EU COMMISSION

DIRECTORATE GENERAL FOR ENERGY AND TRANSPORT

Study TEN-Energy Tunnel for the analysis of synergy between transport and energy sectors by high voltage transmission in rail-road tunnels in EU25 (including Bulgaria, Romania, Croatia)

Project Summary

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1. Problem statement

The guidelines for Trans-European Energy Networks (TEN-E) adopted by the Council and European Parliament set out priority projects, which have been identified as the most important for security of supply or for the competitive operation of the internal energy market (IEM).

The opening of the internal electricity market has considerable effects to the cross-border exchanges of electricity. The exchange volumes have increased and the flow patterns have become more dynamic. However, market actors are faced with a lack of available capacities causing cross-border congestions and refusal of access. The construction of electricity transmission lines on the priority axes laid down in the TEN-E guidelines is delayed for a number of important projects. This is notably due to strong objections raised by local groups to the construction of new transport corridors in the situation of national barriers such as the Alps or the Pyrenees.

In this context, the objective of the present study is:

> *The identification of possible locations for synergy between trans-European rail/road transport tunnels and the reinforcement of cross border electricity interconnections in EU 25.*
>
> *The analysis of the technical feasibility of implementing high voltage transmission links in a selection of existing or future tunnel projects.*
>
> *The analysis of the new technologies in AC/DC links compatible with the requirements for installation in a tunnel.*

2. Methodology

The adopted study methodology includes the following stages:

First, the electricity cross-border countries congestions in EU25 are analysed on the base of existing studies.

Second, it is checked if rail or road tunnels (will) exist at the locations where it will be necessary to reinforce or create new cross-border electricity interconnections.

A priority list of 30 rail/road tunnels projects is then progressively selected for which a possible synergy with electric priority axes is identified.

The priority list is shortened to 8, then to 5 more promising projects, using a simplified multi-criteria analysis.

Each of these five selected projects is studied in detail:

The detailed study starts with a collect of information regarding the current status of the design studies, the construction, the safety requirements and the cross-section of the tunnel.

The detailed study includes notably the analysis of necessary technical adaptations, the diagnose on HV transmission feasibility and the recommendation of the transmission technology to be adopted

In support of the tunnel detailed studies, the new technologies in AC/DC links compatible with the requirements for installation in a tunnel are analysed from the technical and economic points of view. These new technologies available are:

AC transmission with XLPE insulation,

DC transmission with dry insulation,

Gas insulated line (GIL).

3. Major Results

3.1. Stage 1: First selection of potential tunnel synergies with electricity priority axes

From the detailed analysis of electricity cross-border congestions the following conclusions can be drawn:

On one hand, significant price differences exist within the European internal market. These differences result in increased demand for commercial electricity transit at specific borders. The demands for commercial transit are reflected notably by the prices of cross-border capacity auctions.

On the other hand, there is still a low and un-sufficient level of electricity cross border trade due to technical, political and environmental constraints and principally to the difficult Alpine and Pyrenean terrains.

The main needs for cross-border import in the European countries occur:

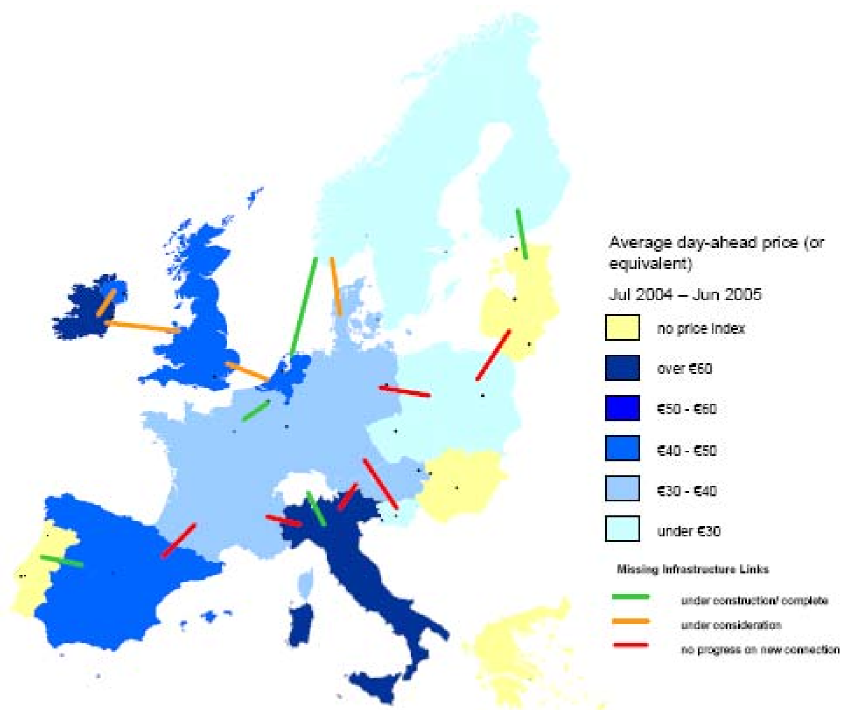
from north and north-eastern countries characterized by a lower day-ahead electricity price to central countries,

from central countries to Great Britain and Spain,

and especially from France, Germany and Austria to Italy, passing directly through one border or indirectly through Switzerland.

It is worth mentioning also the increased future wind generators capacity in the north of Europe that will exacerbate the north-south cross border congestions in the future.

These conclusions are illustrated in the next figure that shows the correlation existing between the missing electricity links and the price differences observed on the internal market:



Correlation between missing electricity links and price differences on the internal market

The comparison of the needs in cross-border links with the existing and future rail/road tunnels has enabled to build up a first selection of thirty potential tunnel synergies illustrated in the following table:

Tunnel/bridge	Countries	Type	Length (km)	Calendar	RTE-T axis	TEN-E axis
Brenner	AU / IT	Rail basis	56	2007-15	N°1	EL2
Messina strait	IT	Bridge	3.3	2005-15	N°1	EL2
Eurotunnel	GB / FR	Rail submarine	50	existing	N°2	EL5/6
Guadarrama	SP	Rail basis	28	under cst	N°3	EL3
Perpignan-Figueras	FR / SP	Rail	8	2005-08	N°3	EL3
Middle of Pyenees	FR / SP	Rail connection	unknown	2013-20	N°16	EL3
Somport	FR / SP	Rail re-used (saf. gal.)	7.9	existing	N°16	EL3
Somport	FR / SP	Road	8.6	existing	N°16	EL3
Lyon-Turin (Mt Cenis)	FR / IT	Rail basis	53+12+(16)	2004-18	N°6	EL2
Frejus	FR / IT	Road	13	existing	N°6	EL2
Frejus	FR / IT	safety gallery	13	under study	N°6	EL2
Oresund	DK/SW	Rail+Road (tun+isl+br.)	4+4+7.5	existing	N°11	EL7
Fehmarn	GE/DK	Rail+Road	19	2007-15	N°20	EL7
Hallandsas Ridge	SW	Rail	17	2011	N°12	EL7
Gothard (old)	CH	Road	16	existing	N°24	EL2
Gothard (new)	CH	Rail basis	57	2013	N°24	EL2
Lötschberg (old)	CH	Rail	35	existing	N°24	EL2
Lötschberg (new)	CH	Rail basis	42	2007	N°24	EL2
Zimmerberg	CH	Rail basis	20	2013	N°24	EL2
San Bernardino	CH / IT	Road	7.5	existing	N°24	EL2
Simplon	CH / IT	Rail	18	existing	N°24	EL2
Grand St Bernard	CH / IT	Road	7	existing	N°24	EL2
Mont-Blanc	CH / IT	Road	12	existing	N°24	EL2
Monte Ceneri	CH / IT	Road	1.4	existing	N°24	EL2
Monte Ceneri	CH / IT	Rail basis	15.4	under cst	N°24	EL2
Arlberg	AU	Road	14	existing	N°24	EL2
Arlberg	AU	Rail	10	existing	N°24	EL2
Tauern	AU	Rail	9	existing	N°24	EL2
Katschberg	AU	Road	6	existing	N°24	EL2
Karawanken	AU / SLO	Road	8	existing	N°24	EL2

This table highlights for each tunnel (or bridge) project the countries involved, its type and length and the priority axes to which it pertains for transport (RTE-T) and electricity transmission (TEN-E).

The projects presented in the table include existing or future rail and road tunnels, some bridges associated with tunnels, and even possible safety galleries under study and associated with tunnels.

The main sites concerned are located in the Alps and Pyrenees or at maritime straights (for examples between central Europe and northern countries or Great Britain). These sites are illustrated on the following map of European countries:

3.2. Stage 2: Selection and multi-criteria analysis on eight more interesting synergies:

Among the first list of possible synergies, a short list of eight more promising rail/roads tunnels were selected for further analysis on the basis of their global characteristics. These tunnels are:

the future Brenner rail basis tunnel (Austria - Italy),

the future Lyon - Turin rail basis tunnel (France - Italy),

the future Monte Ceneri rail basis tunnel associated with the Gothard and Zimmerberg basis tunnels in more internal Swiss territory (Germany-Italy through Switzerland),

the Simplon tunnel associated with the future Lötschberg rail basis tunnel (Germany-Italy through Switzerland),

the submarine railway Eurotunnel (France – Great Britain),

the disaffected Somport rail tunnel re-used as safety gallery for the existing Somport road tunnel (France- Spain),

the under study safety gallery associated with the existing Frejus road tunnel (France – Italy),

the Perpignan – Figueras (Perthus tunnel) future rail tunnel (France-Spain).

These eight tunnels were then compared by means of a multi-criteria analysis (ref. to section 1.5. of the Final Report), focusing on the most important requirements for acceptable feasibility, for example:

a long distance compulsory to obtain acceptable investment and operation costs per km of tunnel length. This generally can only be achieved with basis rail tunnels,

the presence of pilot or service gallery to introduce the transmission cables,

an easy access to the electrical grid,

the matching with highest electricity congestion in the future,

the highest environmental impact avoided cost,

the status of the project(planned, under construction, existing, …).

This analysis led to rank the projects and to reduce the number of most promising tunnels. Five specific case studies were then carried out to determine the technical feasibility of installing HV electrical links in the tunnel or in its pilot gallery.

3.3. Stage 3: Five case studies

The results of the five case studies on the feasibility of installing HV electrical links in the tunnels are summarized on the following table:

Case study name		Length (km)	Type	Transmission solution recommended	Status	Specificities
1. Brenner tunnel	AU / IT	56	Rail basis bi-tube +pilot gall.	AC 400 kV GIL (Gas Insulated Line) in pilot gallery (+/-3000 MW)	Tunnel currently under design Studies of elec. transmission are under way	The pilot gallery suitable for installing the VHV link will be built before the construction of the two rail tubes. Thermal behaviour must be investigated in function of power transmitted. Electromagnetic interference with railway to be investigated further Electromagnetic impact compatible with reference values
2. Lyon - Turin (Mont Cenis)	FR / IT	53+12+(16)	Rail basis bi-tube	DC link with 2 cables per tunnel permitting a bipolar link in each tunnel (+ 500 kV/- 500 kV) (1500-2000 MW)	Tunnel currently under design Today, no elec. transmission is still envisioned	When losing a bipolar link , the other link in the second tunnel is still operable The solution implies a number a adaptations to the present design perfectly feasible at this stage.
3. Eurotunnel	GB / FR	50	Rail subm. bi-tube + service gallery	DC link with 2 bi-pole links (2x1000 MW)	Tunnel in service Studies of elec. transmission are under way	Only DC link acceptable due to the problem of synchronizing the UK and other European transmission networks The feasibility studies of implementing DC link have been completed
4. Monte Ceneri associated with Gothard and Zimmerberg	CH / IT	15.4	Rail basis Two single -track tunnels	DC link but not feasible at this stage	Tunnel currently under construct. Today, no elec. transmission is still envisioned	Optimal solution would be to combine the three basis tunnels of Monte-Ceneri, Gothard and Zimmerberg in a whole DC link but physical progress of construction made so far has a great impact on such installation: especially for the Gothard tunnel where the base raft is already placed in a number of areas. Not compatible at locations where there are linking/evacuation galleries Only HV link possible in Monte Ceneri tunnel, provided that a decision is made before construction starts (but not economic) At this stage a HV link is excluded in this set of tunnels
5. Somport tunnel	FR / SP	7.9	Road + Rail single-track	AC three-phase 220 kV link	Old rail tunnel re-used as safety gallery for the new road tunnel Today, no elec. transmission is still envisioned	The old railway could accomodate a classic AC link at the voltage of the nearest networks i.e. 220 kV. The magnetic field remains within the acceptable limits

This table shows that the implementation of electricity transmission is feasible in the Brenner tunnel, the Lyon-Turin tunnel, the Eurotunnel and the Somport tunnel. However a HV link seems excluded at this stage in the set of tunnels Monte Ceneri – Gothard – Zimmerberg, due to the difficult adaptation of these projects already under construction.

The possible future safety gallery of the Frejus road tunnel was not investigated at this stage for the following reasons:

This tunnel is located not far from the future Lyon-Turin tunnel. For this last tunnel the feasibility indicates that it is possible to install a VHV DC link of substantial transit capacity and with maximum safety.

It was deemed more judicious to examine the possibility of a connection between France and Spain (Somport tunnel) instead of investigating two possibilities between France and Italy.

The safety gallery of the Frejus road tunnel is presently only considered/studied, and it is still not certain that it will be built one day. In turn, the Somport tunnel exists.

That safety gallery is comparatively short. It may be possible to accommodate an AC link at either 220 or 400 kV with a relatively poor connection to the grid, compared to the Lyon-Turin link's connection to the grid.

4. Cable technologies

The study of new cable technologies carried out in support of the five case studies leads to the following major results:

AC - XLPE insulation

This technology is well under control for voltage levels up to 400 kV and even higher. Development work has been done with a view to achieving a better transit capacity with a same cable cross-section.

From the environmental point of view this technology presents a risk of explosion and subsequent fire, and so requires particular precautions.

DC - Dry insulation

This technology is fairly recent and is now under control. Long-term type-tests are underway on cables of ± 500 kV level.

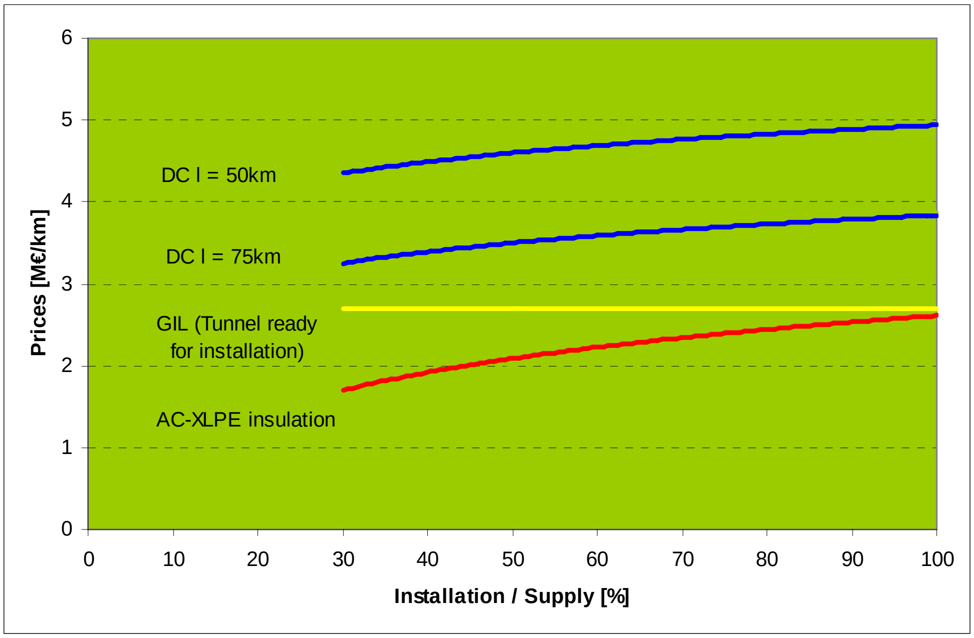
In case of failure, the risk is similar to that expected for a 20 kV AC cable. There is no experience feedback.

GIL technology

This technology is an extension of the GIS technology. It is well under control, but the experience until now with operational installations relates to links that are of relatively short length. This technology permits very high capacity transit.

In case of failure, the tests performed demonstrate no burn-through of the enclosure. There is no real experience feedback.

The following figure compares the installation price of these technologies in function of the level of power transit for a 1000 MW load:



5. Conclusions

The feasibility of high voltage links in cross-border tunnels is ensured only if both economic and technical conditions are fulfilled

The economic conditions required are mainly: a sufficient tunnel length, a great power transfer and a sufficient cost difference in electricity prices between both areas/countries linked by the tunnel.

The technical conditions required are mainly: a sufficient space and access for installation and maintenance inside the tunnel (depending on its configuration), the conditions for security, the thermal behaviour (linked to the technology and gallery ventilation), the electromagnetic impact, the possible access to the electrical grids and the impact of the new link on these grids. Most technical conditions are more easily met when there are pilot or service galleries.

The different kinds of required conditions are met by the following tunnel projects:

the Brenner tunnel (56 km);

the Lyon – Turin tunnel (53 +12+16 km);

and the Eurotunnel (50 km).

It is to be noted that the combination of Monte Ceneri – Gothard – Zimmerberg rail basis tunnels, that should provide the great advantage of linking directly Germany to Italy through Switzerland, must be in practice excluded because the design of these tunnels can no more be adapted at this stage, the tunnels being already partly under construction.

In addition to the three feasible HV links already mentioned it is worth mentioning two additional opportunities of synergy that are interesting, although of minor importance:

The implementation of a HV link in the old rail tunnel of Somport in the Pyrenees that is presently re-used as safety gallery for the recently commissioned road tunnel.

The implementation of a HV link in the planned future safety gallery projected for the existing Frejus road tunnel between Italy and France.

The Somport tunnel is located in the middle of the central Pyrenees which constitutes an important electricity priority axis (EL3) in the long term. This tunnel is a good opportunity and the feasibility of connecting it to the HV Spanish and French transmission grids should be studied more in depth.

Although the future safety gallery of the Frejus road tunnel would be only 13 km long, it provides an opportunity of synergy between electricity transmission needs and an existing road tunnel. This safety gallery is still a project waiting for approval and design adaptation remains possible. Therefore it is worth verifying also this opportunity in further studies.