T E N-ENERGY- I n v e s t

PROJECT SUMMARY

Energy Infrastructure Costs and Investments between 1996 and 2013 (medium-term) and further to 2023 (long-term) on the Trans-European Energy Network and its Connection to Neighbouring Regions with emphasis on investments on renewable energy sources and their integration into the Trans-European energy networks, including an Inventory of the Technical Status of the European Energy-Network for the Year 2003

Contract n. TREN/04/ADM/S07.38533/ETU/B2-CESI

Issue Date: October 2005

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Table of Contents

1. OVERVIEW AND SCOPE OF THE STUDY 3

2. METHODOLOGY 3

3. MID-LONG TERM SCENARIOS 4

4. ELECTRICITY SECTOR 9

4.1 CURRENT TECHNICAL STATUS OF ENERGY INFRASTRUCTURES 9
4.2 INVESTMENT PATTERNS DURING THE YEARS 1996 TILL 2004 AND FINANCING SOURCES 11
4.3 FINANCING SOURCES 12
4.4 AGEING OF THE SYSTEM AND NEED FOR REPAIRS AND UPGRADES 13
4.5 MID-LONG TERM INVESTMENT PATTERNS 14
4.5.1 Methodology for the estimation of future investments on transmission networks 15
4.5.2 Future investment needs 18

5. GAS SECTOR 22

5.1 CURRENT TECHNICAL STATUS OF ENERGY INFRASTRUCTURES 22
5.2 INVESTMENT PATTERNS DURING THE YEARS 1996 TILL 2004 23
5.3 FINANCING SOURCES 23
5.4 AGEING OF THE SYSTEM AND NEED FOR REPAIRS AND UPGRADES 24
5.5 GAS DEMAND 24
5.6 METHODOLOGY FOR THE EVALUATION OF INVESTMENTS 25
5.7 MID-LONG TERM INVESTMENT PATTERNS 28

6. INTEGRATION OF RES INTO THE ENERGY NETWORKS 29

7. USE OF NON-CONVENTIONAL TECHNOLOGIES FOR INCREASING CAPACITY IN TRANSMISSION NETWORKS 33

7.1 NON-CONVENTIONAL TECHNOLOGIES IN ELECTRIC NETWORKS 33
7.2 NON-CONVENTIONAL TECHNOLOGIES FOR GAS NETWORKS 33

1. OVERVIEW AND SCOPE OF THE STUDY

This document presents the main findings of the Project "EU-TEN ENERGY INVEST", Contract n. TREN/04/ADM/S07.38533/ETU/B2-CESI. The Project was aimed at providing a comprehensive overview of past and envisaged medium-term and long-term investments in the Trans-European Energy networks (TEN-E) of the enlarged European Union with particular emphasis on investments on renewable energy sources and their integration into the Trans-European energy networks. The analysis covered the EU 30[1] states and the western Balkan states[2] the energy infrastructures of which are embedded in the European grids.

The study addressed the following topics:

- *Topic 1:* the current technical status of energy infrastructures with a breakdown by energy sectors (electricity & gas), by country and by interface between countries (cross-border corridors);
- *Topic 2:* the investments patterns in the period from 1996 to 2004 and the main sources of financing;
- *Topic 3:* the ageing of the energy transmission networks and its impact on the future developments of the transmission grids and related investments;
- *Topic 4:* the medium-term trend (up the year 2013) for the development of energy infrastructures and related investment needs;
- *Topic 5:* the long-term perspectives (up to the year 2023) for an enhanced integration of the energy infrastructures among the countries of the enlarged EU with an estimation of the necessary investments;
- *Topic 6:* the long-term perspectives for massive integration of renewables energy sources in the EU, taking into consideration their particular characteristics;
- *Topic 7:* the use of non-conventional technologies for increasing capacity in transmission networks.

The outcome of the study shall help the Commission to assess energy policies by estimating costs of the energy transmission infrastructure and the necessary funds to be made available for this sector. In particular, it will help to assess the costs of improving the cohesion of the EU as well as the functioning of the Single Market and the cost-benefit of improving transmission networks with a view on the integration of renewable energy sources.

2. METHODOLOGY

To achieve the study objectives, two main phases have been foreseen:

- data collection;
- analysis and elaboration of the collected data.

The process of data collection has been based on the following steps:

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[1] EU 30 : is composed by EU 25 member states, plus Norway, Switzerland and the three candidate states of Bulgaria, Romania and Turkey.
EU 25 : is composed by the EU 15 old member states and the new EU members : Estonia, Latvia, Lithuania, Poland, Slovakia, Czech Republic, Hungary, Slovenia, Cyprus, Malta.
EU 15 : refers to the following member states : Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK.

[2] Western Balkan states: Albania, Bosnia-Herzegovina, Croatia (new candidate member from October 2005), Serbia-Montenegro, Macedonia.

a) gathering publicly available information relevant to international organisations such as UCTE, NORDEL, DC Baltija for information concerning the main European Power Pools, ETSO for information relevant to cross-border transfer capacities, EURELECTRIC and GTE.
b) gathering publicly available information from the national System Operators and direct contacts with them;
c) Documents produced by the European Commission and, particularly, by DG TEN
d) For a better standardisation of the information and to have a common approach towards the entities to be contacted, two questionnaires have been prepared: one questionnaire for gas grids and one for electricity grids.

In the electricity sector, in addition to the information provided by national TSOs, the total investments internal to the EU30 have been estimated referring to some key parameters as explained in par. 4.5. For the assessment of future investment needs in cross-border lines, a specific mathematical model has been applied. The main features of this models are recalled in par. 4.5.

As for the gas sector, the increase of import capacity, and, consequently, the need for new gas pipelines, has been evaluated on the basis of the evolution of the gas demand, the gas production internal to the EU30 and considering a load factor of 0.8 of the pipeline nominal capacities and a load factor of 0.6 for LNG regasification terminals. Finally, concerning the gas storage facilities, the estimations of additional needs have been carried out with the assumption of maintaining a level not exceeding specified thresholds for the ratios "internal gas production"/"gas storage capacity" and "gas import capacity"/"gas storage capacity".

3. MID-LONG TERM SCENARIOS

A "*Baseline scenario*" for the development of electricity and gas demand, generation mix and fuel cost is taken as an input. This "*Baseline scenario*" is the output of a previous energy study[3] carried out on behalf of the European Commission (E.C), which is based on the PRIMES model. The "*Baseline scenario*" reflects a continuation of current trends and policies into the future. It takes into account existing policies and those in the process of being implemented at the end of 2001.

In addition to the "*Baseline*", a number of variants have been examined to assess the future needs of investments in the energy infrastructures. These are relevant to *"high penetration of Renewable Energy Sources* (RES)", based on the FORRES 2020 project[4], "*high energy efficiency*", "*combination of high efficiency and RES penetration*" and the "*soaring oil and gas prices*" scenario, which assumes a quite sharp and prolonged oil and gas price increase. These latter scenarios are based on the variants of the "*Baseline scenario*" worked out by the E.C. using the PRIMES model[5]. Moreover, in the case of the electricity sector a number of "sensitivity scenarios" have been examined to assess the impact of some important parameters on the cross-border investment needs. The most relevant sensitivity scenario considers the possibility of additional expansion of nuclear generation beyond the quantities forecasted in Baseline scenario taking into account constraints on carbon emissions limits.

Tab. 1 depicts the key assumptions for "*Baseline*" and the variant scenarios, while Tab. 2 shows the main assumptions and outputs of PRIMES model, which are inputs for our analyses.

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[3] European Commission, "*European Energy and Transport Trends to 2030*", DG for Energy and Transport, January 2003, available on the E.C. web site: http://europa.eu.int/comm/dgs/energy_transport/figures/trends_2030/index_en.htm

[4] European Commission - Directorate General Energy and Transport, "*FORRES 2020: Analysis of the renewable energy sources'evolution up to 2020*", Tender n. TREN/D2/10-2002, April 2005

[5] European Commission – Directorate-General for Energy and Transport – – "*European energy and transport scenarios on key drivers*" – September 2004 - http://europa.eu.int/comm/energy/electricity/publications/index_en.htm

Scenario	Carbon emissions limit	RES penetration	Generation expansion plan	Fuel International Prices scenario
BASELINE	Primes (Baseline)	Primes (Baseline)	Primes (Baseline)	Primes (Baseline)
High Renewable Energy Sources (RES) development	Primes (Baseline)	Forres (Policy scen)	Forres (Policy scen)	Primes (Baseline)
High Efficiency development	Primes (Baseline)	Primes (High Effic)	Primes (High Effic)	Primes (Baseline)
High RES + High Efficiency development	Primes (Baseline)	Primes (H-RES+Ef)	Primes (H-RES+Ef)	Primes (Baseline)
Soaring fuel and gas prices	Primes (Baseline)	Primes (Baseline)	Primes (Baseline)	Primes (soaring oil and gas prices)

Tab. 1 – Scenarios and variants examined for the mid-long term evolution of generation and demand

PRIMES SCENARIOS		Refe-rence	**Baseline**		**High efficiency**		**High efficiency + RES**		**Soaring oil and gas prices**	
		2005	2025	2025 vs reference	2025	2025 vs reference	2025	2025 vs reference	2025	2025 vs reference
EU-25										
Gas - Production	bcm	211	136	-35%	136	-35%	138	-35%	149	-29%
Gas - Net imports	bcm	257	532	107%	450	75%	423	64%	347	35%
Total gas demand	bcm	464	668	44%	586	26%	560	21%	496	7%
Electricity Generation	TWh	3041	4173	33%	3644	20%	3590	18%	4272	36%
Installed generation capacity	GW	703	1034	44%	903	28%	932	33%	1089	52%
Final electricity demand	TWh	2583	3673	38%	3203	24%	3162	22%	3760	41%
Europe-30										
Gas - Production	bcm	283	262	-8%	275	-3%	266	-6%	290	3%
Gas - Net imports	bcm	222	504	127%	392	77%	367	65%	274	23%
Total gas demand	bcm	505	766	52%	667	32%	632	25%	565	12%
Electricity Generation	TWh	3473	4935	38%	4309	24%	4254	22%	5036	41%
Installed generation capacity	GW	824	1257	50%	1097	33%	1131	37%	1316	57%
Final electricity demand	TWh	2903	4248	42%	3703	28%	3662	26%	4337	45%

Tab. 2 – Main figures of PRIMES scenarios

FORRES project relies on the computational programme Green-X and econometric projections for its calculations. The results of Green-X model are derived on a yearly basis up to 2020 by determining the equilibrium level of supply and demand within each considered market segment (e.g. tradable green certificate market, electricity power market and tradable emissions allowance market). Under this project two main scenarios were considered:

- Business-as-usual scenario (BAU), which models the future development based on present policies with currently existing barriers and restrictions, e.g. administrative and regulative barriers. Future policies, which have already been decided on, but have not yet been implemented, are also considered.
- Policy scenario (PS), which models the future evolution on the basis of the currently available best practice strategies of individual EU Member States. Strategies that have proven to be most effective in the past for implementing a maximum share of RES have been assumed for all countries. Furthermore, the policy scenario assumes that currently existing barriers will be overcome.

Both scenarios include the effects of technology learning and economies of scale, which have a higher impact in the policy scenario. The main result of FORRES project, used as input of this study, is the forecasted development of RES technology, whose expected energy injected into the grid, is summarized in the table below.

Electricity [TWh]	2001	**BAU** 2020	**Policy** 2020
EU-25			
Wind energy	34	385	461
Hydro power	326	337	354.4
- large-scale	288	293	306
- small-scale	38.0	44.3	48.4
Photovoltaic	0.2	8.8	17.9
Solar thermal electricity	0	12.7	21.7
Wave & tide	0	8.4	33.2
Biomass, biogas, biowaste	37	141	338
Geothermal	6.3	7.5	8.2
TOTAL RES-E	403.5	900.4	1234.0

Tab. 3 – Forecasted RES electricity generation in the long run. Source: FORRES project

Regarding electricity, additional scenarios to those listed above were considered (Tab. 4) as follows:

- ‘*Kyoto for ever + nuclear expansion*’ scenario, showing the consequences of constraints on carbon emissions. This scenario evaluates the effect of maintaining carbon emissions constraints according to Kyoto Protocol commitments along the whole planning horizon, allowing unconstrained nuclear generation expansion after year 2015 as a mean of complying with Kyoto targets.
- *‘New generation optimized’* scenario, which avoids some limitations of using PRIMES outputs to assess the optimal development of cross-border interconnectors. This scenario allows a joint optimization of both transmission expansions and installed generation capacity. Generation expansion is the result of a least-cost optimisation process, where all available technologies compete to meet the expected demand, so only generation data for year 2005 were taken from PRIMES. For thermal generation, notably gas and coal fired, different fuel prices were assumed for each country, based on net-back pricing from international hubs (f.i. Zeebrugge for natural gas, ARA for coal). In order to avoid unrealistic unbalances, a maximum[6] was imposed to the generation expansion in each country per year.
- ‘*New generation and high (or full) transmission cost*’ alternative includes, in addition to generation optimisation, the cost of development of each cross-border interconnector and the costs associated to the required reinforcements in the domestic grids. To this purpose, it was assumed that each additional MW of cross-border transmission capacity should be transported between the load barycentres of the involved neighbouring countries; consequently the transmission expansion unit cost (€/kW) considered in this scenario is higher than in the previous case.

Scenario	Carbon emissions limit	Transmission expansion cost	RES penetration	Additional Nuclear expansion after 2015	Generation expansion plan	Fuel International Prices scenario
BASELINE	Primes (Baseline)	average	Primes (Baseline)	No	Primes (Baseline)	Primes (Baseline)
'Kyoto for ever' + Nuclear expansion	Kyoto for ever	average	Primes (Baseline)	Yes	Primes (Baseline)	Primes (Baseline)
New generation optimized	Primes (Baseline)	average	Primes (Baseline)	No	Simultaneously Optimized	Primes (Baseline)
New generation optimized + High transmission cost	Primes (Baseline)	high	Primes (Baseline)	No	Simultaneously Optimized	Primes (Baseline)

Tab. 4 – Additional scenarios for the electricity sector

[6] For each country it was assumed that generation expansion in a given year should be less or equal to the maximum value between: a) 3% of total installed generation capacity in the previous year, and b) the domestic peak load increase expected for that year.

Background information derived from PRIMES model has a remarkable influence specifically on the future evolution of cross-border capacity for electricity exchanges. Although PRIMES is a comprehensive energy model, it does not provide results on optimal development of cross-border transmission capacity, as stated in the "European energy and transport - trends to 2030" report:

"An in-depth study of trade developments in electricity would necessitate further work on the PRIMES model, which goes beyond the scope of this study. Thus, the country-by-country modelling, performed in the context of the study, has focused on the dynamics of the energy system within a country, while considering electricity trade between countries on the basis of current infrastructure and trends"

No further details on considered developments on interconnections are provided jointly with PRIMES results. However, it can be concluded that PRIMES estimates optimal energy trends in each country taking electric interconnection capacities as an input, as shown below. In this context, it should be expected that results provided by a model for optimal cross-border interconnection development, as used in this study, that takes as an input the expected evolution of electricity demand and generation capacity forecasted by PRIMES, do not show any significant addition on cross-border interconnections to those already assumed by PRIMES.

As for the data on cross-border exchanges, Tab. 5 shows the net electricity imports forecasted by PRIMES for each country. Values of the table refers to the yearly energy imported; f.i.: it can be seen that the net import of Italy is foreseen to be 37.2 TWh in 2005, according to PRIMES, and the energy import forecasted in 2030 will decrease to 27.0 TWh. It can be noted that the forecasted increase of cross-border electricity exchanges is very low: only eight countries show increased exchanges at the end of the horizon planning when compared with 2005, from which only two (Germany and Turkey) show increases over 10%. Moreover, all the scenarios of PRIMES taken into consideration in this project show the same cross-border electricity exchanges evolution, what denotes this is an input of the PRIMES model rather than an output.

Therefore, all those **scenarios modeled on the basis of generation capacity-demand balances taken from PRIMES are expected to show very low development of cross-border capacity**, because countries remain relatively balanced at the same levels during the whole horizon planning.

Regarding FORRES, import / export balance of RES in each country is a result of the model that produces significant unbalances between installed generation and power demand in those countries were RES are more developed. For this reason, **FORRES results, taken as inputs of the optimal cross-border expansion model used in this study, put in evidence the need for higher investments on interconnectors**.

Cross-border exchanges of electricity [TWh/year] - PRIMES / Baseline scenario

EU25	2005	2010	2015	2020	2025	2030	2030 vs 2005
Austria	-1.05	-0.58	-0.47	-0.58	-0.58	-0.58	reduction
Belgium	4.54	4.54	4.54	4.54	4.54	4.54	=
Denmark	1.16	1.28	1.28	1.28	1.28	1.28	increase 10%
Finland	8.84	6.51	6.51	6.51	6.51	6.51	reduction
France	-61.99	-56.87	-55.59	-54.89	-54.54	-54.31	reduction
Germany	4.19	5.12	6.28	6.40	6.51	6.63	increase 58%
Greece	0.00	0.12	0.12	0.23	0.23	0.23	increase
Ireland	0.12	0.12	0.12	0.12	0.12	0.12	=
Italy	37.22	32.68	29.89	28.73	27.33	26.98	reduction
Luxemburg	5.12	4.88	4.77	4.77	4.65	4.65	reduction
The Netherlands	19.54	19.89	20.24	20.47	20.59	20.59	increase 5%
Portugal	0.93	0.81	0.81	0.81	0.81	0.81	reduction
Spain	1.98	1.05	0.93	0.93	0.81	0.81	reduction
Sweden	4.30	4.30	4.19	4.19	4.07	4.07	reduction
United Kingdom	14.30	14.42	14.54	14.65	14.65	14.65	increase 2%
Cyprus	0.00	0.00	0.00	0.00	0.00	0.00	=
Czech Republic	-9.42	-8.61	-8.61	-8.61	-8.61	-8.61	reduction
Estonia	-0.93	-0.81	-0.81	-0.81	-0.81	-0.81	reduction
Hungary	3.37	3.49	3.49	3.49	3.49	3.49	increase 3%
Latvia	1.74	1.74	1.74	1.74	1.74	1.74	=
Lithuania	-0.58	0.12	0.12	0.12	0.12	0.12	reduction
Malta	0.00	0.00	0.00	0.00	0.00	0.00	=
Poland	-6.63	-6.75	-6.86	-6.86	-6.86	-6.86	increase 4%
Slovakia	-2.44	-2.21	-2.09	-2.09	0.58	0.93	reduction
Slovenia	-1.16	-1.05	-1.05	-0.93	0.35	0.58	reduction

Candidates	2005	2010	2015	2020	2025	2030	Change 2030/2005
Bulgaria	-4.42	-4.19	-4.07	-4.07	-4.07	-4.07	reduction
Norway	-18.96	-18.96	-18.96	-18.96	-19.07	-19.19	increase 1%
Romania	-0.70	-0.58	-0.58	-0.58	-0.58	-0.58	reduction
Switzerland	-6.98	-6.75	-6.75	-6.28	-5.82	-4.88	reduction
Turkey	3.37	3.84	4.19	4.77	5.00	5.47	increase 62%

Tab. 5 – Cross border power exchanges assumed in PRIMES.

Note: positive values mean energy import; negative values mean energy export.

4. ELECTRICITY SECTOR

4.1 Current technical status of energy infrastructures

The European power transmission grid is composed of seven power pools (UCTE, NORDEL, Great Britain, the Irish system, the DC Baltija pool, IPS/UPS, Turkey). These power pools are weakly interconnected with each other through HVDC links, with the exception of DC Baltija, which is synchronously and strongly interconnected with the IPS/UPS pool of the Russian Federation and the other CIS countries (*Fig. 1*). The UCTE power pool, including the Central and Western European Countries plus the westernmost region of the Ukraine, is synchronously interconnected with Morocco, Algeria and Tunisia from 1997. This synchronous interconnection will be likely extended eastward up to Syria in the near future. Turkey, in his turn, has already made the application for UCTE membership: the study on the technical feasibility of a synchronous interconnection between UCTE and Turkey is in progress. Two EU member states are operating their power systems in isolated way: Cyprus and Malta. At the moment there are no projects to interconnect these systems with the mainland. The total gross consumption in the EU30 and Western Balkan countries, which are members of the UCTE with the exception of Albania, has been around 3,300 TWh in the year 2003 with an installed power exceeding 800 GW. The following table summarizes the main characteristics of the power pools in the EU30 and the Western Balkan countries

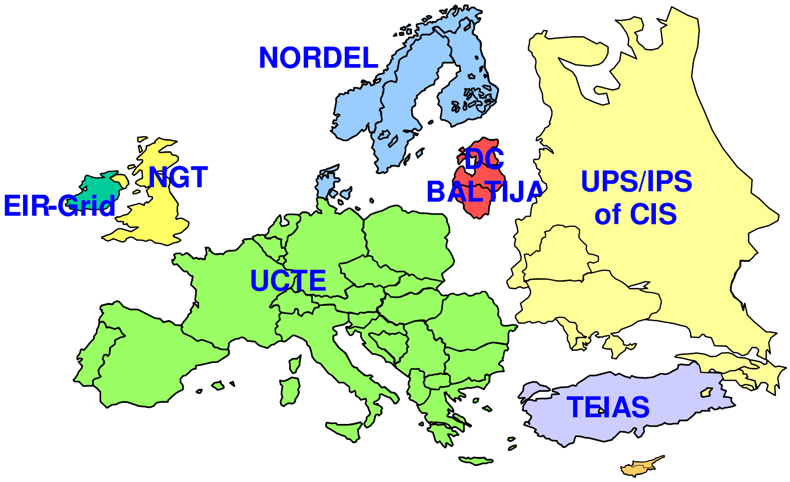


Fig. 1 – The European Power Pools

Power pool	Installed capacity (GW)	Yearly consumption (TWh)	EHV Transmission Grid (km)	
			380-400 kV	220-330 kV
UCTE	585.0	2345	97589	117410
NORDEL	91.2	380	18500	13100
DC Baltija	11.4	23	---	4711 (1)
Great Britain	76.0	384	10200 (2)	3480 (2)
Ireland	5.3	22	440	1700 (3)
Cyprus	1.0	4	---	809 (6)
Turkey	36.0 (4)	140 (4)	13958	31515 (5)
Total	805.9	3298	140687	172725

(1) Includes: 508 km of 220 kV lines in Estonia and 4203 km of 330 kV lines. Power transmission in the Baltic countries relies heavily also on the 110 kV grid which is 12231 km long.
(2) These figures don't include the extension of the Scottish grid.
(3) Power transmission in Ireland is also based on the 110 kV grid, which is 5600 km long
(4) The installed power in Turkey is expected to attain 41,400 MW by end 2005 with a consumption of 163,000 GWh
(5) Out of which: 85 km at 220 kV and 31430 km at 154 kV
(6) Out of which: 1.4 km at 220 kV operated at 132 kV, 124.7 km at 132 kV operated at 66 kV, 358.3 km at 132 kV and 324.6 km at 66 kV

Tab. 6 – Main characteristics of the EU 30 and Western Balkan power systems

Cross-border energy exchanges have been increasing in these last years, however, in some cut-sets they are limited due to the insufficient transmission capacity (bottlenecks). In the UCTE pool the exchanged energy is around 12% of the total consumption, while in NORDEL this ratio attains 25% and in DC Baltija it is about 47%. Some screening indexes have been evaluated to assess potential bottlenecks in cross-border power exchanges; namely, the following indexes have been adopted in the study process:

- Index 1: Ratio of the import capacity of each country to the total installed generation capacity.
- Index 2: Ratio between the physical import flows to a country and the national consumption;
- Index 3: Ratio of the "remaining generation capacity" (i.e. not used generation) within a country to the total transmission capacity between the country and the rest of the system.

For Index 1 a minimum level of 10% is recommended by the European Commission to warrant a sufficient capability for power trade. Situations where Index 2 is bigger than Index 1 may represent a sign of congestion. Concerning the "remaining capacity", according to the recent UCTE study[7], an acceptable value to limit the risk of shortfall at 1% is equal to 5% of the generation capacity, referring the evaluation at the monthly peak load; only for some systems more sensitive to random factors this value shall be higher up to 10%. Remaining capacity higher than 40% of the country Gross Total Capacity[8] (Index 3) may represent an obstacle to the power trade. By applying the above indexes to the present situation the following conclusions can be drawn:

- Index 1: countries below the threshold of 10% are: Ireland, UK, Poland, Greece, Turkey, Spain, Portugal and Italy;
- Index 2: "physical import flows/national consumption" ratio is higher than that obtained from "import capacity/total installed generation capacity" in UK and Norway;
- Index 3: remaining capacity is higher than 40% of the Gross Total Capacity in France, Italy, Portugal, Spain and Poland.

By referring to the priority axes, the most congested cut-sets (bottlenecks) are the following:

- EL 1: France-Belgium-Netherlands
- EL 2: Italy-rest of Europe
- EL 3: France-Iberian Peninsula
- EL 4: Interface between former 1st and 2nd UCTE synchronous zones (Hungary-Serbia and Romania) and Bulgaria-Greece
- EL 5: France-Great Britain
- EL 7: Denmark-Germany; Finland-Sweden; Norway-Sweden
- EL 8: Poland-Czech rep./Poland-Slovakia/Czech rep.- Austria/Slovakia-Hungary/Hungary-Slovenia

The main reasons for congestions are due to:

- High level of power import (e.g.: EL 2, EL 5);
- Wheeling of power across countries (e.g.: France-Belgium-Netherlands);
- Power fluctuations originating by wind generation (e.g.: some cut-sets on EL 7).

To solve possible conflicts in the allocation of cross-border capacities, the definitions of transfer capacities have been agreed within ETSO. Two sets of transfer capacities have been defined: for commercial purposes, used by market operators to set up contracts for cross-border transactions, and for operational purposes, managed by System Operators to check that the physical capacity of lines is not exceeded. Whenever the available transfer capacity is insufficient with respect to the requests, several methods of congestion

[7] UCTE "System adequacy forecast 2005-2015", January 2005
[8] Gross Total Capacity (GTC) is the mere summation of the physical capacity of the tie-lines

management have been put in place. Methods for capacity allocations shall fulfil a set of requirements. More specifically, network congestion problems shall be addressed with purpose of non-discriminatory market based solutions, which give efficient economic signals. They shall preferentially be solved with non-transaction based methods and be as transparent as possible in accordance to the EU regulation 1228/2003 on "*Conditions for access to the network for cross-border exchanges in electricity*".

Conclusions on topic 1:

- *the European electricity transmission grid is composed by power pools;*
- *most of the power pools are weakly connected through Direct Current links;*
- *several bottlenecks still exist causing congestion on cross-border cut-sets;*
- *to manage insufficient cross-border capacity, congestion management mechanisms are adopted by System Operator. These mechanisms are presently evolving to fully comply with the EU regulation 1228/2003.*

For more details see: main report - chapter 4

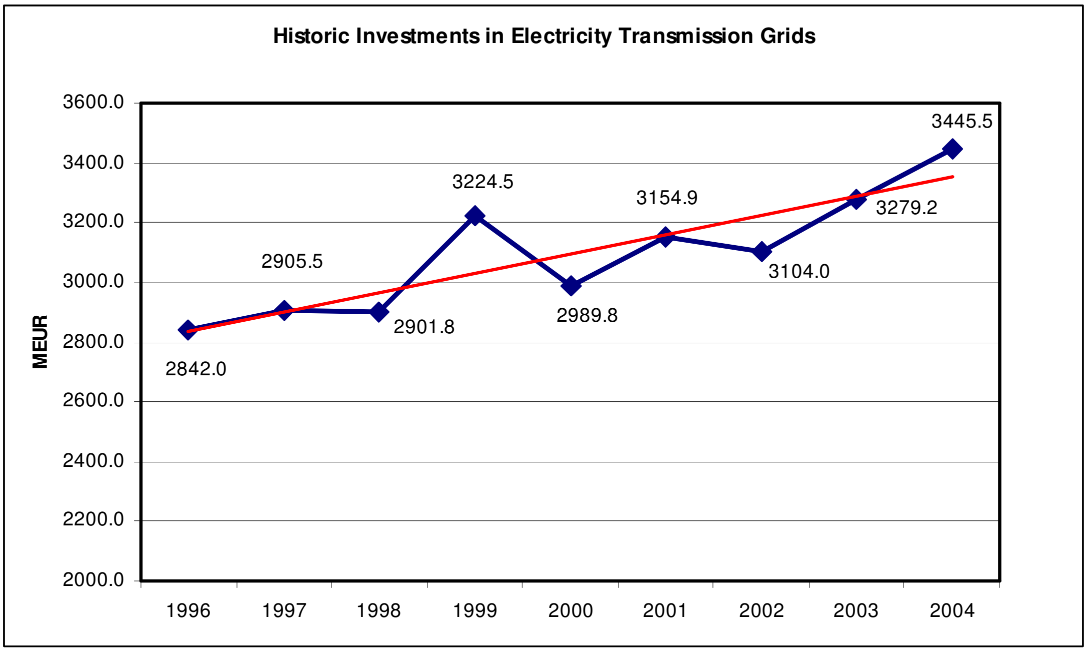
4.2 Investment patterns during the years 1996 till 2004 and financing sources

The pattern of investments from 1996 to 2004 (*Tab. 7*) shows an increasing level of expenditure; in particular, Great Britain, Ireland, Norway, Portugal, Romania and Spain have increased their investments in these last years. Two countries, France and Poland, showed a decline in the investments. However, it is worth mentioning that Poland has high investments levels all over the period under examination comparing the absolute values with the grid extension.

In the period under examination the average investment has been 3.1 b€/yr. The breakdown of expenditure is shown in Fig. 2. Investments on cross-border links turned out to be in the order of 1.1 b€, i.e. slightly below 4% of the total investments. Most of the expenses in cross-border links are concentrated in HVDC (High Voltage Direct Current) interconnections through submarine cables; the most relevant projects have been: SwePol (Sweden-Poland; 295 M€); Italy-Greece (300 M€) and Moyle interconnector (North Ireland-Scotland; 220 M€).

The investment level is quite uniform in the EU 30 countries with the exception of Bulgaria, Romania and Turkey, where investments are low in relationship to the extension of the national electricity transmission grid. Information gathered from western Balkan countries, not belonging to the EU 30, though rather incomplete, shows low investments too. Countries with the highest investments with respect to the extension of the grid are: Lithuania, Poland, Greece, Ireland and Cyprus.

Main reasons for investments have been: lack of generation capacity and consequent need to connect new power plants, improving security of supply and fostering the implementation of the electricity market. Furthermore, one emerging factor prompting additional investments is related to the ageing of the system.



Note 1: the investment values have been updated taking into account of the inflation rates for each year in each country. Data on inflation rates have been retrieved from the European Commission web site: http://epp.eurostat.cec.eu.int/portal.

Note 2: for countries not belonging to the Euro zone, conversion from local currency to Euro has been made directly by the entities involved in the investment plans

Note 3: whenever yearly investments were not available, estimations have been made on the basis of the "equivalent length" of the country transmission grid.

Tab. 7 – Historic investments in electricity transmission grids.

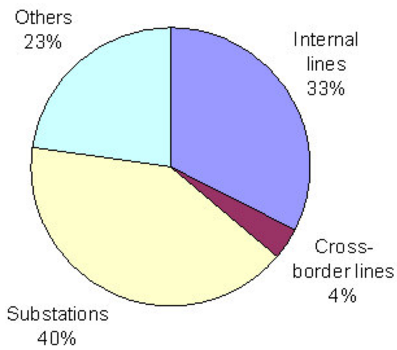


Fig. 2 – Breakdown of past investments.

Note : « others » refers to investments on TLC system, protection&control, Phase Shifter transformers, etc.

4.3 Financing sources

Concerning the financing of the power transmission projects, we have examined the composition of the financing sources of the major projects according to the following breakdown: EIB loans, other EU funds (EBRD loans; structural and cohesion funds), TEN-E funds, other bank loans and TSO equity. The sharing of financing is shown in Fig. 3.

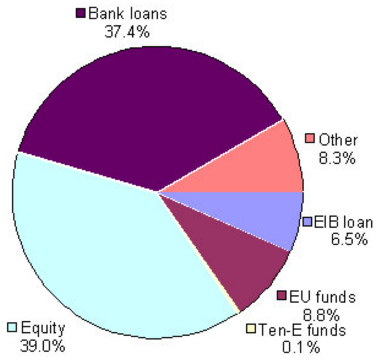


Fig. 3 – Sharing of different sources of financing (percentage referred to a total amount of 14 b€ of past and perspective investments declared by TSOs)

The following conclusions can be drawn:

- In a large majority of cases, the countries make use of bank loans or national TSO equities;
- In some countries (e.g. France and Sweden) all the projects are financed only from internal resources (TSO equity) without resorting to external loans;
- in many cases even in the absence of EU loans (EIB, EU-funds) or aid instruments, projects would have been built; TEN-Energy funding is used essentially to support feasibility or pre-feasibility studies;
- In a non-negligible number of cases, financing is slowing down investments in transmission network projects. Problems related to financing are particularly critical in small countries with a small number of customers;
- In general, there are no more difficulties to obtain finance for larger projects compared to smaller ones. In large projects the main problem is the impact of the related costs in the transmission tariffs that must be approved by the national regulators;
- it is, in general, more difficult to get their financing for cross-border projects with respect to national projects, because of a series of reasons such as: need to agree between two or more System Operators and Regulators; harmonisation between different planning standards;
- as for the cost of capital, no wide differences have been detected between the EU-15 member states and the new EU member states.

Conclusions on topic 2:

- *In the period 1996-2004 the investment level has been in the average around 3.1 b€/yr, with a tendency of a slight increase from the year 2001;*
- *Investments are quite uniformly distributed among the EU 30 countries with the exception of Bulgaria, Romania and Turkey where investments are low in relationship to the extension of the national grids;*
- *In most of the cases, investment projects are financed by TSO equities or bank loans;*
- *in many cases even in the absence of EU loans (EIB, EU-funds) or aid instruments, projects would have been built*

For more details see: main report - chapter 4

4.4 Ageing of the system and need for repairs and upgrades

The mean life of high voltage equipment is between 30 and 50 years, whereas the information technology has a shorter lifetime of about 10-25 years. From the survey carried out at the TSOs the average age of the existing infrastructure is about 30-40 years and it is approaching its expected end of life with very few exceptions such as Cyprus and the 400 kV lines and s/s in Greece.

Comparing the mean design life of equipment with the average age of the network assets of the European power pools, a substantial need for replacement, refurbishment, upgrade and re-design is expected in the next two decades as shown in Fig. 4 who depicts in a qualitative way the potential trend for replacing switchgear components.

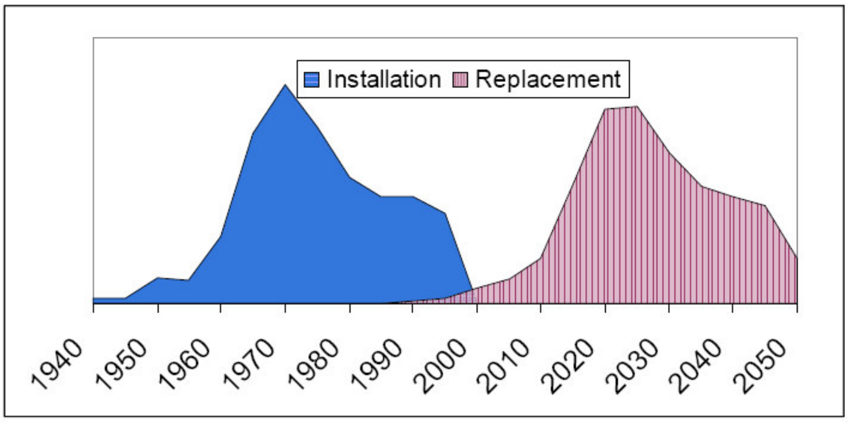


Fig. 4 – Installation and replacement distribution for switchgears (source CIGRE)

In many cases TSOs estimate that their transmission system will be able to operate safely and reliably up to 10 years ahead without taking any countermeasure. All the TSOs stressed that the network they manage requires upgrades and repairs and already now a remarkable part of investments is related to maintaining the present grid and substations. This happens not only in the Eastern European countries but also in the West (e.g.: in western Denmark 1/3 of investments are devoted to maintain the present status of the grid and s/s). The process of replacement of network components, refurbishment, upgrade and re-design shall be undertaken as a continuous action to warrant an acceptable level of security and reliability in the coming years.

To smooth the need for investments while ensuring the requested reliability level, it is recommended to adopt measures based on "life extension techniques".

Conclusions on topic 3:

- *Ageing of the system is becoming one of the major concerns of TSOs*
- *Many components of the transmission grid need repairs and upgrades since they are approaching their expected end of the life and without appropriate measures some transmission systems will be able to operate safely and reliably only up to 10 years ahead.*
- *To smooth the investment effort while ensuring the requested reliability level, measures based on "life extension techniques" shall be adopted*

For more details see: main report - chapter 4

4.5 Mid-long term investment patterns

In the Baseline scenario the gross electricity demand is expected to increase from 3,473 TWh in 2005 to 4,789 TWh in 2023 corresponding to a net demand[9] of 4,134 TWh, while a total reduction of 12% on this value is envisaged in those scenarios that assume an increase of efficiency in energy consumption (High Efficiency and High RES+Efficiency scenarios). The generation and net demand of electricity for the various scenarios is shown in *Tab. 8*.

[9] Note : difference between gross and net (or final) electricity demand is related to losses, auxiliary services for production and pumping consumption.

Generation / demand balance	Medium term (2013)		Long term (2023)	
Scenario	Installed generation capacity [GW]	Net electricity demand [TWh/year]	Installed generation capacity [GW]	Net electricity demand [TWh/year]
BASELINE	976	3,516	1,201	4,134
High RES (Forres)	1,027	3,516	1,400	4,134
High efficiency (Primes)	969	3,251	1,184	3,648
Combined High RES + High effic. (Primes)	992	3,213	1,216	3,609
Soaring oil and gas prices	976	3,584	1,201	4,219
New generation optimized	904	3,516	1,074	4,134
New generation optimized + Full transmission development	908	3,516	1,074	4,134

Tab. 8 – Generation/net demand balance of electricity in the different scenarios examined in the study.
Note: in the High RES scenario the evolution of the demand is the same as in the case of the Baseline, but with the evolution of the generation according to the "Policy Scenario" of the FORRES project.

The main aim of the study has been devoted to identify the needs for future investments on cross-border infrastructures; however, estimations of the total investments required in the electricity sector for the next two decades have been carried out, though these estimations shall be intended as general indications, being the planning of the national grids of the EU 30 countries out of the scope of the present project. The total investments in infrastructures internal to the EU 30 countries have been estimated considering the correlation between the total length of transmission lines and some key parameters, namely: energy demand, country surface and load density. The mid and long term patterns of the total investments in electricity transmission grids that should take place in the different European countries were also analyzed on the basis of information collected from existing expansion plans and studies developed by regional institutions as well as from answers provided by the different TSOs of the enlarged European Union (EU-30) to a specific questionnaire.

Regarding the cross-border interconnections, the required transfer capacities have been assessed through long run simulations of the electricity markets of the enlarged European Union using the above-mentioned scenarios. Simulations were aimed at identifying the capacities of the cross-border cut-sets for the next two decades. For this purpose, a simplified optimisation model having the scope of minimising the investments and operation costs required to meet the system demand during the planning horizon was used. This model was based on generation expansion plans of the PRIMES report. Model results were also compared with the information provided by the TSOs.

Finally, the investment needs associated to the connection of offshore wind farms to the onshore transmission grid have been assessed.

4.5.1 Methodology for the estimation of future investments on transmission networks

Internal investments - The estimation of the future investments in the EU 30 transmission network has been based on a regression analysis to relate the length of the power networks in each country with some explicative variables (peak demand, energy demand, cross-border flows, country surface, load density). The weighted sum of the lengths of all the high voltage lines in the system[10] (or the sum of the "equivalent" length of these lines) was used as dependent variable. The regression analysis showed that energy demand, country surface and load

[10] The "equivalent" length Leq is referred to the capacity of a 400 kV line by adopting the following relationship: $Leq = L_{400} + \sum_i L_i \left(\frac{V_i}{400}\right)^2$, where Li is the length of lines with "i" voltage level.

density are the variables most influencing the total equivalent length. Then, the formula adopted to forecast the evolution of the total length of the transmission lines is:

$$Leq = 0.0021 * E^{0.534} S^{.592} * LD^{-0.247} \qquad (1)$$

where: E: energy demand (TWh); S: country surface (km^2); D: load density (TWh/inhabitant)

This formula was compared with a similar one used by IIT for a study on the benchmarking of transmission tariffs [11], showing that the coefficients of both formulas are quite similar.

To forecast investments starting from the evolution of the line lengths, the following assumptions were taken:

- The length of new transmission lines built at year "n" in each country is the result from the difference obtained applying formula (1) for years "n" and "n-1".
- Unit cost for transmission lines is based on the report "*Unit costs of constructing new transmission assets at 380kV within the European Union, Norway and Switzerland*" by IFC consulting"
- Countries having a length of the transmission system below the EU average, obtained by applying formula (1) to the EU 30 countries, achieve the average by 2013.
- Renewal of old equipment is equivalent to 1.5%/yr of the total assets.
- The length of cross-border lines was discounted from the total length of transmission lines, since the former was separately forecasted.
- Incorporation of new transformation capacity in relationship to the demand evolution is based on information provided by ETSO on a subset of the EU countries
- The average cost of transformation capacity has been assumed equal to 22000 €/MVA
- Other costs (communications, civil works, switching equipment, etc): 23% of lines and transformers cost.

Cross-border investments - The mathematical model applied to assess the need for new investments on cross-border transmission capacity has the following main features:

- Objective function. The objective function to be minimized measures the total incremental cost of meeting the demand of the countries considered. This cost is calculated as the net present value (NPV) of capital and fixed operation and maintenance costs of new generation and transmission facilities, plus the variable costs of existing and new generation facilities
- Generation expansion. Since the expansion of cross-border transmission capacity is closely linked to the generation pattern consisting of the existing and future generation units, as well as the variable costs of those plants, a reference for the expansion of generation in Europe in the medium and long term was adopted. The Baseline scenario as well as the sensitivity analyses assumed that development of new generation facilities follows at least the baseline case of PRIMES modelling mentioned above. The model may add some generation capacity if this results in a least-cost solution, but it cannot reduce the forecasted generation expansion used as input (i.e. generation capacity expansion provided by PRIMES). Scenarios focused on high development of renewable generation assume RES generation expansion according FORRES 2020 study. Scenarios that jointly optimize generation and transmission do not take any generation expansion plan as input. Thus, the model, looking for a least-cost solution, decides all expansions in these cases.
- Demand: in all cases electricity demand by country is an input of the model
- Length of the corridors. Defining the length of each corridor is a very complex task, taking account that reinforcing a corridor typically involves investing in some internal lines within some countries. Therefore, it

[11] Ref.: Pérez-Arriaga, J.I., F.L.P. Montero, and F.J.R. Oderiz, « *Benchmark of Electricity Transmission Tariffs* », prepared for the Directorate-General for Energy and Transport. European Commission. 2002

was defined an upper and a lower limit for this length and then sensitivities with respect to these length values have been computed. The upper limit was defined as the distance between the barycentres of loads in the two countries and the lower limit as the average length of the existing cross-border lines between them, which is on average 30% of the upper limit. In case of submarine interconnections the lower limit was assumed to be the maximum value between the submarine distance to be covered and the length equal to 30% of the distance between the barycentres of the loads. The Baseline scenario and most of the sensitivity analyses use the lower limit, while the higher limit was represented in one sensitivity analysis called "High transmission cost" scenario.

- Investment costs. Different unit costs to compute the required investment in new interconnections were assumed depending on the involved countries [12]. The investment costs are in the following range:
  a) for new lines: between 220 and 746 €/km/MVA, averaging 465 €/km/MVA;
  b) for submarine interconnectors: between 965 and 6,770 €/km/MVA), averaging 2,880 €/km/MVA.
- Upper limit for cross-border transmission capacity. In order to limit excessive development of a given interconnector that may reach unrealistic levels in the long run, the maximum transmission capacity between a given country and its neighbours was limited to 30% of the maximum load of the country.
- Other assumptions:
  1. Each country can be represented as a Single Price Area;
  2. Each cross-border corridor has a transmission capacity that is independent of flows in other corridors;
  3. All the countries have competitive electricity markets;
  4. TSOs have implemented an efficient congestion management method;
  5. All the market participants expect the same rate of return on their investments in generation and transmission facilities;
  6. Capacity of the corridors can be represented as a continuous variable;
  7. loop flows or parallel flows are not taken into account.

Investments associated to the connection of offshore wind generation - Offshore wind generation requires significant investments, mainly submarine cables, to be connected to the onshore transmission grid. For each mid and long term scenario, an estimation of the total cost associated to such investments was carried out, in order to compare the resulting figures with the overall expansion costs of the European transmission grid. Calculations were performed on the basis of :

- the estimated costs reported in the document "*Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020*", carried out by DENA (Deutsche Energie-Agentur GmbH)
- the expected evolution of the offshore wind facilities reported by FORRES project.

For the mid and long term scenarios where the overall generation expansion was based either on results of the PRIMES model (Baseline scenario) or on our own expansion model (Baseline + generation optimized scenario), the future evolution of offshore wind generation was assumed to be equal to the FORRES prediction of future offshore wind generation under the "Business as Usual" (BAU) scenario. On the contrary, the "High RES" scenario assumes an expected offshore generation evolution consistent with that estimated in the FORRES project under the "Policy" scenario.

From the above sources of data, the average unit cost associated to investments required for connecting offshore wind farms to the onshore transmission grids turns out to be 510 €/installed-kW.

[12] References: "*Unit costs of constructing new transmission assets at 380kV within the European Union, Norway and Switzerland*", prepared for the E.C.-DG TREN - Contract NoTREN/CC/03-2002. IFC Consulting Ltd.

Normally, these 'connection' costs are recovered by the wind farms developers from tariffs applied to renewable projects. Then, they are not usually considered as transmission investments but they are often assumed to be part of the associated cost of generation expansion investments. Nevertheless, in our analysis we estimated these costs too since they have a non-negligible magnitude in comparison with the costs associated to the overall expansion of the transmission grid in Europe.

4.5.2 Future investment needs

Internal investments – By applying the methodology above recalled, the annual investment varies from 3.3 b€ in 2005 to 3.2 b€ in 2023. The annual investment slightly declines when approaching the year 2023 because of the lower rate of demand growth. For the period 2005-2013 the accumulated investment is 29.3 b€, while for the whole period 2005-2023 the cumulated investments in internal infrastructures are 61.6 b€.

Cross-border investments - Concerning the reinforcements of cross-border cut-sets, *Tab. 9* and *Tab. 10* summarize the results obtained from the simulations for the mid (up to 2013) and long term (2014-2023) applied to the Baseline and four variant scenarios. All of them set the length of international corridors to their lower limit (30% of the distance between the barycentres of the loads). In these scenarios cross-border transmission is developed for pre-defined expansion plans of power generation, which show most of the countries almost balanced in power generation capacity and demand. Consequently, optimal development of new interconnection capacity turns out to be lower than what would result if the development of power generation were jointly optimized with the expansion of cross-border interconnections. Results in the latter case are also presented in the table below together with the sensitivity of results with respect to the maximum length of international corridors, identified as "*full transmission development*".

ACCUMULATED INVESTMENTS ON CROSS BORDER CAPACITY EXPANSIONS [million €]

Scenario	2005 - 2013	2014 - 2023
Baseline	**666**	**88**
High RES (Forres)	*661*	*1,564*
High efficiency (Primes)	*588*	*628*
Combined High RES + High effic. (Primes)	*588*	*879*
Soaring oil and gas prices	*291*	*48*
Baseline plus New generation optimized	*2,957*	*4,932*
Baseline plus New generation optimized + Full transmission development	*2,570*	*4,838*

Tab. 9 – Accumulated investments in cross-border capacity

The following comments can be made:

- As expected, all the scenarios based on the output of the PRIMES model show a low development of international interconnectors[13].
- Scenarios that optimize the generation development show larger investments on cross border expansions
- The "*High RES scenario*", based on the FORRES project, shows a significant increase of the interconnections in the long run, when most of RES projects are developed.

[13] See section 2 for details on PRIMES characteristics that explain this result.

- On the other hand, the "*soaring oil and gas scenario*" shows the lowest development of interconnectors since local coal-fired generation is more intensively dispatched in most of the countries.
- In the "*New generation optimised + full transmission development*" scenario both the investments in international interconnectors and the costs related to internal grid reinforcements are considered in the optimisation process. Results show similar investment levels to the scenario where these costs are not considered but the amount of interconnection capacity built is smaller (*Tab. 11*)
- in the sensitivity scenario "*Kyoto for ever + nuclear expansion after the year 2015"* the development of new nuclear power plants reduces the expected energy exchanges and, consequently, the need for new interconnectors. This sensitivity scenario results in a reduction of about 15% in investments in cross-border infrastructures with respect to other scenarios.

EU prority axe	Baseline		High RES		High Efficiency		High RES+Efficiency		Soaring oil and gas prices		Baseline + generation optimized		Baseline + full transmission development	
	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023
EL1	309	2	232	225	326	93	278	82	83	0	236	5	58	0
EL2	0	0	0	0	0	0	0	34	0	0	35	0	23	94
EL3	9	0	6	43	87	245	102	334	9	0	70	279	48	19
EL4	164	65	108	26	123	118	129	132	125	30	37	477	36	500
EL5	0	0	0	0	0	0	0	0	0	0	1,385	1,805	1,354	1,058
EL6	0	0	0	24	0	0	0	0	0	0	699	1,373	699	1,373
EL7	5	15	155	424	7	23	36	35	10	10	80	187	84	361
EL8	180	6	161	653	45	150	42	262	64	8	352	558	231	926
EL9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	169	0	0	0	0	0	0	62	248	36	508
TOTAL	666	88	661	1,564	588	628	588	879	291	48	2,957	4,932	2,570	4,838

Tab. 10 – Distribution of investments among the priority axes (values in million €)

By examining the distribution of investments among the EU priority axes (*Tab. 10*), we can conclude that:

- Most of the results are fully consistent with PRIMES results. In particular, some bottlenecks that currently exist (France-Spain EL3, Italy northern borders EL2) are not expanded. This result is directly linked to the hypothesis assumed for modelling: PRIMES model does not envisage future increase of cross-border exchanges through these interconnectors.
- In most of the PRIMES based scenarios, investments are concentrated in EL1, EL4 and EL8 axes, although Iberian interconnectors (EL3) are reinforced in the high efficiency scenarios mainly due to exportation of low cost surpluses from France.

Tab. 11 shows the additional capacity on each cross-border cut-set. *Tab. 12* shows that the investments scheduled by TSOs are larger than those obtained from the scenarios where the generation expansion is fixed by the PRIMES model, but remarkably lower than those obtained from the scenarios where the installation of new generation is optimised across the EU 30 countries. This denotes that the location of new generation is basically determined from a national rather than a continental perspective. Fig. *5* shows the cumulated investments in cross-border lines for the baseline scenario and some variants as well as the investments forecasted by TSOs on a mid-term horizon.

Cross border interconnection between :		EU prority axe	Baseline		High RES		High Efficiency		High RES+Efficiency		Soaring oil and gas prices		Baseline + generation optimized		Baseline + full transmission development	
			2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005 2013	2014 2023	2005-2013	2014-2023	2005-2013	2014-2023
Austria	Germany	EL8	0	0	0	1,200	0	0	0	0	0	0	1,700	2,600	500	1,800
Austria	Slovenia	EL8	0	0	0	0	0	0	0	300	0	0	0	0	0	0
Austria	Hungary	EL8	700	200	0	1,500	700	2,100	500	2,500	100	300	900	2,100	300	1,000
Austria	Czech Rep.	EL8	0	0	0	0	0	0	0	1,200	0	0	0	0	0	0
Belgium	Netherlands	EL1	0	0	0	4,200	0	0	0	0	0	0	0	0	1,000	0
Belgium	France	EL1	2,300	0	1,800	0	2,300	400	1,900	0	100	0	2,000	0	0	0
Czech Rep.	Germany	EL8	0	0	0	1,300	0	0	0	0	0	0	400	1,400	100	500
Czech Rep.	Slovakia	EL8	0	0	0	1,400	100	800	100	1,800	0	0	1,700	2,600	100	600
Czech Rep.	Poland	EL8	900	0	600	0	0	700	0	0	0	0	0	0	0	0
France	Spain	EL3	0	0	0	0	600	1,800	700	2,600	0	0	400	1,700	0	0
Hungary	Slovakia	EL8	0	0	800	1,500	0	0	0	1,600	0	0	1,500	1,800	0	100
Germany	Netherlands	EL1	0	0	100	2,600	200	1,000	200	1,300	0	0	0	0	0	0
Germany	Denmark	EL7	0	0	1,200	4,100	0	0	0	0	0	0	400	800	200	1,000
Germany	Poland	EL8	0	0	0	1,900	0	0	0	0	0	0	0	0	0	0
Italy	Slovenia	EL2	0	0	0	0	0	0	0	700	0	0	700	0	100	600
Poland	Slovakia	EL8	1,400	0	1,700	200	500	0	500	1,100	1,100	0	700	0	0	0
Portugal	Spain	EL3	200	0	100	1,000	200	300	300	0	200	0	400	1,400	300	100
Finland	Sweden	EL7	0	0	0	0	0	0	1,100	700	0	0	0	1,500	0	0
United Kingdom	Netherlands	EL5	0	0	0	0	0	0	0	0	0	0	1,400	1,000	1,400	0
United Kingdom	Norway	EL5	0	0	0	0	0	0	0	0	0	0	200	1,000	200	1,000
Switzerland	Germany		0	0	0	1,900	0	0	0	0	0	0	0	0	0	1,800
Ireland	United Kingdom	EL6	0	0	0	0	0	0	0	0	0	0	1,100	2,100	1,100	2,100
Turkey	Greece	EL4	1,300	500	800	0	900	700	900	1,100	900	100	0	1,300	0	1,300
Luxembourg	Belgium	EL1	2,100	100	1,200	200	2,100	100	2,100	100	2,000	0	900	100	0	0
Romania	Bulgaria	EL4	1,200	200	800	1,000	900	1,400	1,100	1,100	1,200	200	100	700	0	800
Romania	Hungary		0	0	0	500	0	0	0	0	0	0	200	700	100	400
Bulgaria	Greece	EL4	1,000	600	700	500	1,100	1,100	1,100	700	1,000	600	300	600	300	800
Lithuania	Poland	EL7	100	500	800	600	200	600	100	500	300	300	1,100	1,900	0	400
	TOTAL		11,200	2,100	10,600	25,600	9,800	11,000	10,600	17,300	6,900	1,500	16,100	25,300	5,700	14,300

Tab. 11 – Additional capacities in cross-border cut-sets (values in MW)

ACCUMULATED INVESTMENTS ON CROSS BORDER CAPACITY EXPANSIONS [million €]

Scenario		2005 - 2013	2014 - 2023
Baseline		**666**	**88**
Baseline plus New generation optimized		*2,957*	*4,932*
	increase over Baseline	*2,290*	*4,845*
Baseline plus New generation optimized + Full transmission development		*2,570*	*4,838*
	increase over Baseline	*1,903*	*4,751*
TSO questionnaire without UK submarine interconnectors		**920**	**not reported**

Tab. 12 – Investments in cross-border capacity planned by TSOs w.r.t. those obtained from the simulations

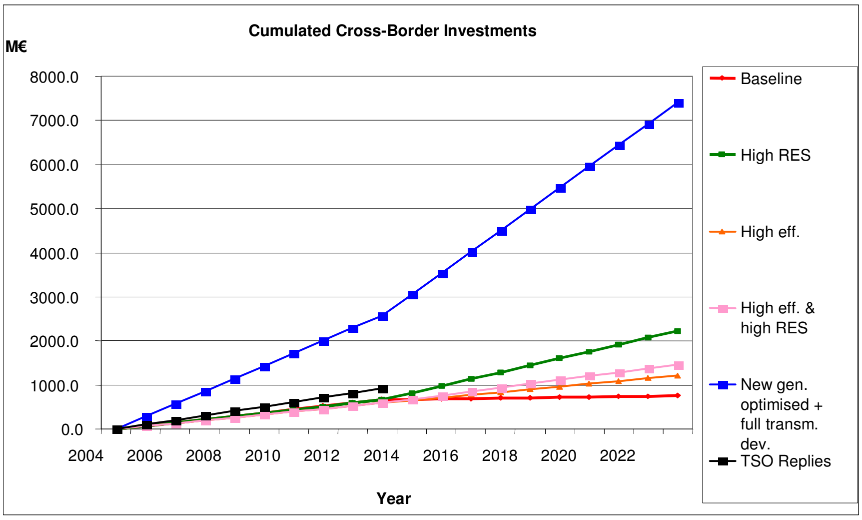


Fig. 5- Cumulated cross-border investments

Investments associated to the connection of offshore wind generation – The cumulated investments associated to the connection of off shore wind generation are shown in the following table with reference to the three most meaningful scenarios. The investments required to connect offshore wind facilities to onshore grids range between 7.7 b€ and 11.8 b€ in the period 2005-2013, i.e.: 0.9÷1.3 b€/yr. In the second decade ahead (2014-2023) a sharp increase in investments is expected; the total investments would be in the range between 17.1 b€ and 25.4 b€, i.e.: 1.7÷2.5 b€/yr.

Expected investment costs
for offshore wind power connection [million €]

	------- EU-30 -------		
	Mid term 2005-2013	Long term 2014-2023	Totals 2005-2023
Baseline scenario [1]	7,766	17,190	24,956
High RES [2]	11,771	25,336	37,108
New gen. optim. + full transm. developm. [1]	7,766	17,190	24,956

[1] based on FORRES - BAU scenario
[2] based on FORRES - Policy scenario

Tab. 13– Investments for connection of offshore wind farms

Total investments according to the TSOs forecasts - Information on investment plans in the mid term was collected for 23 countries. In order to get the total estimation for the EU30 countries, a similar trend on the investment pattern was assumed for the remaining ones[14], which we do not have information about. A clear indication of the increasing investment effort for the next years (up to 2013) emerges from the investments plans declared by TSOs with an envisaged yearly investment level around 4 b€/yr.

Much more difficult is to present a clearly defined investment pattern for the long-term (up to 2023). In the few countries where TSOs declared their long-term investment plans the investment level is quite stable (e.g.: Lithuania, Finland) and in some cases an increase in investments is foreseen (Turkey). By averaging the available information and comparing it with the past and mid term investments, we can conclude that also in the second decade ahead (up to 2023) a steadily high investment level is to be expected.

The investments plans declared by the TSOs for the next decade show the willingness of TSOs to keep up and in many cases to increase the effort for the construction of new lines and the upgrading of the existing infrastructures. To this purpose, it is worth mentioning that, in general, the people responsible for planning highlighted that the on-going implementation of the European IEM is not a hinder for the investments. On the contrary, in some cases (e.g.: Netherlands, Lithuania, Italy, Spain) projects have been motivated by the need of improving the functioning of the internal market through the increase of TTC (Total Transfer Capacity) and the relief or mitigation of congestion. Particularly in NORDEL, the main focus since 1992 has been to increase the capacity between the Nordic countries to improve the Nordic electricity market.

On the other hand, all the people responsible for planning highlighted difficulties in the construction of new infrastructures both inside the country and across the borders. Obstacles can be summarised as follows:

- difficulties in finding the right-of-ways
- slow procedures to get the necessary authorisations
- general opposition from the local population
- in some cases, further delays are caused by the need of co-ordination between TSOs for international lines;
- differences in regulatory practice and TSO priorities.

All the above factors cause a remarkable mismatch between the planned investments and those that are really carried out (e.g.: the ratio “performed investments”/”scheduled investments” can be as low as 60%).

[14] Austria, Belgium, Bulgaria, Germany, Luxembourg, Portugal and Switzerland didn’t disclose any investment plan.

A possible transient solution to increase cross-border transactions without having to resort to further investments is the adoption of an appropriate mechanism for regional congestion management favouring a more intense use of the existing international lines.

Conclusions on topic 4 and 5:
- *according to TSOs forecasts, in the mid term (up to year 2013) investments are expected to increase around 4 b€/yr; a steadily high investment level is to be expected also for the second decade ahead (up to 2023);*
- *estimations based on demand evolution and accounting for country surface and load density indicate the need for investments in infrastructures internal to the EU 30 countries at a level similar to the present one: 3.3 b€/yr;*
- *cross-border investments are expected to decrease to a level below 70 M€/yr when assuming the generation evolution of the PRIMES model;*
- *high RES penetration will cause high investments on cross-border lines in the long-run (>150 M€/yr);*
- *when optimising both new generation and cross-border transmission capacity, very high investments turn out to be necessary, especially in the long-run (>480 M€/yr);*
- *the investments required to connect offshore wind farms to onshore grids are in the range 0.9÷1.3 b€/yr in the mid-term. In the long term a sharp increase of investments is needed (1.7÷2.5 b€/yr).*

For more details see: main report - chapter 4

5. GAS SECTOR

The European gas transmission system varies significantly regarding technical characters such as pipeline size and design pressure. The consequence of these differences is that in one country a gas pipeline is attributed to the transmission, while in another country the same pipeline would be classified as distribution.

5.1 Current technical status of energy infrastructures

The European gas infrastructure has developed gradually, generally first in countries with a national gas production and much later in countries without any significant gas production such as Greece, Portugal, Spain and Sweden. It should be noted that the European gas system is not composed of a number of pools as the power transmission grid. There are, however, different gas qualities and the energy content in a cubic meter of gas varies from one geographical location to another.

The current capacities at the major gas transmission points are presented in the main report. Whereas most nations historically have had a majority of their power produced within their national borders, nowadays most European countries are gas importers. This also implies that it is meaningless for the gas side to adopt an equivalent ratio, as in the case of the power sector, referring to import capacity/total installed generating capacity. The gas import capacities shall be seen in relation to the national gas production and demand. This has been done on a European level as is presented later in the report when looking at the mid-long term investment pattern.

Around half of the companies have reported to have bottlenecks in their transmission system. Concerning the cross-border points, there is currently a limited free (i.e.: not already allocated) transportation capacity. How the future development in the bottlenecks will develop, is difficult to predict. Around a third of the companies did not answer this question.

Conclusions on topic 1:
- *the national gas transmission grids are interconnected which makes it possible to deliver gas from Norway in North to Italy in South;*
- *increasing gas demand and current bottlenecks calls for continuous investments in the European gas transmission system*

For more details see: main report - chapter 5

5.2 Investment patterns during the years 1996 till 2004

From the second half of the 1990s to today the investment level in EU 30 gas transmission has been around 2.6 b€/yr. This includes investments in TSO internal national gas transmission systems, excluding investments in gas storages, LNG terminals, import pipelines and new interconnectors such between UK (Bacton) and Belgium (Zeebrugge) - (only investment type 1 "*Internal TSO Investments*", as described in sect. 5.6).

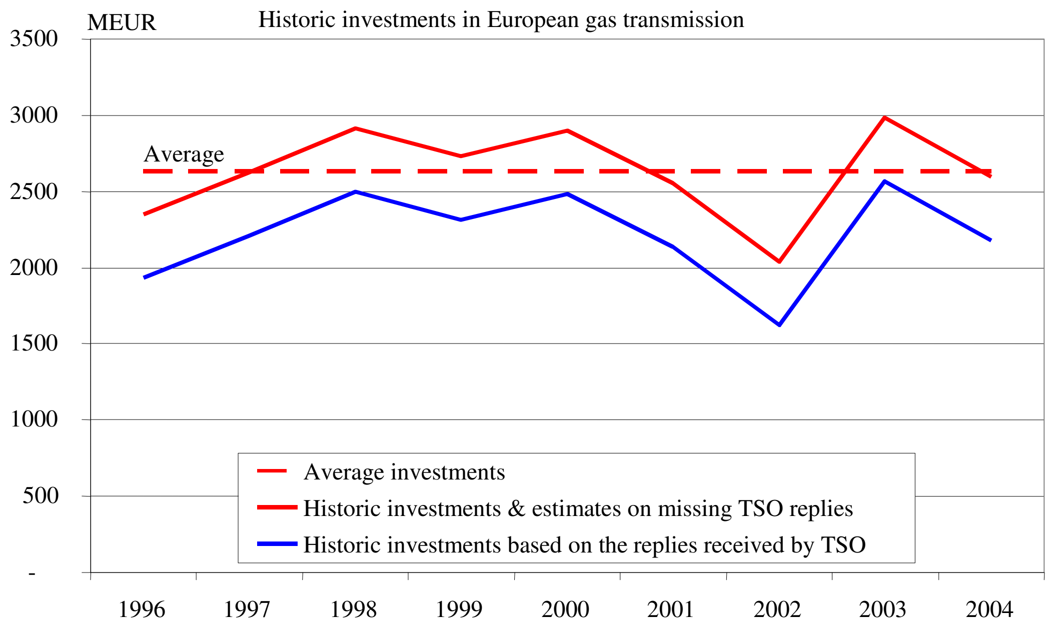


Fig. 6: EU 30 historic investments in EU gas transmission (data are estimated for Luxemburg, Czech Republic, Austria, Bulgaria, Slovakia, three TSOs from Germany and partly for Spain). The data is adjusted to 2005 real prices considering inflation rates.

The backgrounds justifying the historic investments are: lack of transmission capacity, extension of pipeline systems to new areas, need to reach power plants, diversification, new cross border points, development of international transit, need to solve cities air pollution and to improve security of supply.

The creation of the Single Market in EU has had a significant impact on the investments in the gas transmission system. The investments have been needed: to implement TPA (Third Party Access), to deal with uncertainty over the future gas flow in networks, to increase capacity and to reduce the number of tariff zones.

The gas infrastructure has also had an impact on the internal gas market. For example, Finland has got derogation from the EU-gas directive being an isolated market with only one gas supplier.

5.3 Financing sources

EU loans or other aid instruments have been widely used to support gas transmission projects as around half of the TSOs have reported positively on this.

Only six out of 31 TSOs report that even in the absence of EU loans or aid instruments, the same projects would have been executed. However, on the opposite side, six other TSO also reported that projects would not have been executed without EU loans or aid instruments.

A large majority of 16 TSOs reported that financing is not slowing down investments in gas transmission projects. Only six other TSOs reported that financing is slowing down investments in gas transmission network projects. It is difficult to find any pattern or similarities between the countries where financing is reported to be a problem.

Conclusions on topic 2

- *In the period 1996-2004 the investment level in the internal national gas transmission system has been quite stable at around 2.6 billion € annually.*
- *In addition to these investments, other investments have also been made in gas storages, LNG terminals, interconnectors and import pipelines.*
- *Around half of the TSOs have reported to have benefited from EU loans or other aid instruments*
- *Only six out of 31 TSOs report that even in the absence of EU loans or aid instruments, the same projects would have been executed.*

For more details see: main report - chapter 5

5.4 Ageing of the system and need for repairs and upgrades

The average age of gas transmission networks of the various gas TSOs in Europe varies significantly. The youngest transmission systems are around 6 years, while the oldest gas transmission systems are around 31 years in average. The reported design life of the gas transmission system is between 20 and 70 years, but most companies say 40 to 50 years.

TSOs generally expect their gas transmission systems to be able to work safely and reliably for the next 20 years. There are, however, two exceptions: in Bosnia and Herzegovina the reported expected remaining lifetime is between 7 to 10 years, but the gas transmission system is only 190 km long; in Romania the reported expected remaining lifetime is between 5 to 10 years. Here, the gas transmission system is around 12500 km long.

The oldest gas transmission pipelines generally have a lower design pressure and smaller pipeline diameter and hereby also less gas transmission capacity, than new transmission pipelines. The replacement of this older capacity will, therefore, be the less costly, than if it would be the newer gas transmission capacity that should be replaced.

The current condition of the European gas transmission system seems to be fairly good when measuring the grid losses. An overwhelming majority has reported well below 0.5% in grid loss. The country with the highest grid loss reported 2.4% and is aware of the challenge. Plans are to reduce the grid loss to 1.5% by 2007.

Several of the TSOs have reported that there were significant saving potentials by modifying or changing compressor stations. Also, some companies have mentioned that there might be a need for new investments in compressors if there are stronger environmental legislations.

Conclusions on topic 3:

- *the expected remaining lifetime of the European gas transmission system is generally well beyond 2023*
- *exceptions to this are the oldest European gas transmission systems such as Bosnia-Herzegovina and Romania with an estimated remaining lifetime below 10 years.*

For more details see: main report - chapter 5

5.5 Gas demand

In the Baseline scenario the gas demand in the EU 30 is expected to increase from 505 bcm in 2005 to 720 bcm in 2023. The internal gas production is expected to fall from 283 bcm to 257 bcm in 2023. The import dependence on gas will therefore increase from 222 to 463 bcm in 2023.

EU 30: Expected increase in demand	Consumption (bcm)			Gas import (bcm)		
	2005	2013	2023	2005	2013	2023
Baseline Scenario	505	615	720	222	327	463
High RES (12% renewables in 2010)	482	588	686	206	298	422
High Energy Efficiency	470	556	626	197	265	350
High RES + High Efficiency	458	528	592	184	242	330
Soaring oil and gas prices	503	515	542	220	206	256

Tab. 14 : Main characteristics of the EU 30 gas systems

The gas production in all of the current EU members is falling while the gas production in Norway is increasing significantly; Turkey shows a limited growth in the gas production. The country with the largest change in gas demand is UK where the primary gas production is expected to fall significantly at the same time as the gas demand is increasing (Fig. 7).

The countries with the largest expected increase in gas import are Germany, Italy, Turkey, Poland, Spain, France and Denmark. By 2023, the Netherlands will be the only country in the EU with a gas production that is higher than the national gas consumption.

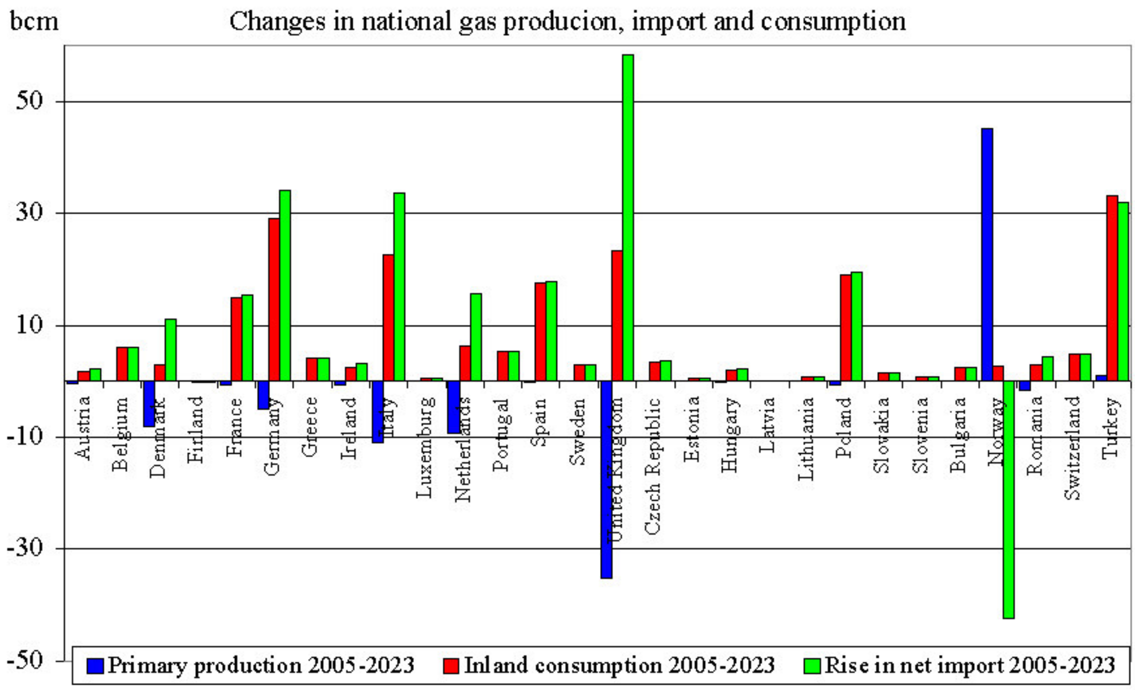


Fig. 7: EU 30 Baseline scenario - Changes in national gas production, import and consumption

5.6 Methodology for the evaluation of investments

The future investments in the gas infrastructure have been divided into the following 5 groups:

1. **Internal investments in each country:** TSOs have been asked about their historic and future investments. These are investments that the TSO are expected to make in their own national gas transmission grid to extend, upgrade and maintain the current system. Investments in gas storages, LNG terminals and major import pipelines have been subtracted from these investments.

In addition, four other groups of investments are foreseen.

2. **Storage:** To utilise the gas import pipelines system with a high load factor it is necessary to resort to gas storage facilities. The historic flexibility of the European gas production is dwindling together with the falling production in Europe. The increasing gas demand and the associated increase in gas import, therefore, require further gas storage capacity within Europe as explained below.

   The internal gas production in EU 15 was 187 bcm[15] and the gas storage capacity was 58 bcm, which gives a production/storage ratio of 3.2 (187/58). The gas import was 164 bcm giving an import/storage ratio of 2.8 (164/58). This means that the internal gas production is 3.2 times higher than the total seasonal gas storage capacity, but the gas import is only 2.8 times the seasonal gas storage capacity.
   Using these two key ratios the need for gas storage will increase in Europe per cubic meter of gas consumed, since a higher share of gas is imported. The cost associated to additional gas storage facilities in the various scenarios is shown in Tab. 17.
   As an overview, the current EU 30 gas storage capacity of around 76 bcm is on average equivalent to the gas consumption of 1.8 month. The increase in gas storage to 103 bcm in 2013 is equivalent to 2.0 months, referred to the demand of 2013, and the increase in storage to 132 bcm in 2023 is equivalent to covering around 2.2 months of gas consumption, referred to the demand in 2023.

3. **Interconnectors[16] and gasification:** Includes interconnectors, which are pipelines that directly connect two EU members gas infrastructures, and introduction of gas into geographical areas that currently do not receive gas. The projects that have been included can be seen in the table below. The first six projects are interconnectors. The first three interconnectors are ongoing offshore pipelines. Norway is the only EU 30 country that is expected to increase its export. To make this possible, in addition to the Langeled pipeline one additional pipeline is expected. Also, one offshore interconnector between Finland and Estonia (Balticconnector) and one onshore interconnector between Poland and Lithuania (short version of the Amber pipeline) are included. The last project is gasification of a new area currently not receiving gas.

EU 30: Expected investments M EUR **Future interconnectors and gasification**	First gas flow	Capacity bcm	Investment M EUR
BBL (Nederland-UK)	Dec 2006	16	500
Bacton Interconnector Upgrade (now: 8.5bcm)	Dec 2006	23.5	250
Langeled (Norway-UK)	2007	25.6	2300
Norway-Europe	Unknown	17	1520
Balticconnector (Finland-Estonia)	Unknown	2	210
Amber (Poland-Lithuania)	Unknown	1	350
Scandinavian Gas Ring (Gas to Sweden & Oslo)	Unknown	1.3	650
Total			5780

Tab. 15 Interconnectors and gasification projects

4. **Ongoing import projects:** Includes just finalised and ongoing gas projects that are increasing the gas import capacity to Europe. The projects are:
   i. Yamal Europe pipeline compressors located in Poland (2005), that are increasing the pipeline capacity at a cost of 0.35 b€

[15] The estimation of gas storage facilities needed for the EU 30 countries has been made by referring to the present situation in the EU 15 considering that the relevant ratios "production/storage" and "import/storage" are sufficient to ensure an adequate flexibility also in the future.
[16] An Interconnector is generally considered to be a pipeline that links two pipeline systems that currently are not connected. Ownership of an interconnector does not need to be limited to the TSO of the two systems it connects.

ii. South Caucasus Pipeline (2006) from Azerbaijan to Turkey with 6.6 bcm a year - investments are outside EU30.

iii. New LNG terminal on Isle of Grain (phase I in 2005 and II in 2009) with a total of 13.5 bcm a year at a cost of 0.7 b€.

5. **Import pipelines and LNG** are import pipelines or LNG receiving terminals to the EU 30. These projects are to ensure that Europe is having sufficient gas transmission or LNG facility to meet the future gas demand. As an example, the Nabucco pipeline is increasing the gas import capacity form the EU 30 border country Turkey to Austria; therefore, this infrastructure has been classified as an import pipeline. Similarly, it has been done for the southward pipeline from Turkey to Italy through Greece.

The method for estimating the expected future gas import need is briefly described by the figure below. The green area represents growth in the net import of gas. The current gas import capacity is illustrated by the red line. The red dotted line shows the import capacity when the pipelines are utilized with a load factor of 0.8, and the LNG regasification terminals with a load factor of 0.6. The figure shows that new import pipelines and/or LNG are needed from 2009 onward.

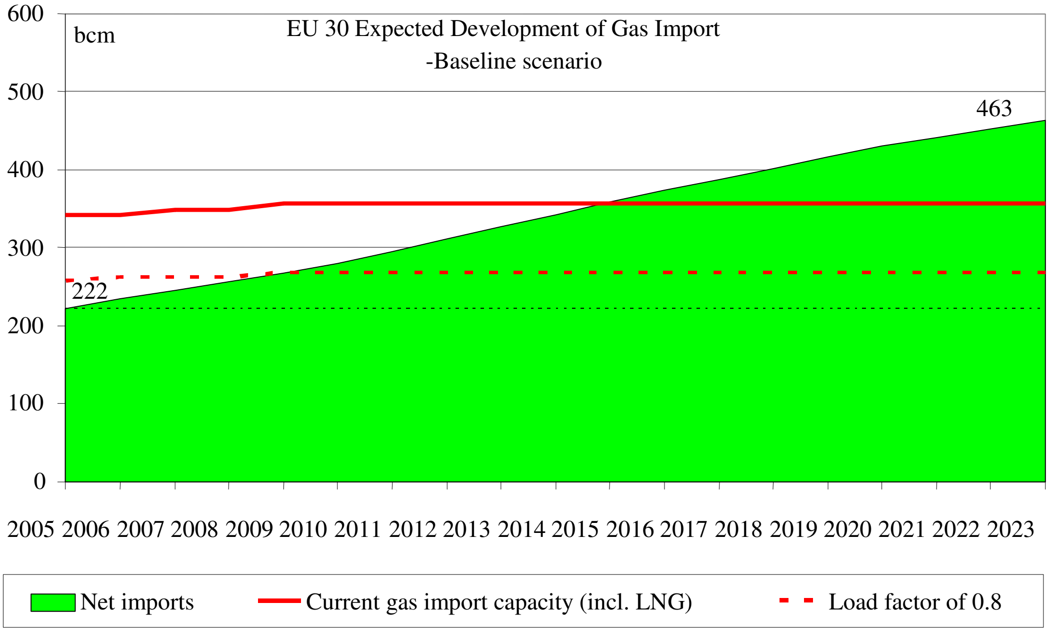


Fig. 8: Expected development of gas import and needed increase in new import capacity

The projects expected to increase the gas import capacity to Europe are shown in Tab. 16, and are also described in the EU publication "Trans-European Energy Networks, TEN-E priority projects" issued in 2004. For some projects, more updated cost data was available and was used.

Pipeline Route	EU list	Type of Work	Capacity bcm/year	Estimated cost M EUR
Russia-Germany	NG1	New pipeline offshore in Baltic Sea	35	4700
Yamal Europe II	NG1	Second line across Poland	32	1520
Third line from Russia	NG1	Onshore/offshore pipeline	32	1520
Across the strait of Gibraltar	NG2	Offshore pipeline	9	150
Algeria-Spain (Medgaz)	NG2	New deep water offshore pipeline	18	1437
Algeria-France/Italy	NG2	New pipeline	20	5000
Turkey-Grece-Italy	NG3	New pipeline	8	1612
Turkey-Austria	NG3	Nabucco pipeline	30	4400
Total			184	20340

LNG Receiving terminal	Type of Work	Storage m^3	Capacity bcm/year	Estimated cost M EUR
Zeebrugge (Belgium)	Extending the LNG receiving capacit	210 000	10	100
Fos-sur-Mer (France)	Extending the LNG receiving capacit		8	365
Mugardos (Galicia) (Spain)	New terminal	300 000	2	320
Tuscany region (Italy)	New terminal	320000	6	600
North Adriatic coast (Italy)	New terminal	500000	8	1200
New LNG terminal France	New terminal		9	520
Total			43	3105

Tab. 16: Name and location o f new import pipelines and LNG facilities to 2023

5.7 Mid-long term investment patterns

The Baseline scenario is calling for significant new investments. Until 2023 the investments are expected to be 48 billions € in the internal TSO transmission system, 22 billions in storage[17], 6 billions in interconnectors, 1 billions in already started gas import projects and 23 billions in import pipelines and LNG regasification terminals - reaching 100 billion € in total. In addition to the baseline scenario, four more scenarios were analysed, which all lead to lower investment costs than the baseline scenario. These scenarios all have a lower expected gas demand and, therefore, also a lower investment level.

The "*Soaring oil and gas prices scenario*"[18] has the lowest expected investment costs of 51 billions € in total, which is around 50% less than the baseline. The reason for this is that the gas demand is only increasing by 40 bcm, compared to 215 bcm in the Baseline scenario.

[17] An investment cost of 0,4 € per cubic meter of working volume of gas, based on depleted gas fields and aquifer storages is assumed

[18] European Commission, "*European Energy and Transport Scenarios on Key Drivers*", DG for Energy and Transport, September 2004

EU 30: Expected investments B EUR 2005-2013: New import capacity	TSO internal Investment	Storage	Intercon-nectors etc.	Ongoing Projects	Import Pipelines & LNG	Total Investment
Baseline Scenario	24	10	3	1	10	48
12% renewables in 2010	23	7	3	1	9	43
Energy efficiency	21	5	3	1	7	37
Efficiency case with high renewables	20	4	3	1	6	34
Soaring oil and gas price scenario	18	4	3	1	0	26

EU 30: Expected investments B EUR 2014-2023: New import capacity	TSO internal Investment	Storage	Intercon-nectors etc.	Ongoing Projects	Import Pipelines & LNG	Total Investment
Baseline Scenario	24	12	3	0	13	52
12% renewables in 2010	23	10	3	0	12	48
Energy efficiency	21	6	3	0	8	38
Efficiency case with high renewables	20	5	3	0	8	36
Soaring oil and gas price scenario	18	1	3	0	3	25

EU 30: Expected investments B EUR TOTAL: New import capacity	TSO internal Investment	Storage	Intercon-nectors etc.	Ongoing Projects	Import Pipelines & LNG	Total Investment
Baseline Scenario	48	22	6	1	23	100
12% renewables in 2010	46	17	6	1	21	91
Energy efficiency	42	11	6	1	15	75
Efficiency case with high renewables	40	9	6	1	14	70
Soaring oil and gas price scenario	36	5	6	1	3	51

Tab. 17: Total investments 2005-2013, 2014-2023 and 2005-2023

For large parts of 2005 the oil price has been above 50 USD/bbl and the peaks have been around 70 USD/bbl (until August 2005). This is a higher oil price than in the *Soaring oil and gas price scenario*. If the oil and gas prices will continue to be at such a high level, the *Soaring oil and gas price scenario* with a total investment level of around 50 billion € will be the most likely. If however, the current high prices just turn out to be a short-term phenomenon that will fall to the baseline scenario prices, then the baseline scenario investments of around 100 billion € will be the more likely investment level.

The real implementation of the above projects and related investments shall overcome a series of obstacles, perceived by the majority of gas TSOs, that can be wrapped up as being regulatory obstacles, technical obstacles and cumbersome approval procedures.

Conclusions on topics 4 and 5:

- *Mid-tem investments: the baseline scenario has the highest increase in the gas demand of 110 bcm in 2013. The baseline scenario, therefore, also has the highest investment level of around 48 billion € by 2013 (5.3 b€/yr in 2005-2013).*
- *Long-tem investments: the baseline scenario again has the highest increase in the gas demand of 215 bcm in 2023 and a total investment level of around 100 billion € by 2023 (5.2 b€/yr in 2014-2023).*

For more details see: main report - chapter 5

6. INTEGRATION OF RES INTO THE ENERGY NETWORKS

In line with the Project objective, an important part of the study addressed the cost-benefit analysis relevant to the introduction of significant levels of new generation technologies based on renewable energy sources (RES) into the transmission network. In particular, the possibility of creating a good combination between wind and gas generation has been investigated; conditions for an economically profitable wind-gas combination have been examined taking into account emission costs, wind plants load factor, emission cost contributions to capacity credits. Furthermore, wind generation can be combined with storage facilities, particularly pumping storage plants and storage through air-compressed reservoirs, to enhance its weak characteristics of firm and dispatchable generation. Moreover, the available technologies to exploit solar energy were investigated as well as the perspectives for possible export of solar power from North Africa to Europe.

The following table shows the main characteristics of the above technologies, the most favourable locations and the conditions to be economically profitable.

Finally, the possibility to transport both biogas and hydrogen in pipeline networks with the technologies existing today was examined. This solution is more expensive than transporting natural gas due to the lower calorific values of biogas and hydrogen and its feasibility is quite low.

Conclusions on topic 6:

- *For the successful integration of massive RES in the transmission grids, the most feasible solution from the economical and technical point of view is the combination of wind generation with gas fired combined cycles;*
- *Solar energy and combination of wind generation with storage (pumping stations and CAES) are not economically feasible in the mid term;*
- *Transportation of biogas in dedicated networks or in natural gas pipelines is not economical feasible without any subsidies;*
- *Transport of hydrogen mixed with natural gas is not economically and technically feasible.*

For more details see: main report - chapter 6

Integration of RES				
Technology	**Location (country or priority axis)**	**Scope of the analysis, characteristics of the technical solutions**	**Prices**	**Feasibility**
Wind-gas combination	Germany-Denmark-Netherlands (impact on EL7 and EL1) Spain (EL3)	Scope: ➢ comparison of the costs of energy production with the combination wind-gas against the cost of producing the same energy only with gas-fired combined cycles (CC) Characteristics: ➢ Wind farms production combined with gas-fired CC to give a constant output. ➢ CC designed to follow inversely the production of wind farms ➢ Load factor of wind farms: 25÷35% ➢ Fuel price and discount rate according to Baseline scenario	Required prices to be economically convenient: ≈ 40 €/MWh	**High** Economic profitability sensitive to: CO_2 emission costs, wind farm load factor, discount rates, wind farm capital costs, capacity credit and gas price
Wind-Pumping storage plants	Denmark-Norway through: EL6 Netherlands-Norway through NorNed Internally to: Spain, Italy, Austria, Great Britain, Lithuania	Scope: ➢ Possibility of firm generation for base load or for peak load Characteristics: ➢ Transmission capacity and water storage capacity optimised to reach a load factor of: 85%	Required prices to be economically convenient: 70-170 €/MWh (depending on the wind speed profile)	**Low** Solution of firm generation for peak load more attractive in the long term than firm generation for base load
Wind-CAES	Germany, Italy	Scope: ➢ Possibility of firm generation for base load or for peak load Characteristics: ➢ Compression of air in caverns through wind generation and gas burners	Required prices to be economically convenient: ≈ 80 €/MWh (referring to load factor: 22%)	**Low** Not economically convenient before year 2025
Solar Energy	North Africa, export to Europe through EL9	Scope: ➢ Solar energy production in North Africa and export to Europe Characteristics: ➢ High potential in North Africa ➢ Load factor: 25% ➢ Possibility to be hybridised with thermal storage to provide firm generation ➢ Possibility to be integrated with gas-fired combined cycles to provide firm generation	Required prices to be economically convenient: ≈ 150 €/MWh (referring to load factor: 25%)	**Low** Not realistic before year 2025 considering the high capital costs and the perspective developments of solar installations in Maghreb

Transport of Biogas and Hydrogen

Technology	Location (country or priority axis)	Scope of the analysis, characteristics of the technical solutions	Costs	Feasibility
Biogas	Potential in all countries. Transport of biogas in pipelines tested in Sweden	Scope: ➢ Biogas used to reduce the use of fossil fuel Characteristics: three ways to distribute biogas ➢ Upgrade biogas to natural gas standard ➢ Local distribution where gas quality is less significant, e.g. town gas and district heating ➢ Dedicated networks	➢ Upgrade: the upgrading process itself costs around the same as natural gas ➢ Local distribution: few such networks exist today ➢ Dedicated networks: small volumes make the unit transporting costs prohibitive.	**Low** This development is dependent on subsidies.
Hydrogen	Potential in countries with surplus energy production	Scope: ➢ Possibility to store energy Characteristics: ➢ Surplus of wind generated power can be converted to hydrogen and distributed with the natural gas system	-------------	**Low** Technical problems when mixing hydrogen with natural gas. Hydrogen has the advantage of being a clean gas: this property is lost when mixing it with natural gas.

7. USE OF NON-CONVENTIONAL TECHNOLOGIES FOR INCREASING CAPACITY IN TRANSMISSION NETWORKS

Non-conventional technologies can be classified in two broad categories: hardware technologies, which rely on the adoption of a new generation of components or the adaptation of already existing equipment to new operating conditions, and software solutions, based on IT and advanced communication protocols. The purpose of this analysis has been the identification of the most promising non-conventional technologies that can be introduced in the European transmission grids of electricity and gas, highlighting their benefits, investment costs (when available) and possible locations along the EU priority axes or internally to the countries.

7.1 Non-conventional technologies in electric networks

It is well recognized that a number factors exist today that force to restrain or slow down the construction of new infrastructures both inside the country and across the borders, as already mentioned above. As a consequence of this, it arises the need to fully utilize the available capacity of the existing transmission assets as much as possible. In transmission systems there are a few factors constraining system's ability to transfer power and, therefore, lower the utilization rates of the existing networks. In general terms two kinds of constraints can be distinguished, namely; technical limits and limits due to operating procedures. Technical limits refer to those physical parameters that are to be kept within allowed limits to avoid damage of the physical assets: thermal constraints, voltage constraints, stability limits and limits due to parallel flow and loop flow phenomenon. Operating procedures are related to the way physical limits are considered in the definition of the transfer capacity that can be used for power transaction in the market; these operating procedures are normally defined in the national grid codes.

There are many technical measures that can be implemented to alleviate, to some extent, the constraints limiting the fully utilization of transmission networks, thus allowing increasing the transfer capacity without the need of erecting new transmission facilities. So far, solutions based on conventional technology have been generally used by various utilities for the transmission systems reinforcement, such as: “reconductoring” of transmission lines, conversion from single to double circuit, voltage upgrade and fixed series compensation.

Although conventional methods can be successfully applied in some cases for transmission systems reinforcement, their practical implementation is limited by several technical factors that make them unfeasible for massive application. A number of new hardware based technologies for increasing the capacity of transmission system have been and continue to be under development; these can be classified as follows: adoption of new types of cables as alternative to overhead lines, high voltage direct current (HVDC) links and Flexible Alternating Current Transmission Systems (FACTS). A view of the most common solutions is given in the following tables.

7.2 Non-conventional technologies for gas networks

The most important break-through in new technologies during the last decade has been without doubt the use of offshore pipeline for very deep water (more than 2000 m). Moreover, during the next decade, the widespread use of LNG and small-scale LNG and the application of high-pressure pipeline for onshore transmission system might change the way gas transmission systems are operated.

Finally, further measures can be adopted to enhance the gas transmission capacity along existing routes, such as the use of electrically driven compressors, adoption of plastic or composite materials and trench less technology. A summary of the most appealing innovative solutions is given in the table here below.

Conclusions on topic 7:

Electricity

- *the most mature non-conventional solutions are based on the installations of high voltage extruded polyethylene cables, connections in high voltage direct current and phase shifter transformers;*
- *Use of static Var compensators and static synchronous compensators is beneficial more on the local level to optimise the voltage profile rather than to enhance power transfer capacity;*

Gas

- *Ultra deep water offshore pipelines and high pressure on-shore pipelines are the most favourable solutions for the construction of new gas routes and for enhancing the capacity of the existing ones;*

Software based solutions

- *In the electricity sector, change of operating procedures and dynamic rating of components are two possible ways feasible to enhance transfer capacities with the mid-term perspective allowing to postpone investments in new lines*
- *In the gas sector, the adoption of new meters coupled with satellite communications will favour the on-line collection of a large amount of reliable data as required by the EU gas market;*
- *The design of new gas pipelines can be eased by the use of satellite three-dimensional charts.*

For more details see: main report - chapter 7

Electricity				
	Location (country or priority axis)	**Characteristics**	**Costs(*)**	**Feasibility**
Technology: CABLES				
Extruded polyethylene (XLPE) cables	Densely populated areas. Main applications in Spain; Germany; Denmark; France; UK; Ireland, Italy	➢ Insulation with "extruded polyethylene" ➢ Possibility of applications to voltage levels up to 400 kV ➢ For high capacity (≈2 GVA), need of forced cooling ➢ Limitation in lengths of XLPE cables in relationship to the short circuit	Ratio "Overhead line/XLPE cable": 1:7 ÷ 1:14	**High**
Gas Insulated Lines (GIL)	Poland Germany	➢ Very high capacity: 2÷3 GVA ➢ Technical characteristics similar to overhead lines ➢ High investment and maintenance costs. ➢ Big diameter of each phase	Ratio "Overhead line/GIL": 1:26	**Low**
High Temperature Superconductor (HTS) cables	------	➢ Technology still at a prototype level	No commercial applications	**Very low**
Technology: HVDC				
HVDC thyristor based lines	EL6, EL7, EL9(**), Italy-Greece, Italy-Corse-Sardinia, EL3 (Balearic connector) (**)	➢ Possibility of controlling power flows avoiding parallel and loop flows ➢ In some cases, it is the only alternative to link regions across the sea	150÷250 €/kW	**High**
HVDC Voltage Source Converter	Sweden. Norway, Germany, Denmark, Netherlands (for supplying off-shore wind farm)	➢ Full controllability of power and voltage ➢ Suitable to feed passive networks ➢ High losses with respect to HVDC thyristor based ➢ Limited capacity (up to 300 MW) ➢ High investment costs	190-350 €/kW (+25%-40% with respect to the thyristor based technique)	**Medium**

(*) Costs are highly dependent on the size of the equipment and the operating voltage, then the costs relevant to the most common size range are displayed.
(**) Planned project

Electricity				
Technology: FACTS	**Location (country or priority axis)**	**Characteristics**	**Costs(*)**	**Feasibility**
Phase Shifter Transformers	EL1 (Netherlands) EL2 (France-Italy) EL3 (France-Spain); Poland	➢ Possibility of controlling power flows in cut-sets with parallel lines having different loading levels	16÷70 €/kVA	**High**
Static Var Compensator (SVC)	Ireland; Belgium(**), France; UK; Sweden,	➢ Voltage control and reactive power management ➢ Dynamic voltage stabilisation	35-90 €/kVar	**High**
Static Synchronous Compensator (STATCOM)	UK	➢ Voltage control and reactive power management ➢ Dynamic voltage stabilisation ➢ Improved power system damping ➢ Power quality improvement	60-130 €/kVar	**Medium**
Thyristor Control Series Capacitors (TCSC)	Sweden	➢ Power Flow control ➢ Improve transient and voltage stability ➢ Damping electromechanical oscillations ➢ Aid in mitigation of subsynchronous resonances	50-130 €/kVA	**Medium**
Synchronous Static Series Compensator (SSSC)	----	➢ Power flow control ➢ Other basic functions as in TCSC technology	--------	**Medium-Low**
Unified Power Flow Controllers (UPFC)	----	➢ Active-reactive power control and voltage control	90-170 €/kVA	**Low** only prototype applications in USA

(*) Costs are highly dependent on the size of the FACTS device and the operating voltage, then the costs relevant to the most common size range are displayed.
(**) SVC installed only in conjunction with arc furnaces

Gas				
Technology:	**Location (country or priority axis)**	**Characteristics**	**Costs**	**Feasibility**
Ultra deep water offshore pipelines	Crossing of Mediterranean Sea, Black Sea and North Atlantic: Algeria-France; Egypt-Greece Georgia-Ukraine; Georgia-Romania	Deep water pipeline development was the background for Blue Stream pipeline from Russia to Turkey, Green line from Libya to Italy. Further development of this technology may be used for Medgaz from Algeria to Spain and Galsi from Algeria to Italy and France.	Cheaper than conventional pipelines due to more direct routes	**High**
High pressure onshore pipelines	Potential in all countries.	➢ design pressure up to same level as for offshore lines (250 bar) ➢ high capacity ➢ avoid intermediate down regulating of pressure when passing from offshore to onshore ➢ safety concerns – need for safety cases ➢ no tradition to use high pressure pipeline – who will be the first	Cheaper than conventional pipelines	**High**
Electrical driven compressors	Potential in all countries. Already used in the UK-Belgium interconnector	➢ fewer restrictions on the location of compressor stations ➢ environmental benefits since there are no local emissions ➢ possible disadvantage: link between electricity and gas systems	----	**High**
Plastic and composite materials for pipelines	Potential in all countries.	➢ Composite materials may be more interesting if high steel prices prevails	----	**Medium**
Trench less technology and new construction methods	Potential in all countries.	➢ Trench less technology may give possibility for more direct routing ➢ Crossing of nature reserves, rivers, cities may become possible ➢ Adoption of welding technology from offshore construction, automatic welding	Twice as expensive as normally trenched pipelines	**High**

Software solutions, based on IT and advanced communication protocols			
Technology:	**Location (country or priority axis)**	**Characteristics**	**Feasibility**
Electricity			
Dynamic rating of lines, cables, transformers	Italy-rest of Europe (EL2) Possible applications on other congested cut-sets	➢ monitoring and control scheme in which the thermal limits of transmission network components is determined based on actual loading and weather conditions ➢ For lines two possible types of measurements: "indirect measurement" of conductor sag and "direct measure" of conductor sag via GPS or Video Sagometer; ➢ For transformers or cables: sophisticated monitoring tools combine several different temperature and current measurements to dynamically determine temperature hot spots	**High**
Changes in operation procedures	Potential in all countries	➢ "on-line security assessment" based on data retrieved by on-line measurements of load, generation and status of transmission equipment. Data are automatically processed to determine the security margins; ➢ shifting from "preventive" to "corrective" security criteria (e.g.: "interruptible" loads, which, in case of perturbations are automatically disconnected)	**High**
Gas			
New meters and communication systems	Potential in all countries	➢ Third party access requires availability of large amount of data with high quality: this is made possible by new meters coupled with communication systems ➢ Communication by mobile telephone systems and/or satellite ➢ Metering of small end users will give possibility for flexible consumption and better utilisation of capacity	**High**
Satellite imaging and other IT based design methods	Potential in all countries, in particular new areas with less sophisticated maps, like - Nabucco, NG3 - Algeria, NG2	➢ Use of satellite imaging for pipeline design ➢ Advanced flow design ➢ Structural design ➢ Safety evaluations	**High**