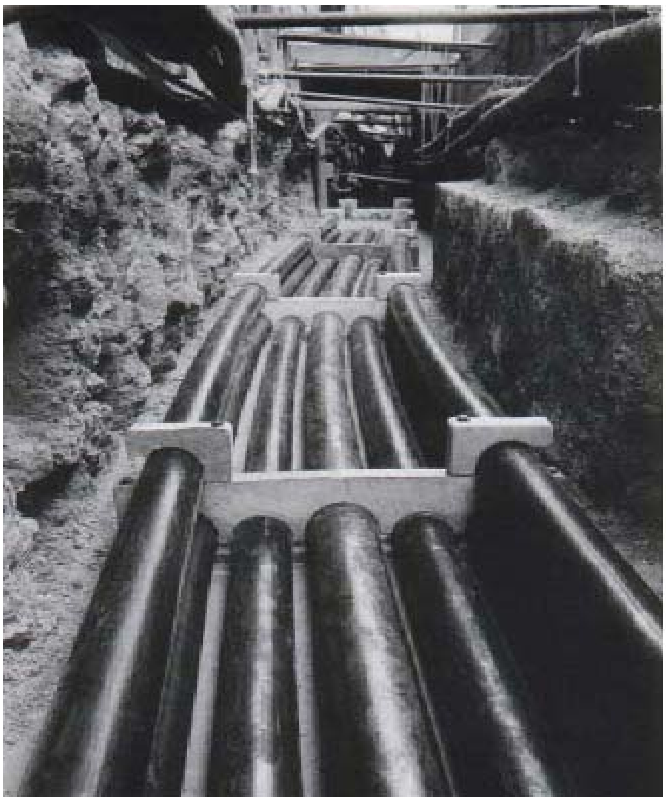

Figure 69 Laterally cooled UGC in Vienna with four cooling pipes (two between cables and two above outer cables)

Cooling equipment

Figure 70 shows the composition of a typical cooling unit, with compressor, heat exchanger and control unit. Figure 71 shows the dimensions of such a unit with a cooling capacity of about 1.4 MW_{th}. A unit of this size is appropriate for a 380 kV UGC with 10 km to 15 km cooling distance (length of cooling circuit 20 km to 30 km). The corresponding distance between sites for the cooling equipment can be 20 km to 30 km with cooling circuits leaving in both directions. Cooling equipment and compensation may be combined at one site.

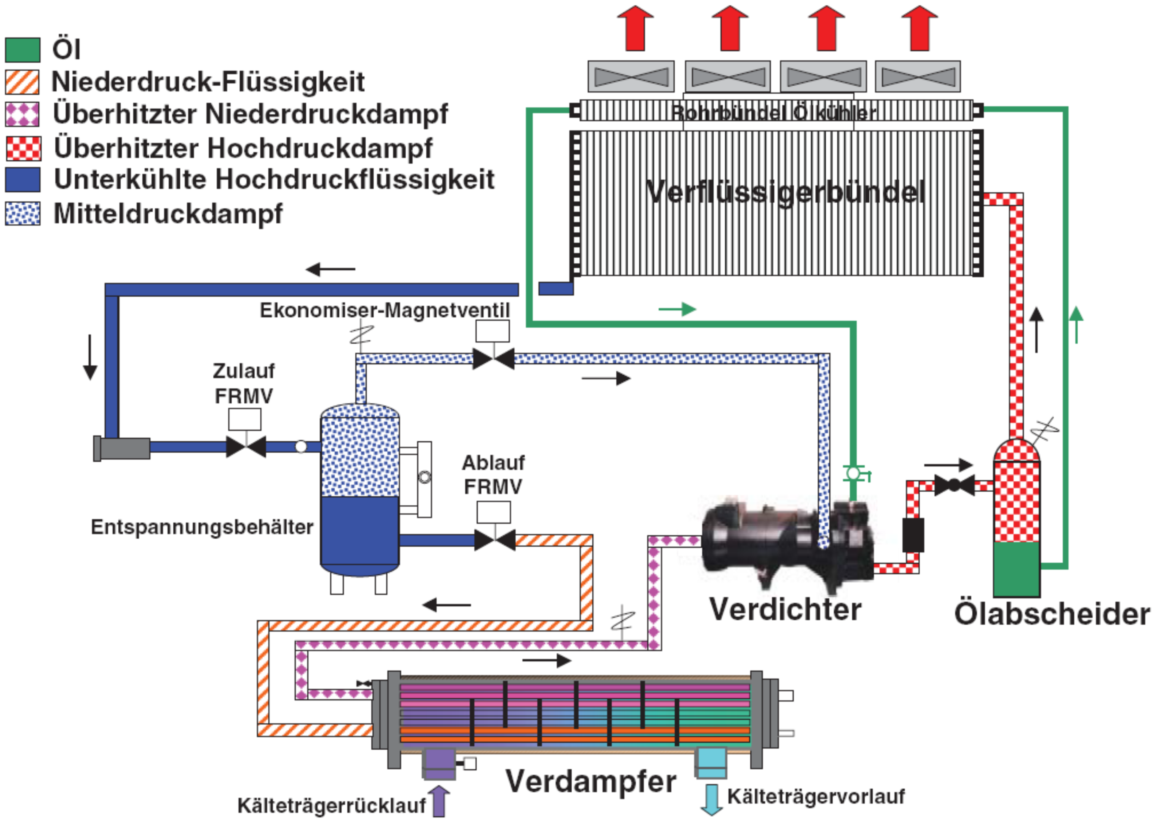

Figure 70 Components of cooling unit (source York)

Figure 71 1.4 MW cooling unit with dimensions (source: York)

Figure 72 shows a possible arrangement of the cooling units, with one extra unit for redundancy. For minimization of the visual impact the units can be installed in holes and surrounded with appropriate vegetation, similarly to existing OHL / UGC transition sites.

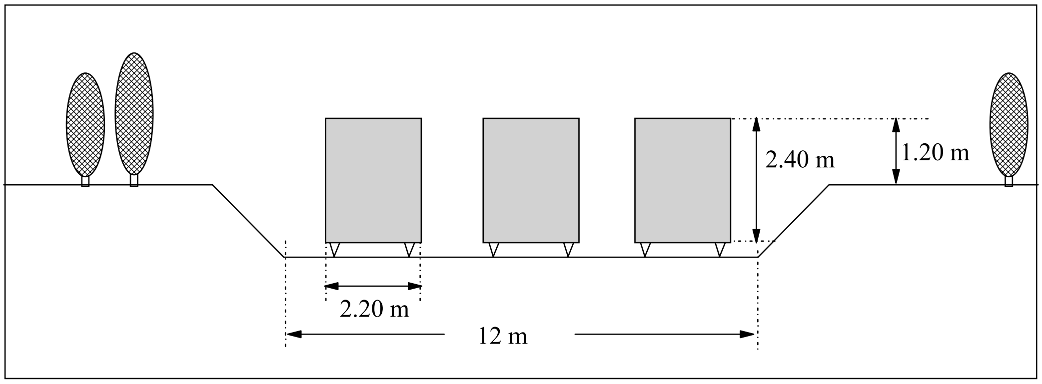

Figure 72 Three cooling units according to Figure 71 (one unit for redundancy) in a hole; required dimensions about 12 m by 10 m

Investments for cooling equipment

Costs for a 1.4 MW cooling unit as shown in Figure 71 are about € 200.000. With a cooling range of 10 km and one extra unit per 20 km for redundancy and a replacement of the units after 20 years the specific investments amount about € 36 per m. Assuming four cooling pipes with specific costs of € 30 per meter (including auxiliaries and laying) the total specific cost are about € 160 per meter.

Operational costs for the cooling circuit

Operational costs for the cooling equipment consist of costs for maintenance and energy costs for the coolers. Annual maintenance costs are estimated at about 1% of the investment related to the cooling units, i.e € 300 per km per year. They are of minor importance for the overall balance.

The energy requirements for the cooling units highly depend on the operational regime. With ambient temperature being ≤ 5°C ‚free-cooling’ is possible with only the blowers running. Additionally, part of the cooling demand is offset by a reduction of UGC losses (decrease of 20 K corresponds with loss reduction of 8%).

Availability of the cooling equipment

[Jacobs Babtie 2005] emphasises the substantially lower availability of cooling equipment compared to UGC and concludes that dependence on cooling for that reason is avoided. This argument is appropriate, in cases where UGC rating requires cooling under normal operational conditions (and under nominal loading).

Different considerations apply when the UGC does not require cooling under normal operational conditions and cooling is activated only in the rare case of a contingency. (Still the cooling capability may be used for reduction of losses and avoidance of the soil drying out.) Availability can be increased further by implementation of redundant configurations as described above.

Even in case a contingency occurs during maintenance of the cooling devices the thermal inertia of UGC in the range of hours or days allows corrective measures before the transfer capacity is affected (see paragraph 4.2.2).

Transmission capacity of UGC configurations with lateral cooling

Table 11 lists stationary transmission capacities of various configurations with two cooling pipes per UGC circuit. For selected configurations these figures are further illustrated in Figure 73.

In the overviews a daily load factor of $m = 0.85$ is assumed together with a 20°C inlet temperature of the cooling water. The reach of one cooling circuit is assumed being 10 km, i.e. a circuit length of 20 km. This allows installation of cooling units at distances of 20 km (circuits leaving in both directions). A maximum water pressure of 10 bar allows a velocity of the water of about 1 m/s.

The described configuration allows implementing or using a variety of redundancies (four pipes per circuit, additional cooling units, lower water inlet temperature, etc.).

Table 11 Transmission capacity S (in MVA) of 380 kV UGC configurations with lateral cooling (capacity without cooing in brackets), parameters: daily load factor $m = 0.85$, cooling water inlet temperature $\Theta_{inlet} = 20°C$, cooling circuit length $l = 20$ km, number of cooling pipes per UGC circuit $n_s = 2$ (source: University of Duisburg Essen)

$m = 0.85$		Cu 2500 RMS	Al 3000 RMS	Al 1600 RE
	B	*S*	*S*	*S*
2 pipes	M	MVA	MVA	MVA
1 system (without cooling)	1.5	1835 (1331)	1645 (1180)	1115 (834)
2 systems	3.4	3185 (2349)	2862 (2074)	1940 (1480)
3 systems	6.5	4750	4277	2899

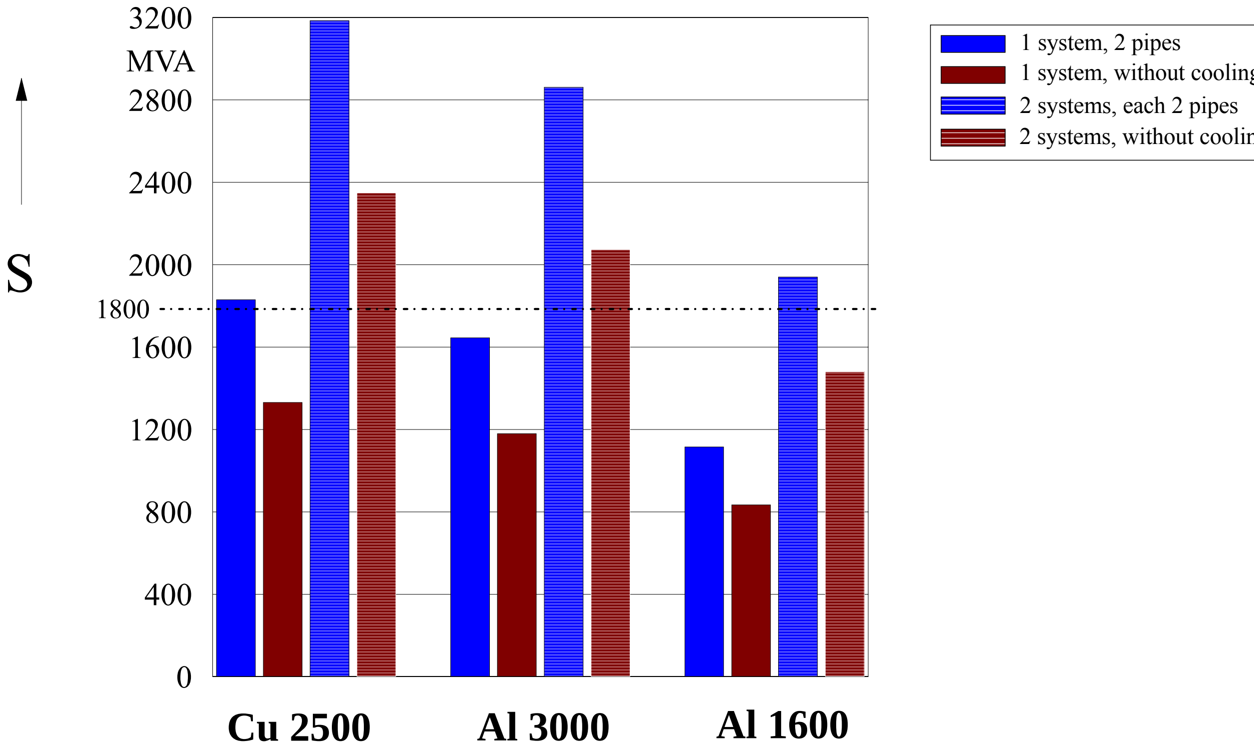

Figure 73 Transmission capacity S (in MVA) of 380 kV UGC configurations with and without lateral cooling, parameters as in Table 11 (source: University of Duisburg Essen)

For a design transmission capacity of 1800 MVA possible 380 kV UGC configurations with lateral cooling are listed in Table 12. The table also specifies the tench width and the remaining stationary transmission capacity without cooling.

Table 12 Two possible UGC configurations with transmission capacity of at least 1800 MVA with differing conductor types, number of systems n_S, conductor arrangement; clear distance between conductor surfaces Δs, trench width at UGC level B, resulting nominal transmission capacity; remaining secured capacity in case of (n-1) contingency as well as loss of the cooling circuit (source: University of Duisburg-Essen)

380 kV XLPE UGC with conductor	Number of electrical circuits n_S	Conductor arrangement	Δs	B	rating	(n-1) rating with cooling	Rating without cooling
			M	m	MVA	MVA	MVA
Cu 2500 RMS	1	flat	0.3	1.5	1835	0	1331
Al 1600 RE	2	flat	0.3	3.4	1940	1115	1480

According to the table, a 380 kV UGC using 2500 mm^2 copper Milliken conductors offers a stationary transmission capacity of more than 1330 MVA even after loss of cooling. Secured remaining capacity in case of a n-1 contingency of the UGC circuit is zero.

A double circuit UGC using 1600 mm^2 aluminium conductors offers a secured capacity of 1100 MVA in case of an n-1 contingency of the cable circuit. With cooling lost the stationary transmission capacity of the two circuits is still nearly 1500 MVA.

Further optimisation of the configurations is possible.

UGC in accessible tunnels

UGC installation in accessible tunnels offers a number of important advantages:

- High level of mechanical protection;
- Ease of installation;
- Extendability, retrofitting of UGC and or cooling circuits;
- Quick identification and location of faults by visual inspection, resulting in high availibility (short mean time to repair)
- Repair possible without earth works and, hence, negligible environmental impact;
- Possible combination with other infrastructure (electricity distribution, water, communication) increasing cost effectiveness;
- Low extra costs for additional conductors (increase of short circuit capability, reduction of external magnetic fields, etc.);
- Simple temperature monitoring and thermal management;
- Simple cooling of UGC circuits by natural or forced convection, or even water cooling;
- Possibility of selective cooling (e.g. cable joints only);
- Negligible heating of surrounding soil;
- Very narrow trench in case of multiple circuits, etc.

The Barajas UGC represents a recent example of an accessible tunnel built in an open trench (see Figure 74).

Figure 74 Impression of construction and final status of the UGC tunnel at Barajas airport (Madrid)

Up to now, the major barrier for extended application of UGC tunnels was the high cost level. There are, however, developments which promise a substantial cost reduction.

[Hoffmann 2007] proposes an accessible tunnel for two UGC circuits built with prefabricated, fiber reinforced plastic segments (3 m length). In this case trench depth is depth is at least 4 m and minimum width 3 m.
In the reference specific costs of the tunnel are estimated at about € 690 per meter, including all earth works, access, crossings etc. plus € 180 per meter for accessories (cable clamps etc.). Additionally, for forced convection of the tunnel € 150 per meter is assumed.

Another innovative process uses special, slowly moving machines creating a concrete tunnel in a continuous process in an open trench (see Figure 75). Per machine construction progress of 15 m per day is feasible. The resulting tunnel has an open cross section of 1.8 m by 2.1 m (or more if desired). Figure 75 indicates that, in principle, such a cross section allows installation of up to three UGC circuits (or combinations of UGC with other infrastructure). Because of the arched roof no steel reinforcement is required which eliminates the usual life time restriction of steel reinforced concrete tunnel (50 to 60 years).

The technology provider communicates total construction costs of € 600 per meter, including openings for access and ventilation and all earth works. The costs for a dedicated UGC support structure in the tunnel are indicated by the technology provider at about € 50 per meter and circuit.

Figure 75 Infrastructure tunnel, system Dupré, Speyer; above: construction works, below left: installation of equipment in the tunnel, below right: schematic drawing of tunnel cross section with three UGC circuits

Taking into account that UGC tunnels offer a variety of advantages compared to UGC directly buried in soil, the extra costs as indicated by the references are reasonable. Under which conditions the cost estimates are realistic and which parameters are potential cost drivers requires further investigation.

Forced convection – investments and operational losses

[Hoffmann, 2007] estimates costs for convection (5 km maximum distance between blowers, air velocity 4 m per second i.e. flow approximately 22 m^3 per second) at about € 150 per meter. Maintenance costs estimated at 1% of the investment (i.e. about € 2 per meter per year) are of minor importance for the overall cost figure.
As with lateral cooling in soil, the energy consumption for the blowers is partly compensated by a loss reduction in the cables.

Transmission capacity of UGC configurations in tunnel with forced convection

Indicates cable ratings of 380 kV UGC configurations in an accessible tunnel. The figures assume forced convection with a velocity of 3 to 4 m/s (i.e. 11 to 15 m^3/s) and a length of the cooling sections (distance between blowers) of l = 5 km resulting in maximum exit air temperatures of 30°C (winter) and 40°C (summer).

Table 13: transmission capacity S in MVA of single and double UGC configurations (380 kV) in tunnel with forced convections, parameter maximum air temperature Θ (source: University of Duisburg Essen)

	number of electrical circuits	**2500 Cu RMS**	**3000 Al RMS**	**1600 Al RE**
Θ (exit air)		S	S	S
°C		MVA	MVA	MVA
30 (winter rating)	**n_S = 1**	1865	1697	1117
40 (summer rating)		1706	1552	1022
30 (winter rating)	**n_S = 2**	3357	3055	2011
40 (summer rating)		3071	2794	1840

Because the cables in the tunnel are installed in air thermal interia is clearly lower than in soil. For that reason the daily load factor m is irrelevant for UGC in tunnels. On the other hand, the circuits are thermally highly decoupled and, consequently, the transmission capacity of a double circuit system is apparently twice that of a single circuit system. Of course, because of the higher heat load, the air flow has to be increased proportionally. Figure 76 to Figure 78 further illustrate these figures.

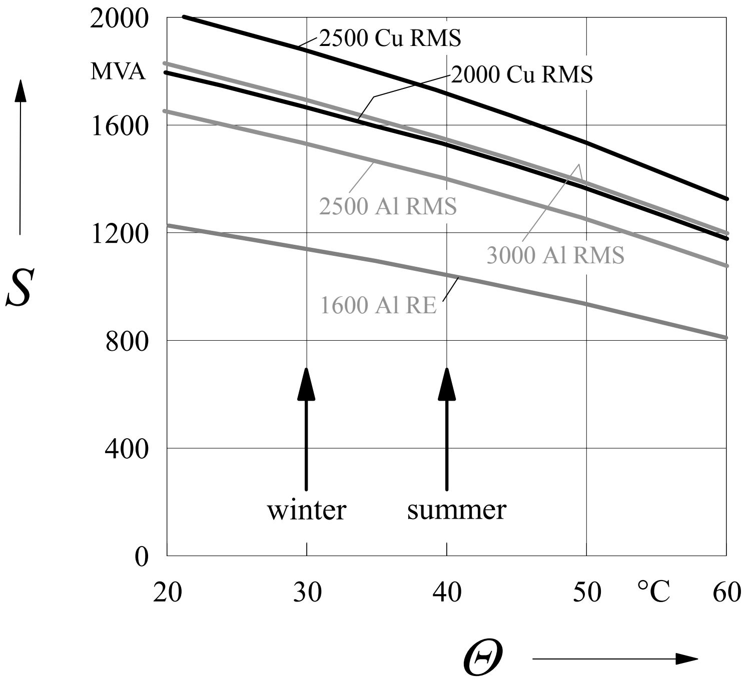

Figure 76: Transmission capacity of 380 kV UGC configurations in tunnel with forced convection, depending on maximum air temperature *Θ* (source: University of Duisburg Essen)

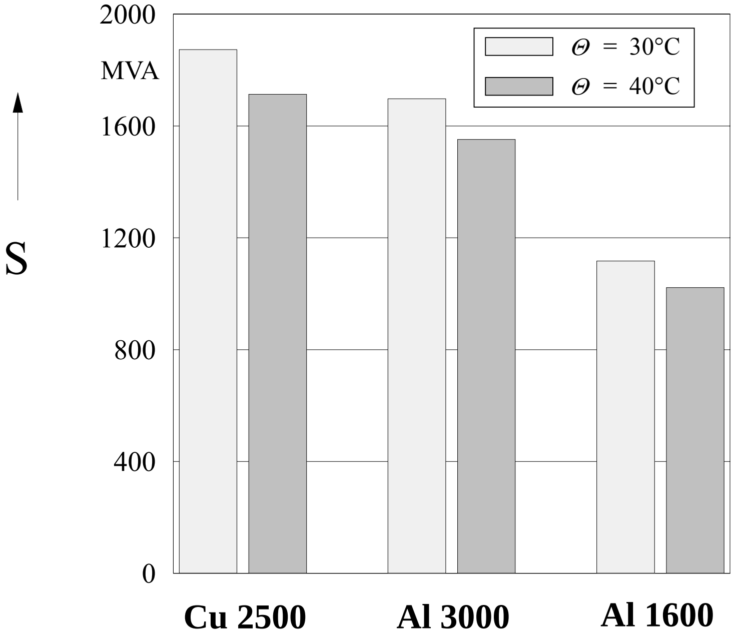

Figure 77 Transmission capacity of three 380 kV **single circuit** UGC configurations in tunnel with forced convection, parameter: maximum air temperature Θ (source: University of Duisburg Essen)

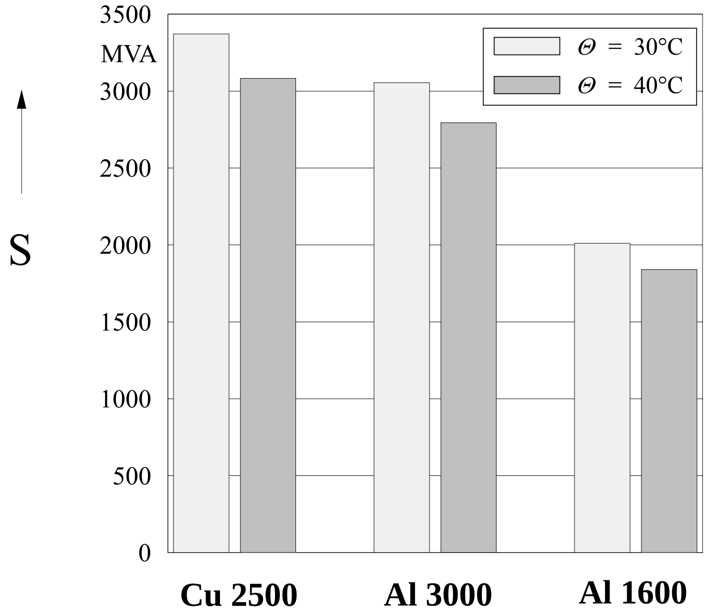

Figure 78 Transmission capacity of three 380 kV **double circuit** UGC configurations in tunnel with forced convection, parameter: maximum air temperature Θ (source: University of Duisburg Essen)

Appendix 5 – Gas Insulated Line Conductors – GIL

Concept

History

This gas insulated line (GIL) technology was developed from gas insulated busbar substation equipment, used where space is limited.

The very first 380-kV double system GIL reported was installed in 1976 in the Black Forest/Germany by Schluchseewerk AG [Koch 2002]. However, in the mid of the 1990's, a second generation of GIL was developed [Koch 2001]. The latter is state-of-the-art nowadays and features [Kindersberger 2005]:

- Automated welding process
- Improved insulation concept
- Modularity
- Assembling equivalent to oil and gas pipelines
- Flexible bending of tubing possible
- Mixture of sulphur hexafluoride (SF6) and nitrogen (N2) gas

The second generation of GIL was installed for the first time in 2001 at the Palexpo Fair, where it replaces a 500 m part of a 300-kV OHL due to the very restricted space at the site [SIEMENS WEB].

Although GIL systems are regarded as technical feasible for high power transmission over long distances [ARGEAUT, IMAI], it has still only been used for very short distances – mainly in tunnels. Their main field of application remains at substations and the connection of power plants.

Setup

Gas insulated line (GIL) systems consist of two coaxial aluminium tubing of around 500 mm and 200 mm diameter. The inner tubing (or busbar) carries the high-voltage conductor with an extra-large cross-section of more than 20,000 mm²; the busbar is insulated against the – usually grounded – outer tubing (jacket) by high-performance epoxy resin based insulators and a pressurised mixture of sulphur hexafluoride (SF6) and nitrogen (N2) gas. Figure 79 shows the general setup of a single GIL phase.

Figure 79 General setup of a single GIL phase [Kindersberger 2005]

Power Performance

The power transmission performance of GIL systems is similar to or exceeding the performance of OHL. Due to the large conductor cross-sectional area, GIL can be manufactured with very high current ratings [Jacobs Babtie 2005].

Further performance of second generation GIL systems is shown in Table 14.

Table 14: Power transmission performance of second generation GIL systems [Kindersberger 2005], [Oswald et al 2005]

Highest voltage	Rated Current	Apparent Power
245-kV	2500 A	~ 1000 MVA
380-kV	2500 A	~ 1645 MVA
420-kV	3150 A	~ 2300 MVA
550-kV	4000 A	~ 3450 MVA

Assembling

GIL is of rigid, preformed construction which cannot be coiled onto a drum. It is manufactured at works in transportable lengths of around 11-20 m, these sections being bolted or welded together on site [Oswald 2007], [Jacobs Babtie 2005]. The GIL sections must also be rigidly supported, either by steel structures or – as proposed more recently – in a trench. As an example, Figure 80 shows the typical dimensions for a GIL double system trench.

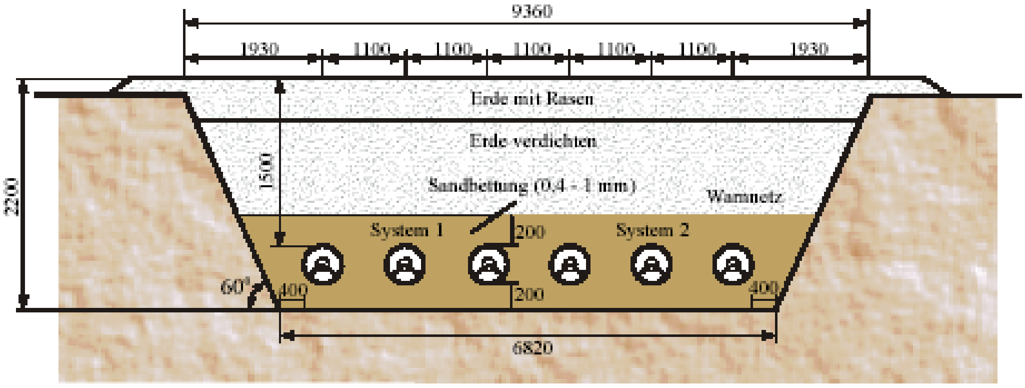

Figure 80 Typical dimensions for a GIL double system trench [Oswald et al 2005]

Every distance of 1200 m extensive concrete shaft structures are necessary giving space to stretching due to temperature changes of the GIL system (see Figure 81).

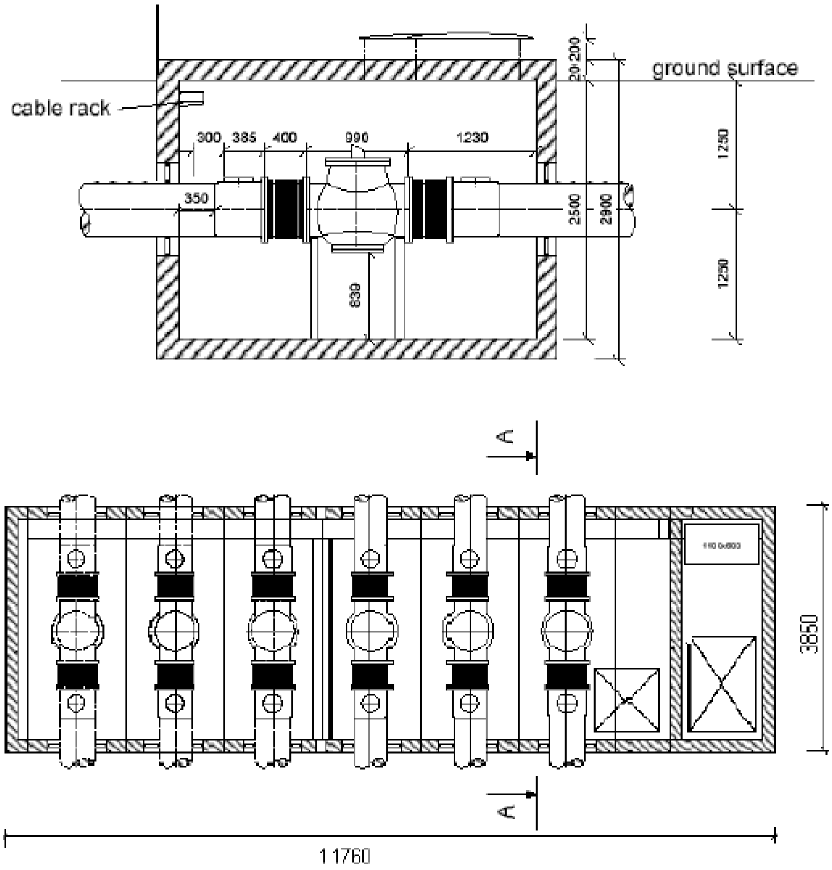

Figure 81 Structure for housing joints of GIL sections (source [Oswald 2007])

Specific technology characteristics

Electrical parameters

GIL systems combine the low specific resistance of UGC and low specific capacitance of OHL. Therefore, GIL systems do not need any reactive compensation equipment even at longer distances [Oswald et al 2005].

Electric losses are distributed evenly between busbar conductor losses and eddy currents losses being induced in the jackets. In total they are in the same order of magnitude as those of UGC [Oswald et al 2005].

Due to the small tan δ and the low specific capacity, dielectric losses and the influence of the capacitive loading current on the total losses can be neglected.

Heat dissipation

The highest accepted conductor temperature for GIL is reported as 105 °C. GIL-systems are designed in a way that the temperature at the surface of the jacket would not exceed 60 °C. To improve the thermal conductivity of the bedding, a sand layer of special granulation is used [Oswald et al 2005].

Maintenance and Reliability

The reliability of GIL systems is regarded as very high, although due to missing operational experience, no further statistical information can be given [Oswald et al 2005]. The maintenance is constraint to the upkeep the functioning of secondary equipment, such as gas emergency recognition and the automatic fault detection systems and, if necessary, the temperature monitoring devices. [Oswald et al 2005].

The current automatic fault detection systems can locate a short circuit with an accuracy of ± 25 m; in worst case, 50 m of a GIL system have to be renovated. The average repair time is reported with 20 days; about the half of this will be needed for works related to gas handling.

The expected life time of GIL systems is determined by corroding of the jackets and the possible degradation of the epoxy resin and the gas mixture. However, due to lacking long-term experience, no life time figures can be presented from nowadays experience. [Oswald et al 2005].

Operation in meshed grids

Similarly to UGC, because of the low impedance, GIL systems would tend to attract power flows from paralleling OHL sections. Therefore, special measures for power flow control (line reactors) must be implemented to prevent the GIL from overloading [Oswald et al 2005].

Loss of insulation

GIL are generally equipped with gas emergency recognition and automatic fault detection systems. Additionally, an online surveillance system for partial discharges can be installed [Oswald et al 2005].

Environmental issues and risks

GIL lines are a massive underground structure with a clear impact on soil. The buildings for the joints additionally inevitably have a visual impact. This is locally but given the short distances between these buildings the overall effect is significant.

A major disadvantage from is the excessive use of SF6 associated with the technology. With extended structure as considered in this study there is always a risk of damage and, hence, leakage. SF6 is a gas with an extremely high greenhouse gas potential being 23,900 times that of carbon dioxide [IPCC 2007]. Additionally, the density of the odourless gas is higher than that of air and hence there is a risk that leakages to cellars may result in health hazards. The latter risk can be effectively managed by monitoring and leakage detection systems.

External magnetic fields induced by GIL systems are low: 6 µT which is much less compared to UGC of similar capacity [Koch 2002].

Cost components

Because of the extreme aluminium conductor’s cross section of more than 20,000 mm^2 (compared to 2500 … 3000 mm^2 for UGC) in each system phase the GIL concept by na-

ture is very material intensive. Because of the size of the conductors and the buildings for the joints construction works are excessive.
Applied on long distances from an economic point of view GIL appears not to be a alternative for OHL or UGC (see also paragraph 9.3). GIL may find wider application in future in tunnels, as the need for separate support structures would be avoided [Jacobs Babtie 2005].