Overview of the Potential for Undergrounding the Electricity Networks in Europe

Prepared for the

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ICF Consulting Ltd
3rd Floor, Hamilton House
Mabledon Place, Bloomsbury
London WC1H 9BB
United Kingdom

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Executive summary

This report has been prepared at the request of DG TREN. Its main purpose is to assist the European Commission in assessing the potential for undergrounding the Electricity Networks in the Member States of the Europe Union, Norway and Switzerland.

Technical and economic factors

Underground electricity cables are used in almost all European countries, mainly for parts of the transmission and distribution electricity networks in urban areas, as well as in the countryside where ecological or historical interests need to be preserved. Undergrounding of electricity lines is, however, more expensive than overhead lines, because:

- Additional insulation is required because the cables are often only laid only one metre below ground;
- Extra land is needed for the sealing end where the cables need to be connected to overhead lines;
- Access to the cables is essential for repairs and maintenance purpose, therefore the land above the cables cannot be used for farming or industrial purposes;
- With Alternating Current, it is necessary to provide for reactive power; at 400kV, this requires compensation/substations every 15 to 20 km;
- Within an existing network of overhead lines, it is difficult to integrate underground cables due to the differences in impedance. To solve this, it is necessary to split up meshed networks and operate them as partial networks, which requires additional investments to increase the transformation power to these partial networks.

For these reasons, cost differences between overhead lines and underground cables are not linear, In general, though, as power ratings increase, the cost of underground cable rises more than the cost of equivalent overhead line. For example, the capital cost of underground cables at voltages up to 90kV are estimated to be around 2 times more expensive than aerial lines; at voltages of 225kV the estimate is around 3 times more expensive, but at 400kV the estimates are around 10 times more expensive. This multiple is, however, subject to wide variations around Europe, which in part recognises some of the technical difficulties involved in large-scale burial of lines at 400kV.

Operating and maintenance costs for cables are estimated to be around one-tenth of the cost of aerial lines and as cables have lower losses than lines, when lifetime costs are taken into account, the cost multiples fall to be between 7 and 12 times. In addition, there is currently over capacity in the European market for transmission cables which has led to falling prices and a current project in Denmark shows that the cost of burying 400kV lines is only 3-4 times more expensive than the overhead line.

Although operating and maintenance costs for cables are much lower than lines, repair costs can be greater as the detection, identification and repair of the underground cables is far more time consuming and complex. As a consequence, underground cabling of networks at 380/400kV is the exception rather than the rule in most countries in Europe and around the world. Within the European Union, less than 1 percent of the EHV network is underground land cable with only Denmark and the UK having more than 100km of underground cable on land. At voltages between 220kV and 300kV, burial is slightly more common with 2.3 percent of the network underground. At these voltages, France and the UK (with around 800km) have the largest number of kilometres of cable underground.

Benefits of undergrounding

One of the principal advantages of underground cables is that they cannot be seen. There are also other benefits for utilities, customers and local communities.

Transmission losses are lower with underground cables than aerial lines, however, most losses (around 80 percent) occur within the lower voltage distribution networks. Even at these lower voltages, although undergrounding is a factor in controlling losses, most occur during the process of transformation or are due to other non-technical issues.

Underground cables are not susceptible to storm damage (apart from water) and are far less likely to cause death or injury due to accidental contact with the lines/cables. Minor storm damage to overhead lines across Europe is a frequent event, particularly at low/medium voltages. This is principally because 400kV pylons are designed to withstand higher wind speeds and because of their height, the conductors are less vulnerable to falling trees. Occasionally, though, as happened in France in December 1999, significant damage can occur to the EHV/HV network.

In most Member States, the construction of new aerial lines has met with strong opposition by local communities and authorities as well as by environmental organisations, to the extent that the approval for the construction of new lines has become at best a long drawn out process (e.g. 10 years) or almost impossible. In these instances, cabling can offer a solution. It can speed up the process, however, there are two main reasons why cabling is not always considered to be the solution:

- Concerns that the incremental costs cannot be recovered;
- The “knock-on effect” - that all local communities and authorities will want “their” network put underground.

Some transmission companies also do not favour cables because it could lead to a situation where the cost reflective tariff of the cable exceeds the difference of electricity prices in the different countries. In which case, it would be more sensible to develop new generation to feed each national market rather than the European interconnection network.

New technology

There has been a significant amount of investment in research and development aimed at reducing the cost differentials between lines and cables in recent years. This includes the development of solid insulated cables (as opposed to oil) based on Cross Linked Polyethylene (XLPE) and Gas-Insulated Lines (GIL).

The technology has now been developed commercially from hundreds of metres of cable to several kilometres and over 100 km of 400kV XLPE cable systems are currently being installed in Europe with the longest individual cable in Europe (Copenhagen) now over 20km. This technology is being used in urban centres as well as rural areas in a sensitive environment. GIL is less developed in Europe although approximately 100 km has been laid around the world at voltages between 135kV and 550kV. The longest installation to date in Tokyo is only 3.5 km but a feasibility study is due to be carried out shortly into the possibility of laying a 52km GIL cable through a rail tunnel between Austria and Italy. Some concerns have been raised over the use of GIL as it uses SF_6, which is a contributory factor to greenhouse gas.

In the United States and some other countries, there has also been a significant amount of investment into the potential use of high temperature superconductivity wires (HTS). With the exception of a small pilot project in Copenhagen, most transmission companies and cable suppliers in Europe remain wary of its potential as a low cost means of transporting electricity of very high voltages over long distances.

Electric and Magnetic Fields

Over the past three decades, a significant amount of research has been carried out worldwide into examining whether electricity and in particular, the presence of electric and magnetic fields (EMFs) have an adverse impact on health. Although the balance of the evidence is against a link, there is some scientific evidence suggesting that excessive exposure to EMFs may be harmful to health.

A large electricity pylon carrying a 380/400kV conductor produces around 10 - 20 microteslas (µT) directly under the line and between 3,000 – 5,000 volts per metre. These levels fall with distance to the sides of the line. For example, approximately 25 metres to the side of the pylon, the magnetic field is estimated to be around 5 µT and between 200 – 500 volts per metre.

Underground cables can produce higher magnetic fields directly above them than an overhead line as the physical distance from the underground cable and the ground is smaller. For example, 400kV cables can produce over 30 µT at ground level falling to 10 µT at 2 metres above the ground. The field falls very rapidly with distance to the side and cables produce no electric field.

The European Union issued a recommendation in 1999 concerning restrictions on the exposure of the general public to electric and magnetic fields. These limits are 100 µT for magnetic fields and 5,000 volts per metre for electric fields. These limits are recognised in countries including France, Germany and Italy but in others, national governments have issued their own exposure guidelines to which transmission companies are required to comply.

Cost benefit analysis of additional interconnection

As far as existing cross border networks are concerned, these are clearly insufficient to allow the free circulation of energy flows and in most countries are insufficient to meet the European Commission's target (endorsed by the Barcelona Council) for Member States to have electricity interconnections equivalent to at least 10 percent of their installed capacity by 2005. With the exception of sub-sea cables, international interconnections are almost all by way of overhead line at present.

The use of underground cables rather than aerial lines may be a solution to some of the congestion and environmental issues around Europe and underground land cable interconnections have or are being considered between France/Spain, France/Italy, Austria/Italy and Italy/Switzerland. In most cases underground cabling for international interconnections has not proceeded due to the substantial costs involved.

As an initial assessment of the economic viability of different potential interconnectors, the cost of constructing additional capacity across a number of borders has been compared to the projected benefits. The analysis has been carried out on a marginal MW basis and the benefits have been estimated from forward electricity price curves produced by the ICF Consulting power market model (IPM). The cost projections are based on those provided by transmission companies in their feasibility studies. On the basis of our analysis, we conclude that the plans to construct an underground cable between France and Spain would not be cost beneficial, although an additional overhead line would. Between France and Italy plans to use either a railway tunnel or a new electricity tunnel would both be cost beneficial.

Impact of undergrounding on cost of electricity

It is difficult to estimate the impact on transmission prices of undergrounding some or all of the high or EHV network across Member States as this would depend on a number of factors, such as:

- Mechanism for funding the programme;
- Impact on cable prices of sudden increase in demand;
- Impact of additional costs of reactive compensation;
- Impact of running the system in a non-optimised manner while cabling work is carried out;
- Cost of writing off parts of the overhead line system prematurely.

As part of this study, we have looked into some cost projections supplied by transmission companies in France, Italy and the UK and some cost estimates from Australia where several studies have been performed into undergrounding power lines, particularly at low/medium voltages.

Following the severe storms in December 1999, RTE made an estimate of Euro 107 billion as the costs involved in undergrounding all HV and EHV overhead lines in France. France has approximately 46,000 km of overhead lines at voltages of between 220-400kV out of a EU wide total of approximately 200,000 km. Extrapolating this estimate across the EU would represent a total cost of Euro 465 billion.

In Italy, over 98 percent of the transmission network in Italy is overhead line. If it is assumed that the current regulated overhead line transmission tariff parameter were to be replaced by the regulated 380kV cable parameter (a multiple of 5.9 times), the transmission part of the end tariff would rise from 0.33 €c/kWh (price at November 2002) to 1.95 €c/kWh and the regulated tariff to domestic customers would increase to 11.92 €c/kWh net of tax which is an increase of approximately 16 percent.

RTE also estimated that the cost of undergrounding all new 225kV lines, or those to be replaced, over a period of 15 years would be approximately Euro 3 billion, which is the equivalent of Euro 200 million per year, which would add around 10 percent to the annual cost base. As transmission costs represent approximately 10 percent of total electricity costs, this additional cost would represent an increase of 1 percent in the cost of electricity.

According to National Grid, the replacement of one quarter of the overhead line EHV network with cables would lead to a three to fourfold increase in transmission prices in England & Wales. This calculation was based on their view that cables are 20 times more expensive than overhead lines to install. If we assume the current high voltage transmission charges increased threefold, average industrial prices would rise by about 9 percent and domestic prices by 3 percent.

At lower voltages, a significant amount of work has been carried out in Australia into the cost/benefit of undergrounding whole areas/States. In Queensland, the estimated cost of burying all electricity lines was estimated at between Euro 2,400-3,600 per house. In New South Wales, the electricity regulator (IPART) estimated the amount to be between Euro 1,400-2,300 per house. The Local Government Association in New South Wales calculated that the funding for an undergrounding project over 30 years would be cost neutral with a consumer levy of approximately Euro 1 per week.

Political and Regulatory Factors

There are few political or regulatory issues that relate specifically to the construction of aerial lines or underground cables. Belgium, however, has a voluntary ban on the construction of new overhead lines and in France, accords has been agreed between the government and industry regarding policies and targets for undergrounding power lines. The most recent accord includes a commitment to put at least 25 percent of the 63/90/kV transmission networks underground, while equivalent lengths of existing aerial line should be transformed into underground cables. The accord does not cover EHV voltages (225kV and 400kV).

Within the European Union, Member States have implemented the Environmental Impact Assessment Directive. This requires an EIA to be carried out for all power lines with a voltage above 220kV and 15 km in length. The specific requirements as what has to be included in an EIA are quite general, however, any proposal to construct a high voltage power line would usually address issues such alternative routes and undergrounding.

1. Introduction

This report has been prepared at the request of DG TREN. Its main purpose is to assist the European Commission in assessing the potential for undergrounding the Electricity Networks in Europe.

Although over 95 percent of the Extra High Voltage (EHV) networks within the European Union are overhead lines, the construction of new aerial lines has met with strong opposition by local communities and authorities as well as by environmental organisations, to the extent that the construction of new lines has become almost impossible in some countries. The undergrounding, therefore, of those sections of the aerial lines that face environmental problems needs to be considered as a realistic solution in spite of the higher construction costs involved.

Also, owing to the substantial damage caused to the French electricity network by the storms of December 1999 and the resulting long blackouts, the French authorities are considering the undergrounding of substantial sections of their electricity network to improve their security of supply with electricity. In the January 2002 agreement *Accord "Reseaux Electriques et Environnement"* the Ministries for Industry and the Environment, EdF and RTE envisage that 90 percent of all new medium voltage distribution network, two-thirds of all new low voltage distribution network and 25 percent of all high voltage transmission networks (i.e. 63/90kV) should be constructed underground, while equivalent lengths of existing aerial line should be transformed into underground cables.

The European Commission is considering that the initiative undertaken by France, if applied Europe-wide, may solve the severe environmental problems related to the construction of new electricity lines as well as reduce congestion and increase substantially the security of electricity supply in Europe. However, the Commission feels that the issue must be studied more in depth in order to investigate on one hand the increased costs entailed by underground cables and their operational problems, and on the other hand to estimate as much as possible the benefits to be accrued to the European electricity networks, particularly at the EHV level.

The report includes:

- An overview of the technical, economic, environmental, political and regulatory issues related to the construction of underground cables and how they affect the EHV transmission electricity network;

- A review of recent developments in the techniques of underground cables as well as the impact of Research and Development into reducing the cost of constructing new cables;

- An evaluation of the costs and possible benefits of a policy of undergrounding substantial parts of the European electricity networks;

- An assessment of undergrounding on the price of electricity, by looking at some cost projections in Italy, France and the UK;

- An analysis of the possible contribution of underground cables to the achievement of the objectives of the Commission's Communication on Energy Infrastructure including a cost benefit analysis of proposed interconnections between France/Italy and France/Spain;

- An overview of the existing underground cables across the European Union, Norway and Switzerland.

2. Underground Transmission - Technical, Economic, Environmental & Political/Regulatory Issues

Technical

High voltage transmission equipment transfers electricity over long distances from the point of generation to subordinate distribution networks. The electricity is transported by either alternating current (AC) or direct current (DC) through transmission lines or cables at a range of voltage levels.

In Europe, the electricity networks are basically composed of four groups of voltage levels:

- Extra high voltage: 750kV (undersea cables)
  400kV (standard in Nordel, UK and Ireland)
  380kV (standard in most of UCTE)
  220kV to 300kV (non standard)
- High voltage 60kV to 150kV
- Medium voltage 10kV to 50kV
- Low voltage 0.2kV to 0.4kV

In most countries, the EHV network is defined as the transmission network with the other voltage levels defined as distribution networks. Some countries such as France and Belgium include HV network as transmission.

Most of the power system in Europe is AC although DC is used to transmit electricity over large distances or linking systems with different operational frequencies (e.g. Nordel – UCTE).

Under AC, electricity is usually transmitted through three active conductors (comprising a single circuit). DC generally involves one conductor however large converting stations must be erected at each end of the line to convert the electricity to AC.

On land, high voltage AC cables made with copper are generally laid in a trench in groups of three in a mixture of cement and sand about a metre below ground and up to a metre apart. Concrete slabs are usually placed on the sand to provide protection to the cable. The cables generate significant heat and due to the absence of air, the conductors need to be much thicker. The conductor is usually insulated by a thick wrapping of fluid impregnated paper that is kept under pressure by fluid tanks along the cable route. There is an aluminium or lead sheath to retain insulating fluid and a tough plastic, or polypropylene, cover to protect against corrosion.

An easement is required for the cable trench and some land either side of the trench (from 3 to 8 metres) to allow a safe working area for excavation and vehicle access. No structure or fixtures can be placed over the cable and trees and shrubs must be cleared so that roots do not damage the cables or dissipate the heat generated by the cables. Where possible, cables are laid over open terrain to avoid the clearance of trees.

A high voltage DC cable usually involves just one cable (largest practical conductor size is around 2,500mm²); to transmit more power another cable would be required.

DC circuits also have lower line losses and at HV and EHV, there is a need in the case of AC underground cables to construct compensation substations to provide for reactive power.

- At 400kV, substations are required every 15 to 20 km;
- At 225kV, every 25 to 30 km;
- 63 kV to 90kV, every 50 to 70 km.

Economic

In the ICF Consulting study for DG TREN entitled *Unit Costs of Constructing New Transmission Assets at 380kV within the European Union, Norway and Switzerland, October* 2002, the standard cost of constructing a single 380kV line over flat land was estimated at approximately Euro 250,000/km and that of a double circuit was estimated at approximately Euro 400,000/km.

Undergrounding of electricity lines is more expensive than overhead lines. The main reasons behind the extra costs are:

- Additional insulation is required because the cables are often only laid one metre below ground;
- Extra land (typically 2,000m²) is needed for the sealing end where the cables need to be connected to overhead lines;
- Access to the cables is essential for repairs and maintenance purpose, therefore the land above the cables cannot be used for farming or industrial purposes;
- Compensation/substations are required to be built along the route to provide for reactive power.

Over long distances, DC transmission circuits are generally cheaper to construct than AC transmission circuits as they have fewer conductors. However, a converter station is required to convert between DC and AC for connection to the AC network. Recent new HVDC land transmission projects include the 44 km overhead line in Italy that forms part of the interconnector with Greece and a 50 km stretch of Basslink project in Australia that forms part of the Tasmania – Victoria interconnection (more details on page 44). For the Basslink Project, where consideration was given to the construction of overhead lines, DC and AC cables, the DC cable was estimated to be 35 percent cheaper than AC (but 10 times more expensive than the overhead line).

The main factors determining the design of transmission lines and underground cables are the power-rating requirement of the circuit and its length. These, in turn, determine the most economic choice of operating voltage and the cost of installation.

As the voltage increases, the electrical stresses become more severe and as a consequence the technology required to manufacture, install and operate the underground cable increases in complexity. As the current increases, energy losses increase and limits on conductor size start to apply. With larger conductors, the cable becomes heavier and the individual manufactured lengths of cable become shorter. This, in turn, requires more expensive joints to be used to connect the pieces of cable.

Also, within an existing network of overhead lines, it is difficult to integrate underground cables due to the differences in impedance. A high voltage network is a meshed network where the laws of physics apply. As soon as there are low impedance links in parallel with higher impedance links, the low impedance links become overloaded, which can lead to short-circuiting. To solve this problem, it is necessary to split up the meshed networks and operate them as partial networks. As a consequence, additional investments have to be made to increase the transformation power to supply these partial networks.

For these reasons, cost differences between overhead lines and underground cables are not linear. In general, though, as power ratings increase, the cost of underground cable rises more than the cost of equivalent overhead line. RTE, for example, states that underground cables at voltages up to 90kV are between 1.8 to 3 times more expensive than aerial lines and at voltages of 225kV are between 2.2 to 3 times more expensive compared to more than 10 times more expensive at 400kV. This multiple is, however, subject to wide variations around Europe, which in part recognises some of the technical difficulties involved in large-scale burial of lines at 400kV.

The unit cost of sub-sea cable is much less than land cable because the sub-sea cable can be transported from factory to site and then laid by a ship in very long manufactured lengths. This reduces the number of joints required and avoids the labour intensity of land cable installation. Also, the cable can be smaller in size as heat dissipation is more efficient on the seabed than on land.

Actual costs will vary from project to project and the true market cost can only be established through a competitive tender. Prices will depend on factors such as metal prices, world demand and available manufacturing capacity. The European market for transmission cables is small and specialised with three main players (Pirelli, Nexans and ABB) controlling the bulk of the transmission cable market. There has not been any major expansion in European transmission networks in recent years (the total network has only increased by about 3 percent over the past five years) and the resulting excess manufacturing capacity (estimated to be twice current demand) has led to falling cable prices and the closure of manufacturing facilities in Berlin, Calais and Erith (UK).

An example of the current low price of cable is the 14 km of 400kV underground cables being installed as part of the 140 km link between Aarhus and Aalborg in Denmark. Cabling is estimated to cost only 3 times that of the overhead line and this low multiple was attributed to the project occurring at a favourable time with a very low demand for high-voltage cables all over Europe. A number of suppliers were very eager to get the order, which put pressure on the price.

A number of the transmission companies, electricity regulators and suppliers in Europe have, however, provided estimates of the costs of construction of cables in comparison to aerial lines (see table below). The cost estimates of a 400kV line to AC land cable vary quite considerably but in general the cost differences have narrowed compared to a few years ago. In France, for example, RTE has reduced its estimates for 400kV cables from 20 times the cost of aerial lines to 10-12 times over the last couple of years. This is attributable to increased Research & Development into the economic life of cables, the laying of cables at reduced depths and technological advances in cable design.

	380/400kV Cables:lines multiplier	150/220kV Cables:lines multiplier	Source
Austria	8	-	Verbund APG Styria link
Denmark	Euro 2.5/km	4.0	Eltra/Elkraft
ETSO	Euro 5m/km more than lines	-	ETSO
Finland	3.5 (sea cable)	-	Fingrid
France-rural France-urban	>10 10-12	2.2-3 1.6-2	RTE-Piketty Report RTE
Ireland	-	7.7	ESB National Grid
Italy	8	5	Terna
Norway	6.5	4.5	Statnett
Spain	25	-	REE
UK	15-25	n/a	National Grid

Lifetime costs

In addition to the capital or investment cost of purchasing and installing specific transmission circuits, there are other costs that are incurred throughout the life of the installed line or cable. These are principally operating and maintenance costs and the cost of losses. Operating and maintenance costs for cables should be less than lines, however the repair of individual faults to underground cables can be much higher. According to data submitted as part of the proposed Basslink project in Australia, approximate costs of maintenance on National Grid's UK AC transmission system derived from 1999 cost data are:

- Overhead line maintenance (£ 600/circuit-km/year);
- Underground cable maintenance (£ 70/circuit-km/year).

Terna in Italy reported a similar annual amount (i.e. approximately Euro 1,000/km) for overhead line maintenance. Their experience with cables to date is that maintenance costs are minimal. In general, though, operating and maintenance costs are a smaller component that the cost of losses over the lifetime of the equipment.

The quantification of the cost of losses is dependant on the amount of power that is transmitted over the life of the circuit and a considerable depth of analysis is necessary for its determination. This would need to take into account the load transmitted, whether the line/cable is heavily or more lightly loaded and estimates for losses in insulation. The costs can be estimated for the life of the equipment and these annual sums can be converted back to an equivalent capital sum at the start of life using a net present value calculation. Some analysis was performed in 1996 as part of a CIGRE working group comparing high voltage lines and underground cables. This included some analysis carried out by National Grid into a 1,700 MVA circuit, which is reproduced below.

	Capital Cost Only		Capital Cost + low load loss cost		Capital Cost + high load loss cost	
$km/MVA	Line	Cable	Line	Cable	Line	Cable
Capital Cost	190	2,910	190	2,910	190	2,910
Loss cost	0	0	71	169	280	243
Capital + loss cost	190	2,910	261	3,079	470	3,153
Cost ratio	15.3		11.8		6.9	

The table shows that the cost ratios fall from 15 times to between 7 and 12 times once lifetime losses are taken into account. With advances in technology since 1996 and the current low price of cables, this cost ratio will have declined. In Italy, for example, the regulated tariff paid by GRTN to Terna for transmission at 380kV is 5.9 times higher for cable than overhead lines. This price is based on lifetime costs (i.e. return on capital, depreciation and operating and maintenance costs).

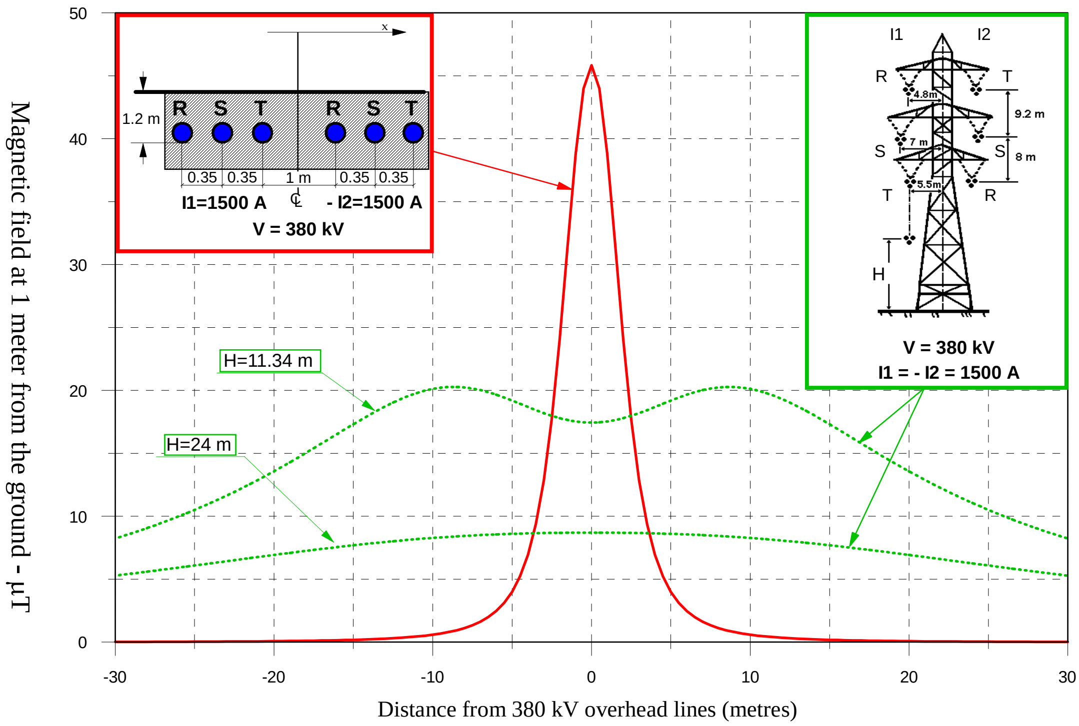
Environmental

Over the past three decades, a significant amount of research has been carried out worldwide into examining whether electricity and in particular, the presence of electric and magnetic fields (EMFs) have an adverse impact on health. EMFs are produced both naturally (e.g. thunderstorms) but also by the production and transmission of electricity.

Electric fields are produced by voltage (the pressure behind the flow of electricity). Generally, a higher voltage produces a higher electric field. Electric fields are measured in volts per metre (V/m). Magnetic fields are produced by current (the flow of electricity) and as with voltage, the higher the current, the higher the magnetic field. Magnetic fields are measured in microteslas (µT). Electric fields can be screened by structures such as buildings, trees and fences but magnetic fields pass readily through most structures.

Much of the worldwide research in recent years has examined whether EMFs have links with cancer and childhood leukaemia. Three significant studies that were carried out in the past 5 years were the 1999 United Kingdom Childhood Cancer Study (headed by Sir Richard Doll), an international group led by Professor Ahlbom from Sweden in 2000 and a 1999 report to the US Congress by the National Institute of Environmental Sciences. In each case, the conclusions were similar; that although the balance of the evidence is against a link, there is some scientific evidence suggesting that excessive exposure to EMFs may be harmful to health.

The European Union issued a recommendation in 1999 concerning restrictions on the exposure of the general public to electric and magnetic fields. These limits are 100 microteslas (µT) for magnetic fields and 5,000 volts per metre for electric fields. These limits are recognised in countries including France, Germany and Italy but in others, national governments have issued their own exposure guidelines to which transmission companies are required to comply. In the UK, for example, the limits are 1,600 microteslas for magnetic fields and 12,000 volts per metre for electric fields. Additionally, limits have been placed on the minimum height clearance for overhead lines and a "buffer zone" each side of the line. In some countries, including the United States, legislation has been introduced preventing the construction of new homes being built near power lines.



Magnetic fields from overhead lines and cables (source Terna)

A large electricity pylon carrying a 380/400kV conductor produces around 5 - 10 µT directly under the line and between 3,000 – 5,000 volts per metre. These levels fall with distance to the sides of the line. For example, approximately 25 metres to the side of the pylon, the magnetic field is estimated to be around 5 µT and between 200 – 500 volts per metre.

Underground cables can produce higher magnetic fields directly above them than an overhead line as the physical distance from the underground cable and the ground is smaller. For example, 400kV cables can produce over 30 µT at ground level falling to 10 µT at 2 metres above the ground. The field falls rapidly with distance to the side and the way the cable is constructed (with insulation material and concrete covers), they produce no electric field.

Decommissioning of overhead lines is easier than for cables. In the case overhead lines, they need to be dismantled and nearly all the components can be recycled. Cables have to be removed from trenches and tunnels and the insulation materials (which may include oil or gas) have to be removed prior to any recycling.

Political/Regulatory

There are few political or regulatory issues that relate specifically to the construction of aerial lines or underground cables. Belgium, however, has a voluntary ban on the construction of new overhead lines and in France, there is an agreement between the government and industry regarding policies and targets for undergrounding. In other countries, such as Switzerland, the approval process can be difficult and long, as the government can refer major infrastructure projects to a Public Enquiry.

Authorisation for the construction of extra high voltage lines usually requires approval at the federal level. Authorisations and permits may also be required at local government level. This process can be very time consuming (over 10 years in some cases). Within the European Union, Member States have implemented the Environmental Impact Assessment Directive. This requires an EIA to be carried out for all power lines with a voltage above 220kV and 15 km in length. Some Member States have set lower limits. In Italy, for example, an EIA is mandatory for all lines above 150kV and longer than 15 km. At the regional level, an EIA is required for all lines above 100kV and longer than 10 km. In addition, a screening process occurs for proposed lines between 3 and 10 km. Proposals to erect lines in environmentally sensitive areas, heavily populated areas or on land already crossed many times by other lines are likely to require an EIA.

The specific requirements as what has to be included in an EIA are quite general, however, it would be expected that any proposal to construct a high voltage power line would address issues such alternative routes and undergrounding.

3. Recent developments in cabling techniques

The environmental constraints on electricity transmission companies to limit the development of overhead lines have pushed forward research on alternative technologies for HV and EHV systems. The high cost of underground cables compared to aerial lines has also led to considerable activity worldwide in seeking to develop cheaper high voltage cables.

New construction and installation techniques include:

- Reducing dimensions and weights of HV and EHV cables through the use of materials such as cross-linked polyethylene (XLPE). Such cables allow longer shipping lengths, less joints, ease of installation and reduction of erection times of cable systems;
- Mechanised laying methods that avoid extensive excavations and transport of material;
- 'Trenchless' methods of cable installation, such as thrust boring and directional drilling which reduce time installing cables around motorway and railway crossings and in rural areas where habitat needs to be preserved;
- Increased use of micro tunnels to lay longer cable lengths that save on joints, installation time and costs.

Up until the last ten years, the majority of high voltage cables were of an oil-filled or mass impregnated design. Early oil-filled cables have had a history of problems. The trench has to be very flat to allow the oil to flow smoothly along the cable and the oil has to be replaced periodically. Location of faults was also complex. Although there have been improvements in oil-filled cable design (mainly through the use of extruded and polypropylene paper insulation), the development of XLPE, gas insulated lines/cables (GIL) and high temperature superconductivity (HTS), offer the main potential to reduce the cost of underground cable systems.

<u>XLPE</u>

Extruded polyethylene is used extensively worldwide at voltages up to 132kV but to date there has been only limited use at voltages of 220kV and above. XLPE involves chemically treating the polyethylene at high temperatures to improve its mechanical properties. The main advantages of XLPE cables over copper cables are flexibility, lightness, strength and lower maintenance costs. There is also no need for an auxiliary fluid-pressure system. At voltages of 220kV and above, higher operating stresses have to be used or the insulation would be too thick for installing practical cable systems. These higher stresses introduce the risk of premature failure particularly to the joint insulation. In the past, this has led to difficulties in calculating the cable's service life and reliability. As a consequence, technical bodies in North America, Japan and Europe have required long term pre-qualification tests and after laying tests on EHV XLPE cable systems.

Applications of EHV XLPE cable systems are, however, steadily increasing in North America and Japan. The longest installation is a 40 km synthetic insulated 500kV cable in Tokyo (The Shin Keiyo Toyusu Line) that was put into operation in 2000. This technology has also been installed in a few places in Europe.

- XLPE cables at lower voltages were used in Denmark in the 1980s but they have since installed two 400kV XLPE underground cables of 22 km and 14 km in length in and around Copenhagen;

- To reinforce the 400kV network in the western part of Denmark, Eltra is building a 140 km link between Aalborg and Aarhus. The line with a capacity of 1,200 MW is mainly overhead but is buried where it crosses urban areas or areas of ecological interest. Three cable sections (2.5 km, 4.5 km and 7 km) will be built and commissioning is scheduled for 2004. The total cost is estimated at Euro 140 million. The underground part which represents 10 percent of the total length is estimated to cost Euro 35 million (25 percent of the total);

- In Germany, Bewag has built a 400kV interconnection through Berlin's load centres. A double 6.5 km cable link was installed in 1998 in a tunnel as a pilot project and was followed by a 5.2 km cable in 2000. Initial plans involved installation of gas insulated cables, but XLPE was finally chosen as it was considered cheaper;

- In the UK, National Grid is installing a 20 km 400kV line with two circuits through a 40m deep tunnel between Elstree and St John's Wood in north London. Construction is under way with commissioning of the first circuit scheduled for 2004 with the second circuit at a later date depending on how demand develops. Estimated cost of the line is Euro 350 million, including the electrical substations at the end of the line;

- More recently, REE in Spain awarded a contract to ABB and Pirelli to install a 13 km 400kV XLPE cable at Madrid's Barajas International Airport. The project is scheduled for completion in October 2003.

GIL

Gas insulated lines using sulphur hexafluoride (SF_6) were first used in the 1970s typically within substations to connect switchgear with overhead lines, the aim being to reduce clearances in comparison to air-insulated overhead lines. More recently SF_6 has been replaced by a mixture of SF_6 and Nitrogen (N_2) which has a far greater insulating capability allowing the transmission of voltages up to 550kV and with longer system lengths (potentially more than 50 km). The lines consist of an aluminium conductor supported by insulators and spacers with a pressurised gas compartment that is enclosed within an aluminium envelope.

GILs are useful for underground transport of high loads of power (above 2,000 MVA) in metropolitan areas and can be laid into tunnels or directly in the ground. They have a high overload, high short circuit withstand capability and can be integrated easily into a network of overhead lines without having to adapt any of the existing protective configurations. The laying of GIL is a complex operation as great care is required to avoid any infiltration of dust or other particulates and joints are required around every 20 metres.

Within Europe, the first GIL cable was laid in a 700 metre tunnel in the Black Forest in Germany in 1975. More recently, a 450 metre underground cable was laid in an underground passage in a densely populated area of Geneva. The technology allowed the removal of an aerial line as well as other advantages such as lower transmission losses and lower maintenance costs.

Elsewhere in the world, approximately 100 km of GIL has been laid at voltages between 135kV and 550kV. Individual cable lengths are, however, small with the longest installation to date, a 3.5 km 275kV line in Tokyo, Japan.

HTS

Superconductivity – the ability of a material to conduct electricity without losses due to resistance – has been known about for about 90 years. However, prior to 1986, applications were restricted by the fact that it seemed possible only below 25 degrees of absolute zero (-450°F). In 1986, the ability of some ceramic materials to become “loss-less” carriers of electricity when cooled to the temperature of liquid nitrogen was discovered in the United States.

In recent years, the United States government has contributed around $30 million in programs aimed at meeting the challenge of long-term development of HTS technology for the transmission of electric power. A handful of commercial companies including American Superconductor Corporation have also developed and manufactured products using superconducting wires and power electronic converters. The technology involves grinding up the ceramic material, packing it into silver tubes, rolling the tubes into tapes and then heating the tapes up to produce wires long enough to be used as superconducting cables.

The main advantages apart from lower transmission losses (less than 1 percent compared to 5 to 8 percent for traditional low/medium voltage power cables) is that HTS cable can carry up to ten times as much power as the same thickness of copper wire. This is seen as a way of meeting the electricity demands within heavy populated urban centres. It could also allow power transmission at a lower voltage, which could reduce or even eliminate the need for transformers and other power equipment, thereby decreasing costs and system vulnerability.

The main disadvantage to date has been the high cost of HTS wire. The wires used for conventional conductors for electricity transmission and distribution are usually made from copper or aluminium and the present cost for copper wire is approximately $10 per kAM (kiloamperes meters) and $2 per kAM for aluminium wire. In contrast, commercial HTS wire (which is made of bismuth strontium calcium copper oxide) costs around $200 per kAM. American Superconductor expects to reduce the cost to about $50 kAM with a new production facility and the US Department of Energy Superconductivity Program for Electric Systems has established a goal of $10 per kAM for second generation HTS wire (based on yttrium barium copper oxide). A study in 2001 sponsored by the DOE (*Analysis of Future Prices and Markets for High Temperature Superconductors – Mulholland, Sheahen & McConnell)* suggested that significant market penetration could be achieved with a cost of $20 per kAM.

A number of cable manufacturers have been working on the development of cable demonstration projects, namely Pirelli Energy Cables (Italy), NKT Cables (Denmark), Sumitumo Electric Industries and Furukawa (Japan), Southwire (USA), LG Cables (Korea) and Condumex (Mexico). This has led to a number of HTS cable demonstration projects including 400 metres of cable in Detroit and 90 metres of cable in Copenhagen.

American Superconductor and Pirelli provided an update of the Detroit project to the US Department of Energy in July 2002. Of the three HTS cables installed, leaks had been determined in two of the cables that were significant enough to make the cables unstable so they cannot be energized. The project is to continue with just one cable, which it is hoped will lead to full commercialisation in due course. Recently, though, Pirelli have stopped investing in HTS technology, as they see no commercial feasibility in the short term.

In December 2002, Southwire and NKT Cables formed a joint venture (ULTERA) whose aim is to produce a 300 metre HTS cable to be installed in an electricity distribution system in Colombus, Ohio by 2005. The new design combines a three-phase system, which before required three separate HTS lines, into one cable. This reduces by about one half the amount of superconducting material required and reduces the amount of space needed to install the cable.

A further study into the value of high capacity HTS cables was issued by RAND (US based R&D organisation) in 2002. It concluded that HTS cables could provide reliability and transfer capacity benefits in areas such as the upgrade of much lower capacity and worn out copper cables in metropolitan areas.

In Denmark, NKT Cables, in collaboration with the Technical University of Denmark and with support from several Danish electricity companies and the Danish Energy Authority's Energy Research Programme, has been working on cable-related superconducting technology for a number of years. In May 2001 this led to the installation of the world's first superconducting cable in a public electricity grid, which entered service at Copenhagen's Imager substation, a central hub in the Danish capital's electricity supply system. The cable, which supplies more than 150 GWh of power, is part of a grid serving some 50,000 households and businesses. The cable, which is cooled using extremely cold liquid nitrogen, consists of three separate superconducting cables each 30 metres long spliced into the grid where the voltage is 30kV.

Comparison of costs of new technologies

Commercial evaluations of HTS cables show that they could prove economic for the bulk transmission of large quantities of power at voltages of 110-275kV. At present, HTS cables at 400kV are still in a prototype state and further research and investment will be required to bring down the cost of the wire before the technology can be used economically on a large scale. In the opinion of BICC Superconductors (UK cable manufacturer owned by Pirelli), it is likely to be 8 to 10 years before this happens.

A comparison of the costs of oil-filled, XLPE and GIL was carried out by Terna in 1999/2000 as part of a feasibility study into a proposed 7 km link between the 2,500 MW Torre Valdaliga Nord Power Plant and Aurelia Nord substation, just to the west of Rome. The plan was to replace the existing double circuit overhead line with cables along a number of possible routes (including a direct tunnel, along the roadside and across a turnpike/fields.

The oil-filled and XLPE cable solutions (4 circuits/12 cables) had a rated power of 1,000 MVA whilst the GIL solution (2 circuits/6 cables) had a rated power of 2,000 MVA.

The total estimated costs for the three alternatives were:

- Oil-filled $44 million (Euro 6.3 million/km);
- XLPE $36 million (Euro 5 million/km);
- GIL $68 million (Euro 9 million/km).

XLPE was cheaper than oil-filled due to lower cable costs and HV switchgear. GIL was more expensive due to higher cable costs and accessories, but would have twice the capacity. Although XLPE was considered to be the cheapest solution and had the lowest maintenance requirement, Terna favoured GIL as it was deemed important to develop this technology. Although this study was carried out in 1998, the project has yet to proceed.

This analysis as well as other analyses and comments made by Transmission companies, indicate that XLPE is generally considered to be the cheapest and most developed of the new technologies, although GIL may be a cheaper solution where very high load levels need to be transmitted in short stretches, particularly in urban areas and from power plants to substations. The modified oil-filled design is also still popular in some of the European markets.

4. Evaluation of costs and possible benefits of a policy of undergrounding parts of the European electricity networks

Estimates of the costs associated with undergrounding have been mentioned in Chapter 2 and the table below sets out the potential benefits of undergrounding (at all voltage levels) and the level at which the greater part of each benefit will accrue.

	Beneficiaries			
Benefit type	Utilities	Customers	Local residents	Wider community
Reduced transmission losses	✓			✓
Lower maintenance costs	✓			
Improved electricity service reliability		✓		
Reduced weather damage	✓	✓		✓
Reduced accidents (inc wildlife electrocutions)			✓	✓
Improved views/property values			✓	
Health & Environment (e.g. noise, EMFs, vegetation management)			✓	✓

<u>Transmission losses</u>

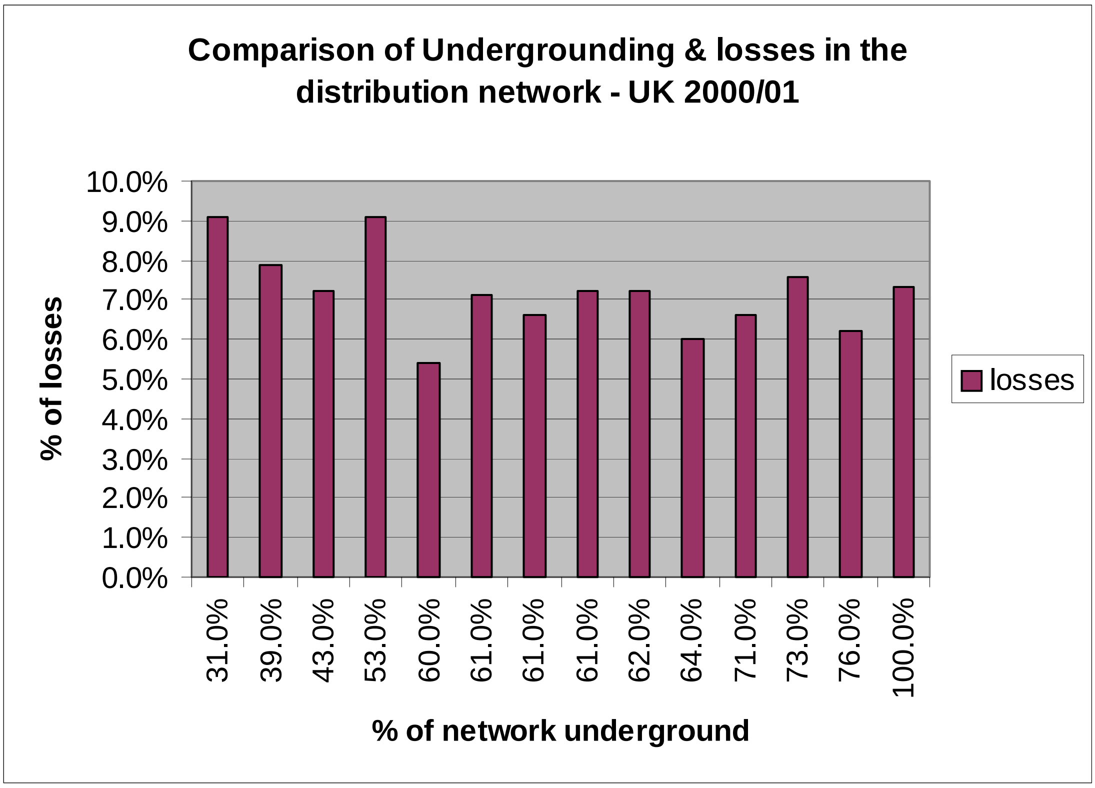
According to data published by The International Energy Agency (see Appendix A), electricity transmission and distribution losses across the EU, Norway and Switzerland in 2000 varied between 3.7 to 10.6 percent of all electricity transported across the networks (European Union average was 7.3 percent).

Although transmission losses are generally lower with underground cables than aerial lines, most losses actually occur within the lower voltage distribution networks. In England & Wales, for example, approximately 2 percent of the electricity is lost during high voltage transmission compared to 7 percent within the low/medium voltage distribution network. In the Netherlands, where transmission losses are lower, approximately 0.8 percent of electricity is lost in transmission and 3.9 percent in the distribution grid (a table showing total losses across the European Union transmission and distribution networks in shown in Appendix A). The reasons for the higher losses at lower voltage levels are due to a combination of factors:

- At lower voltages, a higher current is required to distribute the same amount of electricity. This increases utilisation and therefore losses on the network;
- As the customer base develops independently of the network, the resulting configuration of a network that has been constructed over 40 years will most likely not be the optimal one;

- Transformation to lower voltages can occur at several points in a network (i.e. from 132kV - 110kV - 66kV - 33kV – 11kV) and on each occasion, there are losses and the transformers use electricity during the process;
- Non-technical losses such as meter errors, unmetered supply and illegal abstraction/theft.

Undergrounding at lower voltages is a factor in controlling losses, but is not as significant as management of the above issues. In the tables below, we have compared the losses incurred in the Distribution Networks in the UK with the percentage of underground network.



Maintenance costs

The reliability of cables is often affected by premature aging of components and the time the network is out of service when repairs are carried out. Service experience of high voltage lines across Europe has shown that pylons/towers have a service life of 50-60 years and refurbishment of conductors and fittings is required at approximately 30-year intervals. In general, transmission cables have an estimated service life of 40 years, but service experience in the UK is that some oil-filled cables are ageing prematurely and need to be replaced at significant cost. RTE have also suffered maintenance problems with cable systems, but principally with the joints and the equipment linking the cable and the overhead line. Developments in technology (such as the use of aluminium over-sheaths instead of copper) are expected to resolve some of these issues.

As noted in Chapter 2, operating and maintenance costs for cables are less than lines (up to 90 percent cheaper), however the repair of individual faults to underground cables can be much higher, particularly when the additional time required to repair faults is taken into account.

According to figures produced by Hydro Quebec (who operate over 150km of underground cable at voltages of 120kV and above) in the December 2001 Report *New Technologies for the Undergrounding of Electricity Lines at High and Very High Voltages, Assemblee Nationale de France*, a minor repair for an overhead line can be repaired within one day compared to up to five days for an underground cable. For a major repair, the difference is greater, seven days for an overhead line and up to 20 days for a cable.

Within Europe, National Grid statistics for its 400kV overhead line circuits indicate a non-availability of 0.126 hours per year per circuit km of overhead line. This figure compares with 6.4 hours per year on its 400kV cables and an international average of 3.4 hours per year. Using the international comparison, the ratio of non-availability of underground cable to overhead line is 27:1.

<u>Storm and other weather damage and accidents</u>

Two major benefits of underground cables are that they are not susceptible to storm and icing damage and are far less likely to cause death or injury due to accidental contact with the lines/cables.

Minor storm damage to overhead lines across Europe is a frequent event, particularly at low/medium voltages. This is principally because 400kV pylons are designed to withstand higher wind speeds and because of their height, the conductors are less vulnerable to falling trees. Occasionally (as happened in France in December 1999) significant damage can occur to the EHV/HV network. Those storms resulted in around 8 percent of the EHV/HV transmission network being put out of order and although 90 percent of substations were re-connected within four days, it took six months to complete the repairs to the lines and the total cost was put at FF 1 billion (Euro 150 million).

Following the storm, an assessment was made whether to replace the entire EHV line network with underground cables. The burial of all EHV lines was estimated to cost FF 700 billion (Euro 107 billion) without quantification of the technical difficulties in laying 400kV lines underground over large distances. The view was that the cost could not be economically justified from the general interest and utility bill viewpoint. A more targeted plan to underground new 225kV lines or those to be replaced was assessed at an extra cost of FF 20 billion (Euro 3 billion) over a period of 15 years which is the equivalent of Euro 200 million per year.

Accidental contact with overhead lines is also a concern. Information from France shows that there were 19 deaths due to contact with overhead lines in France in 2000 compared to no deaths for contact with underground cables.

Cost/Benefit at low/medium voltages

A significant amount of work has been done in Australia into the costs/benefits of undergrounding all low voltage electricity networks in major urban areas. Much of the work carried out was summarised in a report prepared by the Ministry of Energy and Utilities (New South Wales Government) entitled *Undergrounding Electricity Cables – 10 January 2002*. The report was prepared in response to calls to commence a project to bury all overhead power lines in the Sydney Basin and looked into various schemes in place in other Australian States and in Auckland, New Zealand. Additional information is also contained within *Electricity Undergrounding in New South Wales – May 2002* prepared by the electricity regulator (IPART).

In Queensland, the estimated cost of burying all electricity lines was estimated at between A$4,000-A$6,000 per house (approx Euro 2,400-3,600). This range of costs was similar to that provided in a 1998 report *"Putting Cables Underground"* where is was estimated that the total cost of putting existing overhead and telecommunication cables underground in urban and suburban Australia was A$23 billion (ECU $12.6 billion) or an average of A$5,516 per household (ECU 3,000). IPART, in its report, arrived at an amount equivalent to A$2,300-A$3,800 per customer (approx Euro 1,400-2,300) by looking at just the total cost of undergrounding electricity cables over a 40 year time frame and discounting the costs over this period.

A number of local government and public lobby groups looked into the possible financial benefits of putting cables underground. Apart from increased property values, these included reductions in:

- Outages, transmission losses & greenhouse gas emissions;
- Network maintenance costs;
- Tree pruning costs;
- Motor vehicle collisions with poles;
- Electrocutions.

The net quantifiable financial benefit of undergrounding all electricity lines in New South Wales was estimated at between A$1,141 and A$5,736 per kilometre of line. At the upper end of the range the cost savings were approximately 50 percent avoided cost to distributors and 50 percent to reduced motor vehicle accidents. The Local Government Association calculated that the funding for an undergrounding project over 30 years and taking into consideration the cost savings would be cost neutral with a consumer levy of A$1.56 (approx Euro 1) per week.

IPART calculated that the quantifiable benefits of undergrounding electricity cables in New South Wales were between A$350-A$400 per customer which was equivalent to 40 percent of their estimated cost of the program. They did not make an estimate of the customers' willingness to pay for undergrounding but did recognise that there is a sizeable gap between the benefits and costs of undergrounding.

5. Impact of undergrounding on the price of electricity

Transmission represents between 5 and 10 percent of the total cost of electricity. It is difficult to estimate the impact on transmission prices of undergrounding some or all of the high or EHV network across Member States as this would depend on a number of factors, such as:

- Mechanism for funding the programme;
- Impact on cable prices of sudden increase in demand;
- Impact of additional costs of reactive compensation;
- Impact of running the system in a non-optimised manner while cabling work is carried out;
- Cost of writing off parts of the overhead line system prematurely.

As part of this study, we have looked into some cost projections supplied by transmission companies in France, Italy and the UK.

France

As noted in Chapter 4, following the severe storms in December 1999, RTE made an estimate of Euro 107 billion as the costs involved in undergrounding all HV and EHV overhead lines in France. France has approximately 46,000 km of overhead lines at voltages of between 220-400kV out of a EU wide total of approximately 200,000 km. Extrapolating this estimate across the EU would represent a total cost of Euro 465 billion.

RTE also estimated that the cost of undergrounding all new 225kV lines, or those to be replaced, over a period of 15 years would be FF 20 billion (Euro 3 billion), which is the equivalent of Euro 200 million per year. It is not clear whether this is the additional capital or operating cost. If one assumes operating costs, the total costs of the transmission business in France in 2001 (according to EDF's 2001 financial statements) were Euro 2.1 billion, so the undergrounding of 225kV lines would add approximately 10 percent to the cost base. As transmission costs represent approximately 10 percent of total electricity costs, this additional cost would represent an increase of 1 percent in the cost of electricity. If one assumes, the Euro 200 million represents the incremental capital cost, the annual amount to be recovered through the transmission tariff would probably be based on the regulatory formula covering depreciation, operating expenses and a 6.5 percent return on capital. This would be of the order of Euro 20 million/year.

Italy

In Italy, the regulated average electricity tariff in the captive market was 11.43 €c/kWh on 1 November 2002, which included 1.13 €c/kWh of taxes. The net amount was made up of three components:

- General charges (i.e. stranded costs, nuclear decommissioning, renewables, research, social tariffs), equal to 1,21 €c/kWh (= 12 percent);

- Cost of fuels (based on a basket of international prices), equal to 4.34 €c/kWh (=42 percent);
- Fixed costs (generation, transmission and distribution), equal to 4.75 €c/kWh (=46 percent), where:
  - Generation equal to 2.26 €c/kWh (=47.6% of the fixed costs or 21.9 percent of the whole tariff);
  - Distribution equal to 2.16 €c/kWh (=45.5% of the fixed costs or 21 percent of the whole tariff);
  - Transmission equal to 0.33 €c/kWh (=6.9% of the fixed costs or 3.2 percent of the whole tariff).

As over 98 percent of the transmission network in Italy is overhead line, we can assume that the transmission tariff includes only a small amount for recovery of investments in cables. If it assumed that the transmission tariff were to increase by 5.9 times the tariff would rise to 1.95 €c/kWh and the regulated tariff would increase to 11.92 €c/kWh net of tax which is an increase of approximately 16 percent.

Free market prices are between 5 – 10 percent lower, so the corresponding increase in transmission tariffs would be higher.

UK

According to National Grid, the replacement of one quarter of the overhead line EHV network with cables would lead to a three to fourfold increase in transmission prices in England & Wales. This calculation was based on their view that cables are 20 times more expensive than overhead lines to install. If we assume a threefold increase in the high voltage transmission price this would increase the current price from approximately 0.40 €c/kWh to 1.20 €c/kWh. The impact on electricity prices would be:

- Industrial prices would increase from the current average price of 9.2 €c/kWh (net of tax) by 8.7 percent;
- Domestic prices would increase from the current average price of 30 €c/kWh by approximately 3 percent.

6. Possible contribution of underground cabling to the European Commission's Communication on Energy Infrastructure

In February 2002, the European Commission published a document *European Energy Infrastructure – Fighting Congestion and Building Links*. The purpose of the document was take stock of the present gas and electricity network infrastructure and to draw attention to the need for action to boost interconnection capacities between Member States.

The actions identified included the focussing of support on key projects that:

- Support the creation of the internal market for electricity;
- Ensure increased levels of security of supply;
- Facilitate the integration of renewable forms of energy;
- Facilitate the integration of ultra-peripheral regions;
- Resolve bottlenecks or ensure the construction of "missing links" that industry alone will not address.

The current electricity infrastructure is insufficient to ensure the rapid development of the internal market for a number of reasons:

- Commercial non-viability of interconnectors, particularly connecting peripheral and ultra-peripheral regions;
- Lack of competitive incentive to relieve congestion by vertically integrated gas and electricity companies;
- Uncertainty regarding the regulatory regime that will be applied to new infrastructure investments;
- Difficulties in gaining authorisation to construct infrastructure, particularly for environmental reasons.

Several actions have been proposed to address these issues and this report has looked into the possible contribution of underground cabling as opposed to overhead lines as a means of contributing towards the Commission's objectives.

<u>Priority projects of European interest</u>

In the above-mentioned document, revisions were also made to the Trans European Network priority projects. Back in 1994, the Essen European Council identified five electricity projects as essential to the development of the internal market. Three of these projects have been completed or are under construction:

- Northern interconnection between Spain and Portugal;
- Submarine link between Italy and Greece;
- East and West Denmark interconnector.

Two projects have not progressed and critical bottlenecks remain at these locations:

- Interconnections between France and Spain;
- Interconnections between France and Italy.

In addition to the above two, the Commission has identified six further “Priority Projects of European Interest” for increasing interconnection capacity.

- France-Belgium-Netherlands-Germany: electricity reinforcements needed to remove frequent congestion across the Benelux region;
- Italian border with Austria and Switzerland;
- Denmark-Germany: increasing interconnection capacity;
- Greece-Balkan countries: development of electricity infrastructure to connect Greece to the UCTE system;
- UK-continental and Northern Europe: increasing electricity interconnection capacity with France and establishing interconnection capacity with other countries (e.g. Netherlands and Norway);
- Ireland with both Northern Ireland and mainland UK.

This report has looked into the possible contribution of underground cabling as a means achieving the Commission’s objectives, in particular the interconnections between France/Spain, France/Italy, France/Belgium and Italy/Austria. Future connections between the UK and Ireland and mainland Europe will be via sea cable and connections between Greece and the Balkan countries were considered peripheral for the purposes of this study.

<u>France/Spain</u>

Several attempts have been made to increase interconnector capacity between France and Spain since the mid-1990s, which currently consists of two 400kV lines (a Western route – 1,270 MVA between Hernani and Cantegrit and an Eastern route –1,650 MVA between Vic and Baixas).

In 1996/97, at the request of the French and Spanish governments, EdF and REE carried out a study into the various alternatives (some 27 were considered) available to increase interconnection capacity between the two countries. This included the feasibility of an underground cable (either on land or under the sea) close to the Mediterranean coast, the use of rail or road tunnels between France and Spain and the construction of overhead lines at various places (East, West and Central) over the Pyrennes. The conclusions reached were:

- The cable by the Mediterranean coast was too expensive (FF 10 billion, approximately Euro 1.5 billion). The estimated cost was 10 times that of an overhead line through the Central Pyrennes and the cable would have only half the capacity of the line. There were also concerns that the synthetic and GIL technologies had not developed sufficiently for such long distances;

- The road or rail tunnel alternative was dismissed as being too difficult to maintain and if a tunnel were considered to be the best alternative, it would be preferable to construct a separate tunnel for the sole use of the electricity cable;

- Aerial routes to the west and east Pyrennes involved technical problems because the French network is two phase AC whereas the Spanish network is three phase. Any proposed development to the west or east would only operate at 1,200 MVA;

- An aerial route through the centre of the Pyrennes (linking Cazaril and Aragon) was considered superior from a technical position but the 187 km line with 2,300 MVA would run through a natural reserve and the project was abandoned on the French side due to environmental concerns.

Since then further studies have been carried out and a 400kV line between Bescano (F) and Baixas (E) is planned for completion in 2006. It will have a capacity of around 1,200 MVA and run parallel to the future Perpignan-Figueres high-speed railway line. This project is one of the conditions laid down by the Commission for the approval of the acquisition of a majority stake in Hidrocantabrico by EnBW, in which EdF has a 34.5 percent stake.

France/Italy

Several feasibility studies have been carried out into expanding the three current interconnections between France and Italy.

A study was carried out in the mid 1990s into the construction of a new 380kV line between Grande Ile in France and Piossasco in Italy. The project would have yielded additional transmission capacity of 1,400MW. Although authorised by the French authorities the project has been suspended because of authorisation problems in Italy.

Since 1992, there has been a protocol in France whereby EDF should work with other infrastructure operators (e.g. SNCF and auto route companies) to examine the conditions for the cohabitation of major projects. EDF and SNCF have looked into the possibility of using railway tracks and tunnels between Lyon and Turin to lay a 400kV cable.

According to a project study, the tunnel route would involve the laying of a 400kV cable on the other side of the track to the railway cables (and escape routes). This would also involve widening the tunnel from a diameter of 8 metres to 8.4 metres. The estimated cost was:

- FF 750 million for widening the tunnel;
- FF 250 million for equipment to maintain the temperature between 25 and 30°C;
- Between FF 200 and 700 million to reinforce 200 tunnel junctions.

The extra cost was therefore in the order of FF 1.2 to 1.7 billion (Euro 183 to 260 million) compared to an estimated cost of FF 2.6 billion (Euro 400 million) to build a new tunnel solely for the electricity cables. Including the cost of two x 1,000 MVA cables, the total cost was estimated at between FF 3 and 3.5 billion (approximately Euro 500 million). We understand that this project is still under review by RTE and GRTN but it seems unlikely that the railway (and health and safety) authorities will approve the installation of the cables within the main railway tunnel. An option that could be considered in the future where there are dual transport tunnels with a separate service tunnel, is to lay electricity cables within the service tunnel.

A third project involves the installation of a phase shifter transformer in La Praz (France) along the Albertville – Rondissone interconnection. This is expected to increase capacity by some 800MW. This project is proceeding.

<u>France/Belgium</u>

At the request of the Belgian and French electricity regulators, RTE and Elia carried out a study into the options for increasing the interconnections between France and Belgium. This study recommended the stringing of a second circuit on the existing overhead line between Avelgem (B) and Avelin (F) and the completion of the 380kV line between Aubange (B) and Moulaine (F).

For the Avelgem – Avelin connection, underground cables were not seen as an economic option as the overhead line already exists and the only work required is to equip the second circuit. Additionally, had a cable been constructed between the two nodes, there would have been a problem of overloading of the underground cable and of underloading of the overhead line. Additional expense would have to be incurred on phaseshifters to address this problem.

Completion of the 380kV link between Aubange – Moulaine has been considered for some time and the necessary 2 km double circuit line in Belgium has been built. Problems obtaining the necessary permits have prevented the construction of the line in France, principally because the proposed 12 km route was through an urban area. The proposals have been revised to involve either a longer aerial route (18 km) or a section of underground cable. The problem with the cable solution is that it would be limited to one circuit and would create additional expense when connected to the double circuit overhead line.

<u>France/Germany</u>

Plans to improve transmission links between France and Germany centre around the reconstruction of a 105 km 225kV line into a 130 km 400kV line between Vigy and Marlenheim. An overhead line was chosen for cost reasons and the route of the new line was redirected away from residential areas in order to gain the support of local communities. Work commenced on the project in June 2002.

Netherlands/Germany/Belgium

There are currently no plans to construct new lines between the countries, although a two phase shifting transformer has recently been installed in Meeden (NL) to increase capacity from Germany by around 1,000 MW.

Denmark/Germany

The Western Denmark grid is connected to Germany with two 400kV, two 220kV and a 150kV link. In connection with imports from Germany, the limit is currently approximately 800 MW. The constraints arise principally due to internal bottlenecks in southern Jutland and on Funen in Denmark.

Owing to the expansion of wind power in Schleswig-Holstein, the internal transmission capacity in the German network reduces the scope for exports from Denmark. Unless the German increase in wind power capacity is accompanied by network expansions, the export capacity will be further reduced to around 300 MW.

The possibilities of implementing network expansion in western Denmark and northern Germany is being analysed by Eltra and E.ON Netz, but it is unlikely that underground cables will be considered as an option to improve interconnections between the two countries. The only interconnection project being evaluated is upgrading the 106km 220kV line between Flensburg and Kasso to 380kV.

Italy/Austria

The development of international interconnection capacity in Austria has been hindered by the difficulties in completing the 380kV grid, particularly in the Styria region. Discussions have been taking place for 18 years but there are still 9 municipalities who are objecting to the construction of an overhead line that is estimated to cost Euro 120 million. Cabling some part of the 100km route has been considered but APG Verbund maintain that cabling would cost 8 times more than the line and a cable over the whole route would increase electricity prices to customers in the Styria region by 30 percent, a situation that is not acceptable to the regulator. APG maintain that lack of transmission capacity will restrict economic growth and are hopeful that the municipalities can be persuaded to accept the line. An alternative solution may be to pass the additional costs of constructing a cable over a broader range of customers as some of the other beneficiaries of the link would probably be generators in Germany and customers in Italy.

At present the only link between Italy and Austria is a 220kV line. There are plans to improve interconnections through the construction of an 80 km 380kV double circuit line between Lienz and Cordignano with a capacity of 800 MVA. The feasibility study has been carried out but the project has yet to be authorised by the local authorities but it is hoped that the line could be completed by late 2004. The estimated cost is Euro 60 million (which represent Euro 750,000/km and Euro 75,000/MVA).

Some consideration has been given to an additional interconnection between Italy and Austria through a new 52 km railway tunnel near Brenner that will form part of the Austria/Italy high-speed rail link. A consortium including GRTN and TIWAG has carried out an initial feasibility study. As an XLPE cable would necessitate the construction of two compensation stations in the tunnel a further study will look into the possibility of installing a GIL cable. The advantage of this would be that the cable is non-flammable and would not require the compensation stations. However, GIL technology has yet to be established over such a long distance.

Italy/Switzerland

There are 8 interconnections between Italy & Switzerland (2 at 380kV and 6 at 220kV). There are plans to add an additional interconnection through the construction of a 35 km 380kV double circuit with a capacity of 1,500 MVA between San Fiorano Brescia and Robbia. GRTN is developing the project on the Italian side and Ratia Energie is developing the Swiss side. Authorisations in Switzerland are complete. GRTN started the authorisation process and EIA in December 2001, but some local authorities have not yet given authorisation. The cost of the Italian part of the line is estimated at Euro 20 million.

We understand that there are plans to construct an 11km 220kV merchant transmission interconnection between Italy and Switzerland. 9km of the link will be underground XLPE cable. The capacity of the link will be 400MW from Italy to Switzerland and 250MW in the other direction. The estimated total cost of the project is Euro 20 million and the cable is estimated to cost five times the overhead line. In Switzerland the cable will go below the highway connecting Mendisio and Gaggiolo and in Italy the cable will be buried along a disused railway line. The project developers are AET (Swiss utility) and an Italian railway company. Authorisations are being sought and completion is expected by the end of 2005.

Cost benefit analysis of additional interconnection

As an initial assessment of the economic viability of different potential interconnectors, the cost of constructing additional capacity across a number of borders has been compared to the projected benefits. The benefits have been estimated from forward electricity price curves produced by the ICF Consulting power market model (the Integrated Power Model or IPM). Currently, wholesale electricity prices in Italy and Spain are higher than in France and our market modelling anticipates that this will continue to be the case through to 2012 when the situation will reverse due to additional amounts of new capacity in both Italy and Spain. The analysis (see Appendix B) has been carried out on a marginal MW basis, i.e. what benefits would one additional MW of capacity produce. Given the possible impact of additional interconnection on market prices on one or both ends of a link, a more detailed feasibility analysis would have to be carried out for any specific proposal.

The following table shows the per MW benefits (discounted present value of future benefits from electricity trade) of four possible interconnections (between France - Italy and France - Spain) and per MW cost estimates that have previously been made for their construction. The assumptions used and supporting spreadsheet are shown in Appendix B.

Interconnection	Option	Cost Euro million	MW	Cost Euro/MW	NPV of Revenue Euro/MW*
France – Italy	Existing rail tunnel	500	2,000	250,000	317,238
France – Italy	New electricity tunnel	570	2,000	285,000	301,398
France – Spain	Mediterranean Cable	1,500	1,200	1,250,000	(663,602)
France – Spain	Overhead line Central Pyrennes	168	1,200	140,000	466,579

* Revenue is based on 75 percent of the capacity price plus energy revenues net of an estimate for losses (2 percent), outages (3 percent) and maintenance (1 percent for cables and 10 percent for lines)

The analysis shows that there is a cost benefit associated with the interconnections between France and Italy and with the overhead line through the Central Pyrennes. The cable route, however, is not cost beneficial unless the overall cost can be brought down by approximately 50 percent.

Appendix A Overview of the existing underground cables across the EU, Norway and Switzerland

There are over 104,000 km of 380/400kV overhead lines in the Member States of the European Union, Norway and Switzerland plus over 121,000 lines at voltages between 220 and 300kV. There are approximately 5,300 km of underground cables at voltages above 150kV of which 3,200 km are on land.

Voltages of 150 –400kV

Voltage kV	400	400	220-300		150	land cable as percent of total network		
Amounts in km	land	sea	land	sea	land	400 kV	220 kV	150 kV
Austria	56	-	5	-	-	2.3	0.1	-
Belgium	-	-	-	-	225	-	-	5.7
Denmark	134	16	-	152	5	9.0	-	1.3
Finland	34	99	-	-	-	0.9	-	-
France	11	-	828	-	-	0.1	3.1	-
Germany	62	423	35	-	-	0.3	0.2	-
Greece	-	-	-	-	170	-	-	2.1
Ireland	-	-	75	-	-	-	4.5	2.3
Italy	53	316	165	-	222	1.7	1.3	0.7
Luxembourg	-	-	6	-	-	-	2.5	-
Netherlands	-	-	6	-	220	-	0.9	3.7
Norway	36	-	-	64	-	1.2	-	-
Portugal	-	-	11	-	-	-	0.5	-
Spain	-	15	92	-	-	-	0.6	-
Sweden	4	319	-	87	7	0.4	-	0.1
Switzerland	-	-	22	-	-	-	-	-
UK	132	327	755	150	-	1.3	5.6	-
Total	522	1,515	2,000	453	849	1.0	2.3	-

Source: UCTE, Nordel and direct contact with TSOs

Low, medium and high voltages

Voltage	60-150kV		MV		LV	
km	Overhead	Under ground	Overhead	Under ground	Overhead	Under ground
Austria			34,200	22,800	55,250	9,750
Belgium	4,777	395	9,750	55,250	60,480	47,520
Denmark	10,256	1,902	32,450	22,550	32,200	59,800
France	50,111	1,896	393,190	180,810	463,888	168,112
Germany	71,609	4,740	190,000	285,000	231,500	694,000
Italy	36,228	449	215,801	115,380	498,960	210,327
Netherlands	6,011	3,655	-	101,900	350	145,000
Norway	19,001	624	63,480	28,520	114,700	70,300
Portugal	8,953	358	48,720	9,280	90,720	21,280
Spain	37,639	559	96,448	26,025	241,102	40,141
Sweden	15,000		93,440	52,560		
UK	21,836	3,789	204,600	167,400	71,360	305,370

Source: Europacable and Sycabel and direct contact with TSOs

Austria

Austria has only added 8 km of 380kV underground cable since 1990, principally in urban areas and linking power plants to sub-stations. However, plans by Austrian Power Grid to complete the 380kV ring in Austria, particularly in the area between the south of Burgenland and the east of Styria, have been stalled with several local communities refusing to allow right-of-way for the line. The communities are arguing for an underground cable, which, APG contends is eight times costlier than an overhead line. Permit proceedings to complete the 380kV ring in the Salzburg area with the construction of a 150 km overhead line are progressing more smoothly.

Consideration is also being given to the construction of an additional interconnector with Italy running through the Brenner Pass. The proposed technology for the link is GIL although no decisions have yet been made on whether to proceed.

Belgium

The Belgian transmission network operated by Elia has six different voltages between 30kV and 380kV. Almost all the network at 36kV and below is underground. Some 8 percent of the 70kV network and 11 percent of the 150kV network is also underground. EHV networks are all overhead lines.

There has been minimal new investment in new overhead lines in Belgium over recent years due to a government policy restricting the construction of new lines. In 1992, Electrabel made a declaration of principle about the development of new electricity networks. Since then, there has been a ban on the construction of overhead lines in conurbations and new overhead lines outside the conurbations may only be installed along existing or planned general infrastructure projects (i.e. railways, highways, waterways and airports). It was also agreed not to increase the total number of kilometres of overhead lines at voltages of 30 – 220kV. Following Elia’s appointment as TSO for Belgium, they plan to discuss with the regulator whether this policy should be maintained, or amended, given the impact these measures have on the cost of transmission activities.

Major investments over the past few years have been the construction of a 14 km 150 kV underground cable between Braine-L’Alleud and Baisy-Thy and a 24 km 150kV underground cable between Avernas-Brustem-Landen. This latter project is to supply the Brussels-Liege HST rail link. Other 150kV cable projects are planned (e.g. to connect offshore wind farms) but the award of the appropriate permits has often been delayed.

Denmark

Denmark has two separate high voltage grid networks. The network in Western Denmark is operated and managed by Eltra, and in Eastern

Denmark, Elkraft Transmission own the 400kV grid and Elkraft System operate as TSO.

The Eltra network is connected by DC sea cables to Norway and Sweden at voltages of 250kV. The Elkraft network is connected to Sweden via AC cables at voltages of 400kV (two cables established in 1973 and 1985), 132kV (established between 1951 – 1964) and 60kV. The total capacity is around 1,900 MW. The Eastern Denmark grid is also connected to Germany by a 166 km 400kV DC cable with a capacity of 600 MW. This was completed in 1995.

A decision has also been made to connect the two systems. The capacity will be 300 MW and a 70 km 400kV underground cable (Green Belt) will be laid. It is expected to be operational by 2004.

Within Europe, Denmark has been at the forefront of the replacement of transmission lines with cables following a decision in the early 1990s to restructure the power supply to the greater Copenhagen area. This included replacing six 132kV overhead lines linking the metropolitan area with the rest of Zealand with two new 400kV cable links and substations in the northern and southern parts of the city. More than 100 km of 400kV XLPE insulated cable were needed to form the two independent power links that went into operation in 1997 and 1999 respectively.

Finland

The transmission network in Finland consists of 3,793 km of 400kV overhead lines and 2,500 km of 220kV lines. There is also 34 km of underground land DC cables and 99 km of submarine cable representing the Fenno-Skan link with Sweden. Cables are used minimally, because they are considered by Fingrid to be unreasonably expensive at long transmission distances typical of Finland, and because they restrict land-use in the area where the cable has been buried. In the most densely populated areas, such as Helsinki, there are some 110kV cables.

Further increases in capacity between Finland and Sweden are under consideration. The options are increasing the capacity of the Fenno-Skan DC cable by 10 to 20 percent and the construction of a third 400kV AC line in the North. The feasibility study for this line is due to be completed at the end of 2003.

France

RTE (Gestionnaire du Réseau de Transport d'Electricité) operates two sub-systems: a 400kV main transmission and interconnection network which is used for energy exchanges between the French regions and other countries, and a regional sub-transmission network with three voltage levels: 225kV, 90kV and 63kV. Approximately 3 percent of the 63/90kV and 225kV network is buried, principally in urban centres.

In 1997, an Accord was agreed whereby EDF would bury 20 percent of all new high voltage lines. RTE state that this was achieved in 1998 when one quarter of all new HV lines (i.e. 63kV – 150kV) were laid underground. In the 1999 Accord, which runs for three years, this target was raised to 25 percent. It was also agreed that there would be no increase in the total length of the overhead line network. Priority is given to investments in urban areas, where the voltages are lower and although France is one of the most advanced countries when it comes to burying lines between 150kV and 230kV, there has been almost no undergrounding of 380kV lines in recent years.

Major proposed projects require approval from the National Commission of Public Debate (an independent body) plus the acceptance from local authorities. The authorisation process usually takes at least five years.

France has been using XLPE technology at lower voltages since the 1970s and has a built a small (300 metres) GIL linking a nuclear power plant to a substation. There are some concerns in France over the future use of GIL, mainly to the use of SF_6, which is a contributory factor to greenhouse gas.

Germany

The structure of the German electricity industry is complex with over 900 electricity companies, many of them small municipal utilities. The high voltage grid, though, is now owned by four large integrated companies – E.ON Netz, RWE Net, EnBW Transportnetze, which are subsidiaries of the three largest German electricity companies and Vattenfall Europe AG, which controls HEW, BEWAG and VEAG. There is approximately 35 km of buried 220kV and 62 km of 380/400kV underground cables principally in densely populated centres such as Berlin.

Authorisation for new transmission projects is set out in the Environmental Planning Act 1990. This stipulates the planning procedures to be adopted for construction of overhead cables of 110kV and above. The procedures set out in this legislation include the preparation of the planning document and the involvement of affected municipalities. An EIA is also required. Planning permission is not as strict as some other EU Member States and overhead pylons are generally exempt from the federal building planning permission procedures and regulations. A planning application to construct a tower simply has to be submitted approximately 14 days before construction commences. Many lines and cables are situated close to railway lines and motorways since the land is owned by the federal or regional authorities and has a low ground cost/rent.

Greece

Greece’s transmission network consists of around 11,000 km of power lines and has until recently operated in isolation from the western European grid systems. The interconnected mainland transmission system consists of 400kV, 150kV and 66kV lines and is linked to neighbouring Albania, Bulgaria and the former Yugoslavia through lines of 400kV and 150kV. There is a new DC 400kV overhead line (Galatina-Arachthos) that links Greece with Italy.

Ireland

The national grid in Ireland comprises over 5,800 km of high and medium voltage lines and cables. There is approximately 75 km of underground cable principally at 220kV in urban areas of Dublin.

In terms of future interconnections, Eirgrid and National Grid in England & Wales are considering the construction of a sea cable between Ireland and Wales.

Italy

The Italian network consists of 9,761 km of 380kV lines, 12,557 km of 220kV lines and 20,332 km of 150/132kV lines. There is a 380kV AC cable linking Sicily with the Italian mainland (and there are plans to double the capacity) and 44km of DC land cable that forms part of the sea cable link with Greece.

The link between Otranto (It) and Aetos (Gr) required the laying of 163 km of submarine cable, which for a large section of its length lies at a depth of around 1,000 metres (a record for sea cables). At the Italian end, the 44 km of underground cable is an oil-filled single DC conductor that connects to a conventional substation at Galatina via a DC-AC conversion station. The project is designed to accommodate a doubling of transmission capacity in future years.

A report prepared in July 2000 by Terna and PPC into the construction of the HVDC link showed that total cost of the 207 km of sea and land cables was Euro 137.5 million, which equates to Euro 664,000/km. The converter stations cost approximately Euro 40 million each.

There also DC 200kV sub-sea cables linking Corsica with Sardinia and Italy with Corsica. There are plans to build a direct link between Italy and Sardinia and a feasibility study is being carried out. At 220kV there are underground cables in urban centres including Rome, Naples and Turin. The only land cable project under discussion at present is part of a new 27 km 380kV line linking Turbigo with Rho in the Milan area. A feasibility study has been carried out by Terna, but the project has not yet been authorised.

Cabling may be considered in order to complete the 207 km 380kV line between Santa Sofia and Matera. The project commenced in 1992 and 200 km (97 percent) has been constructed but problems with remain with the final 7 km. Authorisation has been suspended by the regional authority due to planned changes in the line and an EIA has yet to be approved. Once completed, the line will link up with the Italy – Greece interconnector.

Other planned investments include a 40 km 380kV line linking Redipuglia and Udine. This would link up with the planned Cordignano – Lienz interconnection with Austria. There are also plans to build a 215 km 380kV line between Rizziconi and Laino in southern Italy to reinforce the network between Sicily and Calabria. Work is due to start in April 2003 and the line should be operational by April 2006.

There are also plans to study a new interconnection between Italy and Slovenia.

Luxembourg

There are no 380kV lines at present in Luxembourg. The 220kV network measures around 236 km of which 6 km is underground cable.

Netherlands

The 380kV circuit length in the Netherlands is approximately 2,000 km and is all overhead line apart from a few cables close to power stations and industrial sites. There is over 220 km of underground cable at 150kV (mainly owned by TZH). There has been only minimal investment in extending the network over recent years, due in part to the difficulties in getting planning approval for new transmission lines. Some new lines are plans and cabling will be considered if there is significant environmental opposition, but Tennet prefer overhead lines as they are cheaper and more reliable.

Tennet and National Grid of the UK have established a joint venture (BritNed) to assess the feasibility of the construction of a 1,320 MW sub-sea DC cable link between the Netherlands and the UK.

Norway

Over the past ten years, Statnett has not invested significantly in new power lines or cables with the exception of a subsea cable between Norway and Denmark (Skagerrak). Planned investments within Norway include the laying of a 130 km 300kV line between Klaebu and Sunndalsøra. Statnett is also planning to develop new subsea cable links with the Netherlands (NorNed) and the UK (North Sea Interconnector), although Statnett (with Statkraft and E.ON) terminated their discussions to construct the planned Viking Cable between Norway and Germany.

The long-term strategy aimed at expanding the transmission network in Norway includes construction of new lines at 420kV, reconstruction of existing 300kV lines to 420kV including reinforcement of towers. No underground land cable projects are included in the plan.

Portugal

The use of cables as an alternative has not been a major consideration in Portugal although Rede Eléctrica Nacional (REN) is required to carry out an EIA for ministerial approval on all new power line investments. Only 11 km of the 220kV network is cable. The main transmission priorities in Portugal in recent years have been to improve the interconnections with Spain. The increase in capacity of the Balboa - Alqueva line is expected to be completed in 2004 and a new 86 km line with 1,350 MVA (Douro International) linking Recarei and Aldeadavila is expected to be completed by 2006.

Spain

The Spanish grid network has expanded rapidly in recent years and Red Electrica de Espana (REE) currently has some 1,800 km of 400kV lines under construction. As with Portugal, the use of cables as an alternative has not been a major consideration although as elsewhere in the EU, all new HV power lines with a length in excess of 15 km are required to have an EIA.

Construction of new overhead lines has met strong opposition in Spain, but according to REE, the local community in Tarifa also opposed the underground cable link with Morocco.

Spain has been funding research into superconductivity and is looking closely into the developments in GIL, which was considered for the 400kV underground project at Madrid airport.

Sweden

The Swedish network consists of some 10,643 km of 400kV and 4,295 km of 220kV lines principally running north to south. There is only 4km of 400kV cable and 7 km of 130kV cable. There are HVDC cable links with Denmark, Germany and Poland.

As with the other Nordic countries, overhead lines are preferred to cables at 400kV. The country is sparsely populated and the average length of lines is much longer than in much of Continental Europe.

A study is underway concerning increases in transmission capacity between Norway and Sweden, in part due to planned increases in capacity between Sweden and Finland. These plans will focus on new lines rather than cables with the exception of a possible sub-sea HVDC cable between Norway and southern Sweden.

Switzerland

The high voltage grid consists of some 1,600 km of 400kV lines and approximately 5,000 km of 220kV lines and is managed by seven integrated companies: Atel Netz, BKW-FMB and EOS form the ‘western group’ and CKW, EGL Grid, EWZ and NOK form the ‘eastern group’. In 1999 the companies established ETRANS whose principal role is to coordinate the power transmission between the grids. There is, though, a significant amount of uncertainty regarding the future electricity market in Switzerland, including the future organisation of the Swiss electricity grid.

United Kingdom

There are four transmission systems in the UK, each separately owned and operated. The largest system is owned and operated by National Grid in England & Wales. Scottish Power owns and operates the system in the south of Scotland and Scottish and Southern Energy own and operate the system in the north of Scotland. The fourth is the transmission system operated by Northern Ireland Electricity.

National Grid's transmission system operates at 400kV and 275kV and has an electrical circuit length of approximately 10,400 km of 400kV lines, 3,615 km of 275kV line, 132 km of 400kV underground cable and 425 km of 275kV cable in England & Wales. Most of the 275kV network was constructed in the 1950s and 1960s with the 400kV network being constructed in the 1970s. There is an interconnector with Scotland that has a capacity of 1,600 MW and also operates at 400kV. The link is currently being strengthened by the construction of a 75 km line (5.7 km underground) in North Yorkshire. Once completed the interconnector will be upgraded to 2,200 MW.

National Grid's network is connected to France via a 270kV DC cable with a capacity of 2,000 MW. A 500 MW sub-sea interconnector has recently been completed to link Northern Ireland with Scotland. The transmission systems in Scotland and Northern Ireland operate principally at voltages of 275kV and 132kV.

In England & Wales, approval for the construction of all but the most minor overhead line proposals rests with the Secretary of State for the Department of Trade and Industry. As undergrounding is considered to be a "permitted activity" for the utilities, consent is not needed for installation of underground cables. As part of any approval process, the construction of an overhead line of 220kV or more and over 15 km in length requires an Environmental Impact Assessment. The government can also request an EIA for construction of any overhead line in a sensitive area or any line with a voltage above 132kV. In practice, these are rarely required.

Applications for overhead line projects are notified to the relevant local planning authorities. If they object to the planned line, the Secretary of State is required to call for a public enquiry. A recent case was the 75 km line between Middlesbrough and York. Significant public concern was raised over the decision to put overhead lines, rather than cables, through the Vale of York. An application to construct the line was made in 1991. Following several years of public enquiries and hearings it took 10 years for all consents and wayleaves to be put in place. National Grid was not in favour of an underground cable on the grounds of cost (the overhead line was expected to cost £540,000/km and the cable £8.9 million/km, a cost factor multiple of 16 times) and environmental concerns over a 15-metre swathe of sterilised land through the countryside. The UK government took the view that the additional cost could not be justified and the aerial route was eventually given the go-ahead with the exception of a 5.7 km cable section.

More recently, the UK government announced that it was examining a scheme to link wave and wind farms to the national grid by running a sub-sea cable down the west coast of Scotland and England.

National Grid is also the owner and operator of the Basslink Project, a major Australian energy initiative that will allow the trade of electricity between Tasmania and the mainland. This $500 million electricity interconnector will also allow Tasmania to enter the Australian competitive wholesale market.

The Basslink interconnector will run from Loy Yang in Gippsland, Victoria across the Bass Strait to Bell Bay in northern Tasmania. The HVDC 295 km undersea cable component will be among the longest of its type in the world. Basslink will have the capacity to operate at 480 MW continuously or up to 600 MW for some hours to provide for peak export demand.

In September 2002 Basslink received the final approvals from the relevant authorities to enable the project to proceed. Pirelli is the lead contractor to build the cable and expects to lay down its three components -each one about 100 km long- on the seabed in early 2004. Siemens is the lead contractor for building the overhead line. The project is expected to be commissioned in 2005/06.

Transmission and Distribution losses in the European Union, Norway and Switzerland (2000)

Country	T&D losses* percent	percent EHV underground	percent MV/LV underground
Finland	3.7	0.5	n/a
Netherlands	4.2	0.2	100
Belgium	4.8	-	59
Germany	5.1	0.3	70
Italy	7.0	1.0	28
Denmark	7.1	8.2	63
Switzerland	7.4	-	n/a
France	7.8	1.8	29
Austria	7.8	0.1	27
Sweden	9.1	0.3	n/a
United Kingdom	9.4	3.8	63
Portugal	9.4	-	18
Norway	9.8	0.4	36
Ireland	9.9	3.5	n/a
Spain	10.6	0.3	19
Average	7.5	1.7	46
Average – EU	7.3		

* International Energy Agency

Appendix B Cost Benefit Analysis of new interconnections

Basic assumptions used

- All values are expressed in terms of a marginal MW of capacity;
- A capacity of 2,000MW was assumed for the Italy-France projects and 1,200MW for the France-Spain interconnection;
- Capacity prices and energy prices are the results from a core run of the IPM (i.e. ICF Consulting's main tool for price forecasting);
- These forward prices are based on marginal production costs estimates and do not take into account of possible strategic behaviour by generators (e.g. market power);
- The capacity revenue between France and Italy (as well as between France and Spain) is the sum of the capacity price in each country, less a 25 percent reduction due to the interconnections between the two markets;
- The energy revenue is the difference between the energy prices in the two neighbouring countries, less 1 percent for maintenance (10 percent in the case of the overhead line), 2 percent for losses and 3 percent for outages;
- The NPV is the net present value of investing in 1 MW of interconnection capacity, based on a 6 percent discount rate between 2005 and 2025;
- Cost estimates are taken from the feasibility studies carried out by the transmission companies;
- Under the above assumptions, the only project not to have a positive benefit is the Mediterranean cable between France and Spain.

Cost Benefit Analysis of new interconnections

Capacity prices (Euro/kW year)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
France	5.80	9.36	12.92	16.49	20.05	23.61	25.53	27.45	29.38	31.30	33.22	33.37	33.51	33.66	33.80	33.95	35.27	36.58	37.90	39.21	40.53
Italy	7.10	9.38	11.66	13.95	16.23	18.51	19.96	21.42	22.87	24.33	25.78	25.95	26.12	26.28	26.45	26.62	27.65	28.68	29.71	30.74	31.77
Spain	15.27	18.00	20.73	23.45	26.18	28.91	30.02	31.13	32.25	33.36	34.47	34.13	33.79	33.45	33.11	32.77	34.91	37.05	39.19	41.33	43.47

Capacity revenues (Euro/MW year)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
France-Italy	9,675	14,058	18,441	22,824	27,207	31,590	34,122	36,654	39,186	41,718	44,250	44,486	44,721	44,957	45,192	45,428	47,187	48,947	50,706	52,466	54,225
France-Spain	16,778	20,535	24,293	28,050	31,808	35,565	37,490	39,414	41,339	43,263	45,188	45,059	44,930	44,801	44,672	44,543	46,920	49,298	51,675	54,053	56,430

Energy prices (Euro/MW year)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
France	29.40	29.81	30.22	30.64	31.05	31.46	31.33	31.20	31.07	30.94	30.81	30.47	30.14	29.80	29.47	29.13	28.97	28.81	28.65	28.49	28.33
Italy	36.86	36.02	35.19	34.35	33.52	32.68	32.05	31.42	30.80	30.17	29.54	29.19	28.83	28.48	28.12	27.77	27.65	27.54	27.42	27.31	27.19
Spain	35.12	34.37	33.62	32.86	32.11	31.36	30.80	30.25	29.69	29.14	28.58	28.28	27.98	27.68	27.38	27.08	26.81	26.55	26.28	26.02	25.75

Energy revenues (Euro/MW year)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
France-Italy (cable)	53,993	43,602	33,210	22,819	12,427	2,036	2,036	6,107	5,592	1,327	2,937	3,176	3,415	3,653	3,892	4,130	3,797	3,464	3,131	2,798	2,465
France-Spain (cable)	39,651	29,952	20,253	10,554	855	7,170	3,517	136	3,789	7,442	11,095	10,875	10,654	10,434	10,214	9,994	10,935	11,877	12,818	13,760	14,701
France-Spain (line)	12,793	3,669	5,455	14,578	23,702	31,229	27,477	23,724	19,972	16,219	12,467	12,430	12,394	12,357	12,320	12,284	11,220	10,156	9,092	8,028	6,964

NPV of capacity and energy revenues in 2005 (Euro/MW)

France-Italy (cable)	567,238	(A)
France-Spain (cable)	586,398	(B)
France-Spain (line)	606,829	(C)

Capital cost of a new link (Euro/MW)

France-Italy (cable)	250,000	(D)	(widening an existing railway tunnel)
France-Italy (cable)	285,000	(E)	(a new tunnel specifically built for the cable)
France-Spain (cable)	1,250,000	(F)	(a new Mediterranean cable)
France-Spain (line)	140,250	(G)	(a new ovehead line, Cazaril-Aragon)

Net benefit of the Italy-France link (Euro/MW)

France-Italy (cable)	**317,238**	=(A)-(D)
France-Italy (cable)	**282,238**	=(A)-(E)
France-Spain (cable)	**-663,602**	=(B)-(F)
France-Spain (line)	**466,579**	=(C)-(G)

Appendix C Sources of Information

The main sources of information that have been used in the realisation of this study were:

- Web-sites of the Transmission Owners and Transmission System Operators;
- Direct contact with Transmission Owners, Regulators, Trade Associations and Equipment Suppliers;
- “European Energy Infrastructure, Fighting congestion and building links”, European Commission;
- Report into New Technologies for the Undergrounding of Electricity Lines at High and Very High Voltages, Assemblee Nationale de France, 19 December 2001;
- Accord “Reseaux Electriques et Environnement” 2001-2003, January 2002;
- Guidance on the Electricity Works (Environmental Impact Assessment) (England & Wales) Regulations 2000;
- Nordic Grid Master Plan 2002;
- “Analysis of Electricity Network Capacities and Identification of Congestion”, Institute of Power Systems and Power Economics of Aachen University of Technology (IAEW) and Consentec Consulting, December 2001;
- “Undergrounding Electricity Cables” 10 January 2002, Ministry of Energy and Utilities, New South Wales Government;
- “Electricity Undergrounding in New South Wales” Final Report to the Ministry of Energy, Independent Pricing and Regulatory Tribunal of New South Wales, May 2002;

Appendix D Glossary

AC	Alternating electric current that reverses in direction and fluctuates in voltage requiring mechanisms to stabilize both voltage and frequency.
Conductor	Wire strung between towers for transmitting electricity.
CIGRE	International Congress on Large Electrical Networks.
DC	Direct electric current that flows in one direction with little or no voltage fluctuation.
EHV	Extra high voltage (i.e. 220/275/380/400kV networks).
EIA	Environmental Impact Assessment.
EMF	Electronic and Magnetic Field.
ETSO	European Transmission System Operators Association.
GIL	Gas-insulted line/cable.
Grid	A synchronized transmission network that delivers electricity from generating stations to local distributors and other users at high voltage.
Horizontal network	Interconnections, lines and transmission sub-stations at voltages of 380kV and above.
HTS	High Temperature Superconductivity.
HV	High voltage (60 to 150kV) network.
Reactive power	The electricity that establishes and sustains magnetic fields of alternating current equipment. Reactive power must be supplied to equipment such as transformers.
System operator	The entity responsible for monitoring and controlling the electricity system.
TSO	Transmission System Operator.
UCTE	Union for the Coordination of Transport of Electricity.
Vertical network	Access of generation and load onto the transmission network.

Wayleave	Agreement granted by the landowner to the transmission company to permit the installation of equipment on, over or under the land in return for annual payments.
XLPE	Extruded cross-linked polyethylene.

ICF Consulting

3rd Floor, Hamilton House, Mabledon Place, Bloomsbury,
London WC1H 9BB
United Kingdom

Switchboard: +44 (0) 20 7554 8730
Fax: +44(0) 20 7554 8731

www.icfconsulting.com