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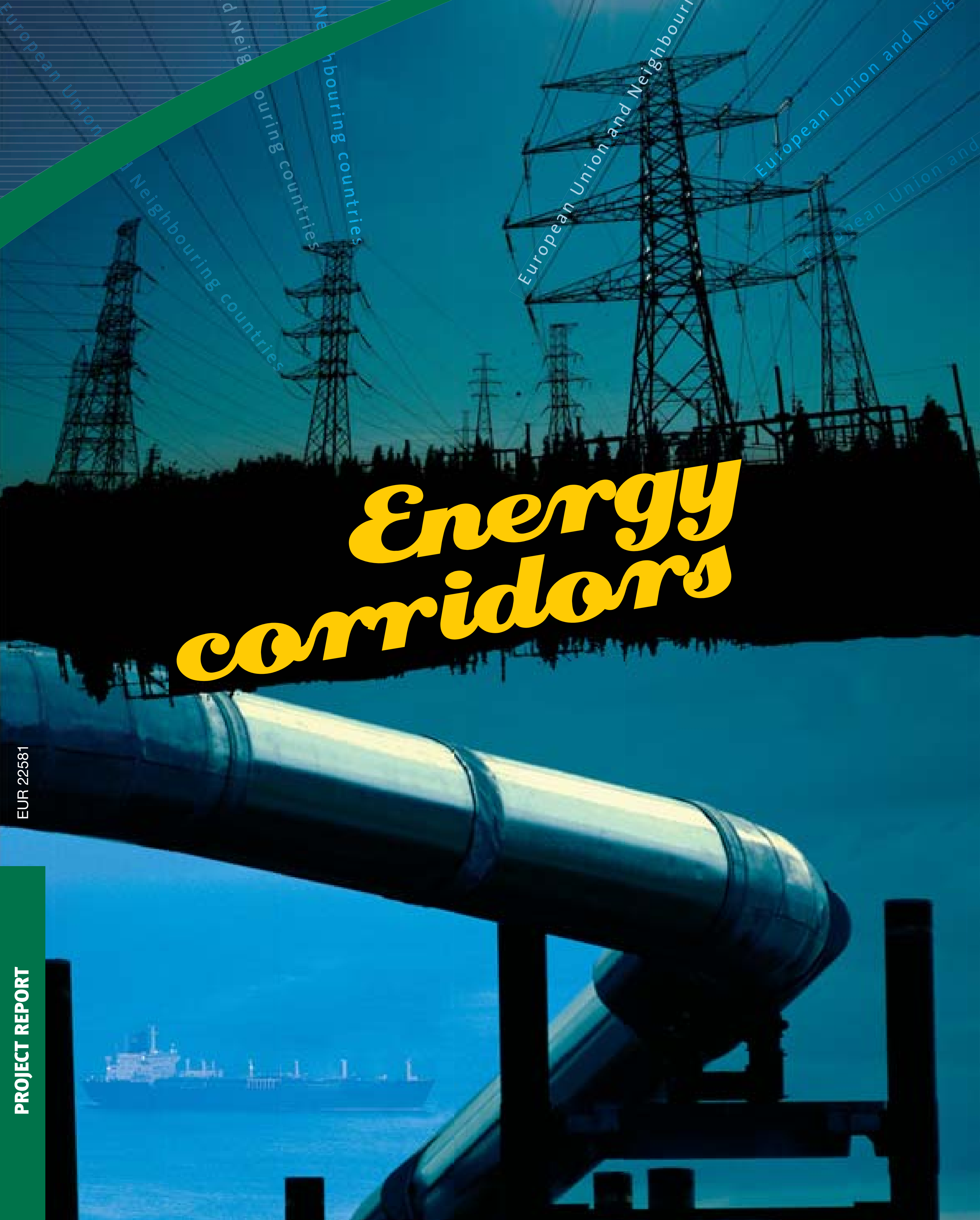

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EUROPEAN COMMISSION

Energy corridors

European Union and Neighbouring countries

Directorate-General for Research
Sustainable Energy Systems

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Foreword

The European Union (EU) imports today half of its energy needs and it is generally recognised that this figure could increase to 70% by 2030. While our EU natural gas production will decrease in the future, our consumption will double in the next two decades. At the same time, due to our increasing transport needs, it is expected that the EU oil consumption will continue to grow. EU electricity demand could increase by 50% in the next 25 years.

To face these challenges, both EU internal and external action is needed. As internal EU policy, we insist on the emergence of new energy technologies. Supported by the Research Framework Programme, the Technology Platforms and the Strategic Energy Technology Plan, new and clean energy technologies have a key role to play for a sustainable future.

On the external side, the "energy corridors" (or energy routes) between the EU and our neighbouring countries are of a crucial importance. EU neighbouring countries are major suppliers and transit countries of oil and gas. Concerning electricity (and potentially hydrogen in the future), there is a clear need to improve the interconnection capacity between EU and neighbouring countries.

De facto, our Nordic, Eastern and Southern neighbouring countries will play an increasing role in our future energy supply. As underlined by the ENCOURAGED project, three elements are needed for the integration of the energy markets of the EU and neighbouring countries:

- compatible interconnections;
- compatible market framework;
- compatible environmental policies.

When we speak about an "integrated" European Energy Policy, we also mean a policy that takes account of all aspects of energy, both internal – with a focus on technological development – and external – with a focus on the EU neighbouring countries.

Strong and smart energy corridors between EU and neighbouring countries are a key element of our EU energy policy. They contribute to our security of supply, to our competitiveness and to our sustainability.

Raffaele LIBERALI

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The project and implementation studies were co-ordinated by Frits van Oostvoorn from ECN. The studies for the gas corridors were coordinated by Manfred Hafner of OME, for the electricity corridors by Riccardo Vailati of CESI RICERCA, while Martin Wietschel of FhG-ISI coordinated the studies for assessment of the hydrogen corridors.

The consortium included the following organisations: Coordinator ECN (Energy research Centre of the Netherlands), Work-Package (WP) leaders OME (Observatoire Méditerranéen de l'Energie, France), CESI RICERCA (Italy), FhG-ISI (Fraunhofer Institute for Systems and Innovation Research, Germany) and partners ENVIROS (Czech Republic), CEP (Centre for Energy Policy, Russian Federation), EnCoG (ENergy COnsulting Group, Ukraine), IBS Research and Consultancy (Turkey), BSREC (Black Sea Regional Energy Centre, based in Bulgaria), IAEW (Institute of Power Systems and Power Economics) at RWTH Aachen University (Germany).

The main authors of contributions of the different partners were: ECN Frits van Oostvoorn, Michiel van Werven, Wietze Lise and Jeroen de Joode, from OME Manfred Hafner, Sohbet Karbuz, Benoît Esnault, Habib El Andaloussi, and Giacomo Luciani, from CESI RICERCA Riccardo Vailati, Antonio Gatti, Paola Bresesti, and Roberto Bernante and from FhG-ISI participated Martin Wietschel and Ulrike Hasenauer. Other members of the ENCOURAGED team were Miroslav Maly (Enviros), Sergey Molodtsov and Garegin Aslanian (CEP), Yuri Kubrushko and Alexey Romanov (EnCoG), David Tonge and Ceren Uzdil (IBS), Lulin Radulov (BSREC) and Thomas Hartmann (IAEW RWTH Aachen).

In addition to the aforementioned team members, several expert organisations participated and actively contributed to ENCOURAGED studies and activities: CESI (Centro Elettronico Sperimentale Italiano, Italy) Bruno Cova, REE (Red Eléctrica de España, Spain) Carlos Artaiz Wert, VTT (Technical Research Centre of Finland) Seppo Kärkkäinen, ECON (France) Andrew Ellis, DIW Berlin (German Institute for Economic Research, Germany) Christian von Hirschhausen et al, UNECE Gas Centre (Switzerland) Tans van Kleef, ENEA (Ente per le Nuove tecnologie, l'Energia e l'Ambiente, Italy) Antonio Mattucci, New Energy (Iceland) Hjalti Páll Ingólfsson, DFIU (Deutsch-Französisches Institut für Umweltforschung, Germany) Michael Ball, LBST (Ludwig-Bölkow-Systemtechnik, Germany) Hubert Landinger, Helio International (France) Robert Gould.

The following final reports of ENCOURAGED, also see http://www.encouraged.info/, were used as key input to this Summary report:

- CESI RICERCA et al, Final WP1 report on "Optimised Electricity Corridors between the enlarged EU and the neighbouring areas", September 2006.
- OME et al, Final WP2 report "The Development of natural gas corridors to Europe: Long term trends, priority Infrastructures and policy Options", September 2006,
- FhG ISI et al, Final WP3 report Optimal Hydrogen Corridors to the EU, FhG ISI, September 2006
- ECN et al, Final report on "Investments in Electricity and gas Corridors", November 2006
- ECN and OME, Final report on "International political framework in Europe for energy corridors", November 2006

Finally it is stressed that in-depth consultations and discussions of findings and recommendations of ENCOURAGED have been held in the period from February till December 2006 by means of workshops and seminars on study results with respectively the electricity, gas and hydrogen stakeholders (representatives from industry, regulators, investors, traders, policy makers, etc). See Annex A for an overview of most important seminars and stakeholders that contributed.

For any questions regarding this project and reports, please contact the coordinator Frits van Oostvoorn, E-mail: oostvoorn@ecn.nl or the project's website: www.encouraged.info.

Summary

Context

The ENCOURAGED (Energy corridor optimisation for European markets of gas, electricity and hydrogen) project has been launched in beginning 2005 to identify and assess the economically optimal energy corridors between European Union (EU) and neighbouring countries. The objectives of the project are to:

- Assess the economic optimal energy (electricity, gas and hydrogen) corridors and related network infrastructure for connecting the EU with its neighbouring countries and regions.
- Identify, quantify and evaluate the barriers to and potential benefits of building optimal energy corridors connecting the EU with its neighbours.
- Propose necessary policy measures to implement the recommended energy corridors with a focus on investment and the geopolitical framework.
- Organise stakeholder workshops and seminars to discuss the results and findings and reach consensus among scientists, stakeholders and non-governmental organizations and validate project results.

Need for gas corridors

According to the two scenarios used in this study (base case and low demand scenario) which are based on the European Commission DG Transport and Energy scenarios (EC, 2003), the gas import requirements in the European Union, Switzerland and Balkan countries will increase from 221 bcm in 2000 to 472 bcm in 2030 in the low demand scenario and reaches 652 bcm in the base case scenario. This would require increasing supplies in the next decades from the traditional European gas suppliers – Norway, Russia and North Africa – as well as the development of new additional supply resources.

The total gas supply potential available to Europe has been assessed to reach a level of about 450 bcm by 2010, 640 bcm by 2020 and 715 bcm by 2030, which has to be compared to 304 bcm imported in 2005. Algeria, Norway and Russia are expected to expand their dominant role as far as supply potential is concerned. Moreover, there appears to be a spectacular progression of the supply potential from the Middle East, the Caspian region, Nigeria, Egypt and Libya. This means that Europe will need to develop both important new pipeline and LNG infrastructure.

The identification of economic optimal gas corridors to the EU have been studied using a market equilibrium model for Europe and taking into account the supply potential and demand projections, transport capacities and supply costs, as well as issues linked to market behaviour and security of supply. Pipelines are expected to remain the most dominant means of gas transport in Europe in the next decades. In the reference scenario, the investment requirements are €126 billion. This figure includes pipelines, storage facilities as well as liquefaction and gasification terminals. Table S.1 summarizes the most important gas corridors requiring priority in building.

Table S.1 *Main Greenfield pipeline projects to Europe*

Project	Supplier	From	To	Capacity [bcm]	Investment [M €]	Foreseen Start-up
Medgaz	Algeria	Hassi R'Mel	Spain	8 to 10	1300	End 2008
GALSI	Algeria	Hassi R'Mel	Italy	8 to 10	1200	2009-2010
ITG-IGI	Caspian	Greece	Italy	8 to 10	950 (IGI)	2011
Nord Stream	Russia	Vyborg	Germany	2x 27.5	4000	2010
Langeled	Norway	Ormen Lange	UK	22 to 24	1000	2006-2007
Nabucco	Caspian	Turkish border	Austria	25 to 30	4600	2010
Total additional supply capacity to Europe				98.5 to 139		

The realisation of the above mentioned pipeline projects could provide an additional 100 bcm/yr of import capacity to Europe by the beginning of the next decade. It should be noted, however, that these projects mainly focus on carrying more gas into the European market, while fewer operators are keen on developing the needed interconnections inside Europe. While not being the scope of this study, it might be useful to investigate the incentives for 'de-bottlenecking' the internal EU gas market to connect these pipelines from neighbouring supply countries. Moreover, the announced LNG projects would represent an additional import capacity of about 100 bcm/yr by the beginning of the next decade.

The number of proposed projects could support the idea that there is no problem of investment in international gas infrastructure to Europe. It should be underlined, however, that many of these projects have been around and announced for quite a while and that many of these projects require long lead-times for completion. Ultimately, not all projects will be realized and it is therefore necessary to ensure that at least the required additional supply will be made available in due time.

At the heart of the investment financing issue is the relation between uncertainty, cost of investments and profitability. The examples presented hereafter show that some projects remain sustainable by themselves, while others are more difficult to realize and may need a political or regulatory support.

- The **Nord Stream** is a big offshore pipeline (2x27.5 bcm) across the Baltic Sea, directly linking Russia and Germany. While E.ON, Wintershall and Gasunie are now official partners, it was designed and decided without any supply agreement with importers. Promoted by Gazprom, it aims at bypassing transit countries like Ukraine and Belarus. Supported by a few big promoters, this project does not seem to face any important obstacle.
- The **Medgaz** project (8 bcm) from Algeria to Spain was first proposed by CEPSA and Sonatrach to secure gas supply to Spain. Rapidly, several partners entered the project, including the main Spanish utilities as well as Total, GDF and BP. In fact, Medgaz also targets France and the European market. Promoted by importers, the investment decision has been taken at the end of 2006 and the pipeline should be operational by 2009.

- The **Galsi** pipeline (8 to 10 bcm) from Algeria to Italy via Sardinia, is a joint initiative of Sonatrach, Enel, Edison and several other partners, all booking a small part of the shipping capacity. The shipping agreements will decide of the timing of the project. Contrary to the Nord Stream, the Galsi does not benefit from the support of one or two big importers which could provide some guarantees about the future throughput.
- The **Nabucco** project is a big pipeline (25-30 bcm) which aims at directly connecting the Caspian and Middle East gas resources to the EU gas markets. While the potential benefits of this project are very significant in terms of diversification of supply and stimulation of competition, it remains difficult to complete so far because of the complexity of transit issues and difficulties in coordinating investments in production and transit infrastructure.
- Some **LNG gasification projects** advance rather easily when supported by incumbents or large producers (like the Fos terminal developed by Gaz de France, and gasification terminals in Spain and UK), while some, promoted by new entrants (like Brindisi terminal developed by British Gas as well as several other terminals in Italy), are regularly delayed because of administrative obstacles and commercial risks.

In fact, the level of the barriers to investment in these capital intensive gas infrastructure projects can be related to the exposure of these investments to three different types of risk, namely market risk (uncertainty on price and volume), regulatory risk (impact of market rules and regulation) and political risk (uncertainty relating to international relations and often involvement of several transit regimes). These risks influence the expected profitability and therefore the decision to invest. The most difficult to realise are the so called 'midstream promoted' projects, both pipelines and LNG terminals, which are mainly intended at penetrating markets rather than consolidating a downstream or up-stream based position.

Therefore, to promote investment in gas corridors, the action of policy makers should in particular focus on reducing the risks mentioned above. Among the proposed options are the completion of the Internal Market; the removal of barriers to entry to non-incumbents; the approval of joint venture arrangements; allowing long term contracts with provisions for open season procedures; the development of market based allocation procedures for transport capacity reservation and usage. Regulatory risks could be reduced by enhancing predictability and transparency of regulation particularly for TPA. The international political risks could be reduced by the removal of local obstacles to projects; the promotion of existing dispute settlement bodies and the enhancement of dialogue and confidence between different countries involved in bringing the gas from key suppliers outside the EU into the EU markets.

Need for electricity corridors

In order to identify and assess the economic optimal electricity corridors connecting the EU with its neighbouring countries in the long term, first we estimated the costs of the possible reinforcement projects and, second, we calculated by a multi-area production optimisation model the benefits of each additional system interconnection. The benefits of transmission reinforcements were calculated on the basis of substitution effect of expensive generation with cheaper one and included the economic effect of reduction of greenhouse gas emissions. Benefits in terms of system reliability and adequacy, which are normally low in strong systems as the European one, are not taken into account. Benefits in terms of increased competition between market participants - which could be significant in some cases – are also not considered. Benefits in terms of improved security of supply for the EU countries, export diversification and creation of internal value for the neighbouring countries (which are exporters of natural gas) are not explicitly considered, because the translation of these concepts into monetary value is very difficult and questionable. Therefore, the interconnection development resulting from cost-benefit analysis could be considered to be based on a relatively conservative estimation of benefits.

Two sets of model simulations were performed to assess and optimise the transfer capacities between EU and the neighbouring countries:

- A mid-term (year 2015) assessment, that takes into account the presence of existing major internal bottlenecks in the EU electricity transmission system (e.g. Spain – France, the Italian border, Belgium – France, etc.), which will influence the electricity exchanges between EU and neighbouring countries.
- A long-term (year 2030) assessment. For this year it is assumed that the development of the Internal Electricity Market is completed and that the transmission network is not hampered by major congestion in cross border interconnections among countries in Central Europe.

The identification and assessment of need for potential interconnection corridors and capacity between European Union and the neighbouring countries up to 2030 gave the following insights. A significant electricity exchange growth might be expected at the 'main EU borders' (South border with North Africa, South East border with Turkey, East border with IPS/UPS [1] system), see Figure 3.2. Electricity trades are estimated to range from 110 TWh up to 180 TWh (from 10 Mtoe to 15 Mtoe), which still represent a relatively small percentage of total electricity demand in the EU and the neighbouring regions: 2-4 % of total electricity demand in EU-27 (about 4700 TWh in 2030) or 1-2 % of total electricity demand of all forty-four countries investigated in the study (8000 TWh in 2030).

Regarding the optimal development of interconnection capacity between EU and neighbouring countries, the main results of the study can be summarised as follows:

Need of new cross border capacity between Turkey and South-Eastern Europe

Large exports from Turkey (85-100 % utilisation of the capacity) are foreseen. A 2000 MW short-term transfer capacity is expected for the next years, while currently the interconnection is out of operation due to technical reasons. An increase of transmission capacity up to 5000 MW is economic-efficient in the long run, using AC (alternating current) overhead lines, whose estimated costs are about €70 million for each connection.

1 IPS/UPS consists of Independent Power Systems of Baltic States (Latvia, Lithuania, and Estonia), Armenia, Azerbaijan, Belarus, Georgia, Moldova, Kazakhstan, Kyrgyzstan, Tajikistan, Ukraine and Uzbekistan and of Unified Power System of Russia. Other acronyms: UCTE is the Union for the Co-ordination of Transmission of Electricity, the association of transmission system operators in continental Europe; NORDEL (NORDic ELectricity system) comprises transmission system operators from Denmark, Finland, Iceland, Norway, and Sweden.

Need of new interconnection capacity between Northern Africa and Southern Europe

Despite the high investment costs (e.g. €400 million for a 1000 MW submarine link), large benefits are expected by means of large electricity exports from Northern Africa, as the 90-100% utilisation rate of the available capacity suggests. The benefits could justify an increase of the interconnection capacity up to about 5000 MW in 2030 (the current transfer capacity is 800 MW). The expected future economic-optimal exchanges of electricity with Africa will take place if investment plans for generation in Northern Africa will be fulfilled by the countries (plans: +300% in the period 2005-2030) and if sound operational mechanisms for cross-border transactions (e.g. extension of existing EU regulations and policies) will be set up and realised.

Expectation of bi-directional electricity trades at the 'Eastern Europe' border

Thanks to existing lines, a 5100 MW transfer capacity is theoretically available at both borders Ukraine and Belarus – UCTE and Russian Federation – Ukraine and Belarus, even if the first one is not fully utilized today due to non-synchronous systems and consequent 'island mode' operation. The opportunity to interconnect the IPS/UPS and UCTE systems and to exploit these existing capacities is emphasized by large trades (40 TWh/year) in both directions foreseen by the study. A similar result is obtained for the borders Baltic Countries – Russian Federation and Finland – Russian Federation, with 30 TWh/year exchanges.

The bi-directionality of the expected electricity trades is characterised by remarkable seasonal variations. Especially in the cold period, UCTE and NORDEL are expected to supply electricity to the IPS/UPS system, contributing to face severe peak loads in Russian Federation and Ukraine and reducing the need of electricity production from obsolete power plants. This 'unexpected' phenomenon suggests the need and the importance of interconnection capacity expansion for the neighbouring countries too. However the uncertainties about Russian developments, e.g. the level of fuel prices, the future of nuclear energy and the current lack of investments in the Russian generation sector, are important and difficult to predict today.

The total investments needed for the realisation of these economic-optimal infrastructures are estimated as:

- at least €300 million to realise four new alternating current (AC) lines between Turkey and EU,
- about €2000 million to realise four submarine high voltage direct current (HVDC) links between Northern Africa and Southern Europe (rating: 1000 MW each cable),
- about €200 million to realise a submarine HVDC link connecting Turkey and Cyprus.

The investments needed for a "first-step" future interconnection between the Eastern Europe countries (European part of Russian Federation, Belarus, Ukraine and Moldova) and the UCTE system were not quantified, because these figures are strongly dependent on the technical solutions which will be adopted. The list of necessary investments and their associated costs to be made on both sides of the investigated electrical interface are one of the main objectives of the ongoing feasibility study "Synchronous Interconnection of the Power Systems of IPS/UPS with UCTE", financed by the European Commission. This study is also expected to present in 2008 an open outlook on other non-synchronous system coupling possibilities with the aim at a global benchmark in terms of economic efficiency for the investigated system coupling.

The consultation process with stakeholders during the ENCOURAGED project revealed a number of barriers for the exploitation and development of electricity corridors. This process leads us to conclude that the major obstacles, although different in nature at the various borders, generally are:

- Between Turkey and South East Europe, the current obstacle for the exploitation of existing and under-construction interconnection capacity is mainly technical (i.e. the need of adaptation of the Turkish power system to UCTE standards, especially concerning the improvement of frequency control);
- At the 'Eastern Europe' border, the main technical barrier is the asynchronous operation of the large power systems IPS/UPS, UCTE and NORDEL. This issue determines the need of relatively large investments, whose allocation among countries remains a point of discussion;
- Between Northern Africa and Southern Europe, national Transmission System Operators (TSOs), and their countries, are interested in new interconnection projects as is clearly demonstrated by various feasibility studies. But the possible impact of very high investments on national tariffs is today an important drawback. For this reason Red Eléctrica de España (Spain) and Terna Rete Elettrica Nazionale (Italy) do not include interconnection projects with Northern Africa in their present national transmission planning. The alternative to regulated investment, namely a 'merchant' approach with private investors, is now under investigation by some companies and seems to be a feasible alternative option.

The discussions with stakeholders revealed that the financing of electricity corridors is not considered to be a major barrier for the regulated investments by the Transmission System Operators (TSOs). Generally the TSOs are prepared to undertake the necessary investments in interconnection capacity provided that this is done within a stable regulatory investment climate and this is supported by the TSO of the neighbouring country.

However, the lack of a stable and coherent legal and regulatory framework for interconnection corridors (incomes of TSOs are often regulated through different national regulatory schemes) acts as a barrier to investment and as a delaying factor. In addition, long approval procedures, could hinder grid development. Regulation should be made more stable and predictable and possibly harmonised and authorisation procedures should be faster and more efficient.

Need for hydrogen corridors

Today's energy and transport systems are mainly based on fossil energy carriers, which need to be changed in the future to become more sustainable. Concerns over energy supply security, climate change, local air pollution, and increasing price of energy services have a growing impact on policy decisions throughout the world. Increasingly, hydrogen is seen as offering a range of benefits with respect of being a clean energy carrier, if produced by "clean sources". So creating a large market for hydrogen as an energy vector could offer an effective solution to meet both the goals of emission control and the security of energy supply: hydrogen is nearly emission-free at the point of final use, it is a secondary energy carrier that can be obtained from any primary energy source and it can be utilized in different applications (mobile, stationary, and portable). But since EU domestic energy resources are limited the question can be raised whether it is an economic efficient as well as sustainable option to produce hydrogen outside the EU and import it over very long distances to consumers inside the EU?

To answer that question first the potential hydrogen demand in the EU in the very long term was projected. Next the potential cheapest hydrogen production centres were identified including the costs of producing the hydrogen there. As a next step the costs of selected hydrogen pathways are compared with conventional transport fuels, namely gasoline, see Figure S.1. The figures are shown without taxes and assets in order to have a fair basis for comparison and it can be assumed that the taxes and earnings of different fuels are very similar and therefore not decision relevant.

For the appropriate comparison, the costs of hydrogen distribution in Europe and compression at the filling station are added. Furthermore, the negative effects of carbon emissions are included in monetary terms for fossil fuel-based paths at a cost assumption of 20 €/tCO_2. At present, the transport sector is not covered by the European emissions trading scheme, but its future integration into this scheme or other climate policy instruments cannot be excluded. Furthermore, the European Automotive Manufacturers Association (ACEA) has made a voluntary commitment to the European Commission to reduce CO_2 emissions from transport fuels (ACEA 1998).

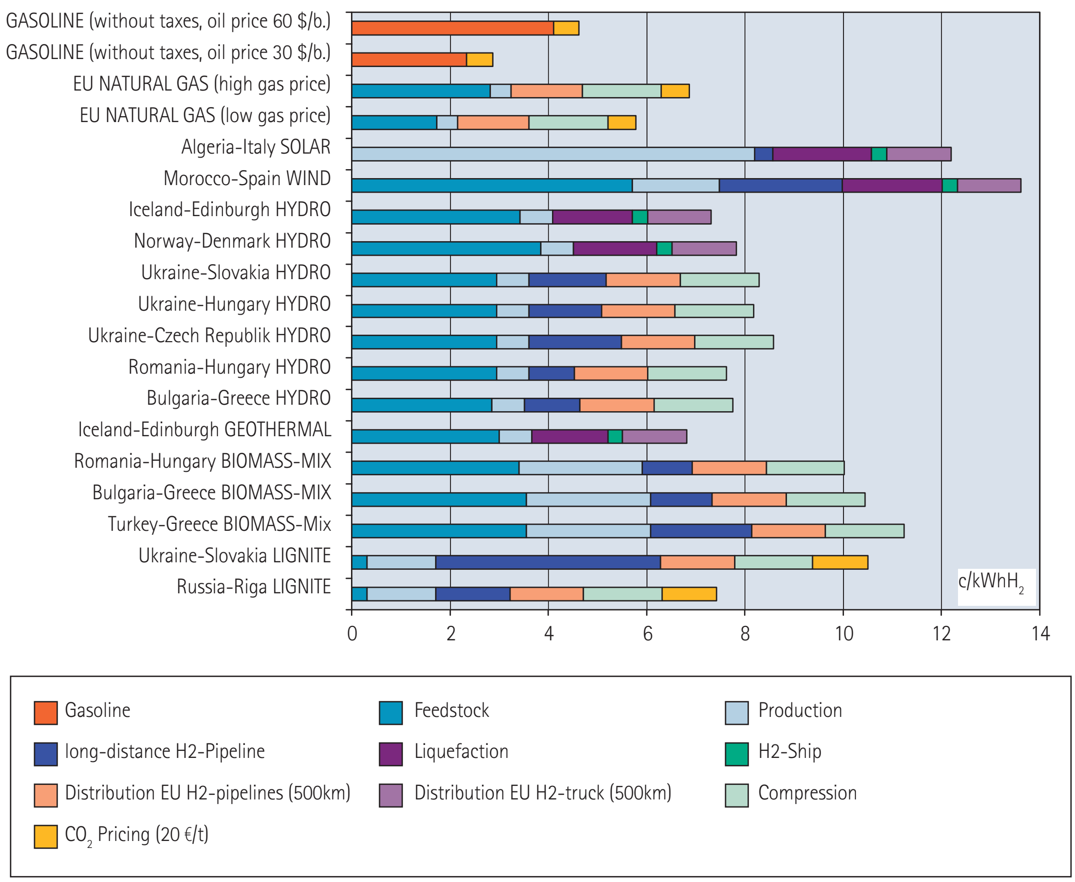

Figure S.1 *Comparison of hydrogen with conventional fuel supply costs in EU markets in 2040*

In summary and on the basis of the analysis of the potentials and the economic feasibility of different hydrogen corridor options with sources in the neighbouring countries, including a cost comparison with domestic hydrogen production in the EU25 (as benchmark), the following conclusions can be drawn:

- Hydrogen import supply routes are particularly attractive in the very long term, if based on renewable energy sources and can significantly contribute to the EC policy goals of securing energy supply and reducing greenhouse gas emissions if sustainability is the key objective.
- Importing renewable hydrogen could start first with some selected corridors after the introduction of hydrogen as a transport fuel, expected from 2015 onwards. Sources could be in Norway and Iceland.
- When a significant level of hydrogen demand (as a transport fuel) is reached. i. e. more than 10 % hydrogen vehicles in the total vehicle stock around 2030/2040, a wide supply portfolio is possible.
- Even when renewable feedstock is used, the supply cost (without tax) of many pathways is within a range of double the current cost of gasoline and hence only economically viable under similar terms as presently applied to bio-fuels.
- Due to the relevant influence of transport costs on the economics of hydrogen corridors, it is important to consider only large-scale production sources in order to exploit economies of scales to lower the relative high specific costs today.
- Of all corridor options analysed, hydrogen from hydro or geothermal power from Iceland offers the cheapest hydrogen and the lowest barriers with respect to competing with alternative use of it. This is followed by hydrogen from hydropower in Norway and Romania. The following corridors are promising but have certain limitations, e.g. hydrogen from wind power and solar radiation in North Africa (high potential, but also relative high cost) and hydrogen based on biomass from Romania, Bulgaria and Turkey. Are comparatively cheap, but these options meet various alternative very competing applications too.

It should be noted that many uncertainties are surrounding the main conclusions regarding economic, feasibility and assumptions underlying the recommendable corridors for the three types of energy carriers. Nevertheless the authors think that the suggested energy corridors with neighbouring countries are robust options to be further investigated in more detail.

1. Introduction

1.1 Background of the study

In several official Communications and publications the European Union (EU) has repeatedly emphasized its role as a force for stability and a sustainable development in Europe and formulated as key energy policy objectives for the EU:

- enhance security of energy supply;
- strengthen the internal energy market;
- develop sustainable energy markets.

According to many studies for the European Commission (EC), official EU energy scenarios and the Green Paper [2] the dependency of the EU-27 on gas supplies from neighbouring countries is expected to increase from 40% to 70% or more in 2030. Consequently the role of current and future neighbouring countries in the development of the energy markets of the EU, as they are the main gas and oil suppliers and often key transit counties of oil and natural gas to the EU is increasing. But not only the EU imports of oil and gas will grow significantly in the next decades, also electricity exchanges and perhaps later period the hydrogen supply from neighbouring countries might also increase in the long term. In this manner these countries will also benefit of the Internal Market and become a part of actions of the EU to integrate the energy markets of the EU and its surrounding countries.

The European Commission also promotes in particularly the development of an effectively functioning electricity and gas transmission infrastructure within the EU and between the EU and its neighbouring countries by earmarking interconnection projects of trans-European importance (TEN-E programme). Most of the projects cross several national borders or are of importance to several EU Member States and neighbouring countries. The Trans European Energy Networks are integral to the European Union's overall energy policy objectives, namely increasing competitiveness in the electricity and gas markets, reinforcing security of supply, and protecting the environment.

The first set of guidelines for trans-European energy networks was adopted by the Council and the European Parliament in June 1996 [3]. They have been amended several times to reflect developments in the internal market for electricity and gas supplies [4]. The new guidelines issued in 2003 set out priority projects which chiefly concern the security of supply and the competitive operation of the internal energy market [5]. Twelve priority axes were identified, seven electricity networks and five natural gas networks.

2 A European Strategy for Sustainable, Competitive and Secure Energy-COM(2006) 105, 8 March 2006.

3 European Parliament and Council Decision of 5 June 1996 (1254/96) establishing a series of guidelines on trans-European networks in the energy sector.

4 Amendments have been made through Commission Decision (97/548) of 11 July 1997; and Decision 1741/1999 of the European Parliament and of the Council.

5 Decision No 1229/2003/EC of the European Parliament and of the Council of 26 June 2003.

Last years the priority of this programme was enhanced due to international developments and on 24 July 2006, the Council adopted the Commission proposal for a revision of the Trans-European Energy (TEN-E) Guidelines, confirming the favourable vote of the European Parliament in second reading in Plenary on 4 April. In this resolution certain projects of European interest were given a top priority, including with respect to funding [6]. A European coordinator can be appointed to specific projects (or parts of projects) of European interest which encounter implementation difficulties. The coordinator will be tasked with facilitating and encouraging cooperation between the parties concerned and ensuring that adequate monitoring is carried out. With respect to cross-border sections of infrastructure, the concerned Member States need to exchange information regularly. Joint coordination meetings are to be held to ensure the harmonisation of public consultation procedures and carry out project evaluation. If delays occur then the Member States have to report on the reasons behind these delays.

In short the integration of the European Energy System can only be achieved by building the necessary energy infrastructure and connections between the national systems, avoiding energy islanding of some EU regions or countries and facilitate energy trading between countries. Consequently sufficient energy connections and connection capacity are a key condition for realising the overall EU energy policy objectives of a competitive, efficient and sustainable Internal Energy Market and Energy Supply Security for consumers. However to meet these goals one must realise that gas and electricity infrastructures usually last a very long time and take a relative long time to be built, consequently one can say for developing efficient infrastructures for energy transport one needs also a long term vision on the developments shaping and driving the infrastructure. Particularly if more countries and different systems (infrastructure crossing/connecting different national borders) need to be connected an in depth analysis of the long term key drivers such as socio-economic and technology changes, trade-offs and barriers, which are shaping the infrastructure in the next decades, is of the utmost importance.

1.2 Objectives, approach and structure of ENCOURAGED

The ENCOURAGED project has been launched in beginning 2005 for identifying and assessing the economically optimal energy corridors by building new and expanding existing one's, for electricity, natural gas and hydrogen supply between EU and neighbouring countries as well as identifying the barriers to and benefits of connecting the different European energy systems. The objectives of the project are:

- Assess the economic optimal energy (electricity, gas and hydrogen) corridors and related network infrastructure for connecting the EU with its neighbouring countries and regions.
- Identify, quantify and evaluate the barriers to and potential benefits of building optimal EU connecting energy corridors with the neighbours.
- Recommend necessary policy measures to implement the recommended energy corridors with a focus on investment and international political framework.
- Organise stakeholder workshops and seminars to discuss the results and findings and create consensus among scientists, stakeholders and non-governmental organizations and validate project results.

6 Directorate-General for Energy and Transport, MEMO/06/304, 24 July 2006.

The project concerned three parallel studies, one on each type of energy corridor, i.e. electricity, gas and hydrogen. These studies included first a projection of expected demand and supply per country in the long term in Europe, for conducting an assessment of the imbalances between supply and demand per European country and region. Second step in each study was assessing the need for electricity interconnecting and building new and/or expanding the existing infrastructure for connecting the different electricity systems/countries and connecting the different gas demand markets/countries/regions of the EU with the gas supplies from non-EU countries.

Third the investments and barriers to invest in connection projects were analysed. The parallel studies were finalised by recommending the development of a number economic attractive electricity, gas and hydrogen corridors with the EU neighbouring countries.

Finally for the implementation of the electricity and gas infrastructure projects the key investment conditions and relevant international political framework were reviewed and possible improvements were analysed and suggested.

Note that in order to secure a reasonable compatibility between the results of the studies on the three different types of energy corridors, the official EU energy scenarios published by DG Energy and Transport [7] were used as a reference scenario for projecting the gas, electricity and hydrogen demand and supply in the long term in Europe. In addition, e.g. for hydrogen corridors and updating the EU projections for many countries also other additional scenario studies from other country ministries and international organizations were also included. For example the projections of individual non-EU countries and experts organizations in Europe together with other reports provided by our partners and experts involved in the project were useful. To deal with uncertainties in energy prices and demand and supply over the long term we also conducted sensitivity analysis for the different type of corridors on the possible variations in demand, supply and prices (alternative scenario variants) being the key assumptions and basic drivers for interconnecting different European countries.

In the next chapter first we present the results of the study on the required gas connections and related infrastructure. In the following Chapter 3 we present the key results of the study on the electricity interconnections between EU and the neighboring countries. In Chapter 4 the feasibility and potential benefits of different routes for long distance transport of hydrogen is presented and discussed. Finally in Chapter 5 we summarize some of the principal findings and conclusions on the proposed energy corridors in the long term for Europe.

[7] European Energy and Transport-Trends to 2030, EC 2003.

2. Gas corridor assessment

Due to the increasing gas demand of the enlarged European Union (EU) and declining domestic gas supplies, the EU faces a growing import dependency over the next decades. Europe's neighbouring regions are endowed with substantial reserves and resources which could cover the increase in EU demand in the medium to long term. With the development of its different uses, especially for power generation, gas is increasingly gaining importance for European energy security of supply. The substantial rise in captive demand during the past decade explains the essential role the EU gives to natural gas in its energy policy.

Securing and increasing gas supply to meet growing demand in the EU, however, requires huge investments on all the segments of the gas chain including exploration and development, international transit and downstream infrastructures (gas lines and storage). These investments will mainly be realised by energy companies and will, therefore, require an appropriate investment climate, which not only involves economic considerations but also a stable policy environment, a clear regulatory regime and the possibility for operators to develop necessary strategic partnerships.

This study assesses the future long term (2010-2020-2030) gas import requirements and supply potential for the enlarged European Union, and identifies future gas corridor needs taking into account supply and demand outlooks, existing and proposed infrastructure, supply costs as well as institutional, strategic and geopolitical issues. A Europe-wide gas network model is used to analyse and identify the economic optimal expansion of gas connections, LNG and storage facilities and routes (corridors) needed to meet long term gas demand in the EU up till 2030. Finally, the study identifies the key barriers, possible measures and policies to create a more favourable investment climate for the gas industry investing in the future gas infrastructure.

2.1 Long term gas import requirements and supply development

Import requirement is the difference between domestic demand and domestic production. According to the two scenarios used in this study (base case and low demand scenario) which are based on the official energy scenarios of DG-TREN (EC, 2003), the gas import requirements in the European Union, Switzerland and Balkan countries will increase from 221 bcm in 2000 to 472 bcm in 2030 in the low demand scenario and reaches 652 bcm in the base case scenario (Figure 2.1). This would require increasing supplies in the next decades from the traditional European gas suppliers – Norway, Russia and North Africa – as well as the development of new additional supply resources.

Figure 2.2 shows the summary results of OME's assessment of the external long term gas supply potential to the European Union, Switzerland and Balkan countries. The supply potential corresponds to the maximum gas volumes that these key gas producing countries could export to Europe at a given time horizon. This assessment is based on geological information (reserves and resources), on country and company strategies and planning, on institutional and geopolitical as well as world gas market developments including the fact that Europe has to compete with other world markets to attract future gas supplies.

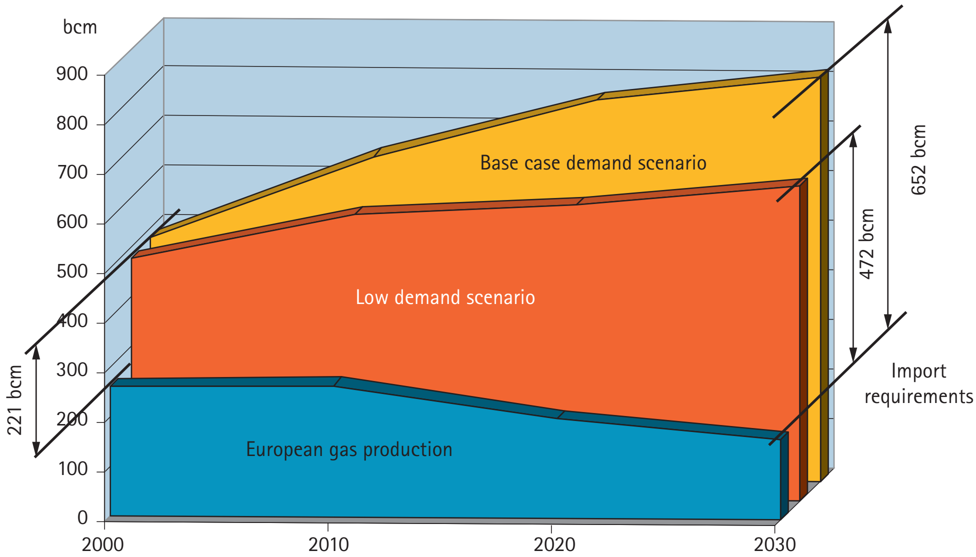

Figure 2.1 *European Union, Switzerland and Balkan countries gas import requirements according to European Commission, DG TREN scenarios*

The total gas supply potential available to Europe has been assessed to reach a level of about 450 bcm by 2010, 640 bcm by 2020 and 715 bcm by 2030, which has to be compared to 304 bcm imported in 2005. Of course all this potential supply will not be tapped in the future if import requirements do not call for it. However, should import requirements be higher than expected, additional gas volumes to Europe could be made available especially (but not only) from Russia and Qatar. These countries do not only have a huge reserve potential, but their allocation between different world markets can and will be adjusted to the different demand requirements.

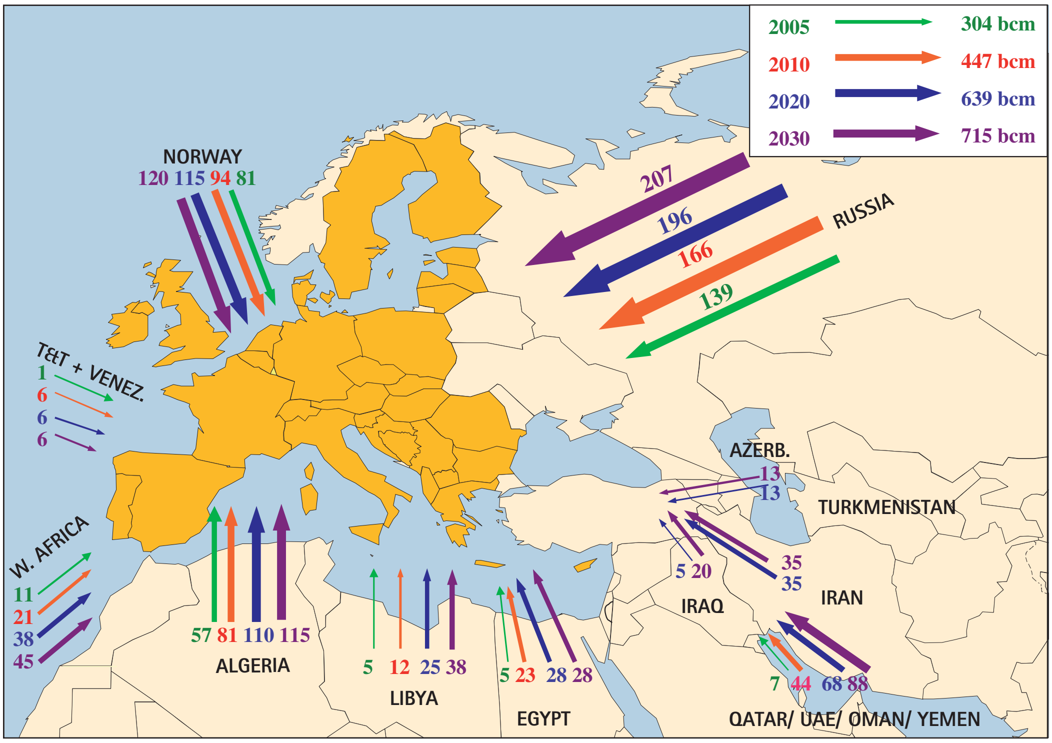

Figure 2.2 *Gas export potential of the main producers to the European Union, Switzerland and Balkan countries*

Algeria, Norway and Russia are expected to expand their dominant role as far as supply potential is concerned. Moreover, there appears to be a spectacular progression of the supply potential from the Middle East (especially Qatar), Nigeria, Egypt and Libya. This means that Europe will need to develop both important new pipeline and LNG infrastructure.

Figure 2.3 and Figure 2.4 show the main existing and the required future gas corridor developments from Russia and from North Africa to Europe to make the above mentioned supply potential available for Europe.

In addition, it is also important to develop direct gas export routes from the Caspian region to Europe through Turkey and possibly directly across the Black Sea to Europe, as well as to develop a number of new LNG chains, especially from the Gulf, North and West Africa to reach different EU countries.

Figure 2.3 *Russian gas export and transit infrastructure and projects*

Figure 2.4 *North African gas export infrastructure and projects*

2.2 Expected development of gas corridors to the EU

The identification of economic optimal gas corridors to the EU have been studied using a market equilibrium model for Europe and taking into account the earlier discussed supply potential and demand projections, transport capacities and supply costs, as well as issues linked to market behaviour and security of supply. Four scenarios have been developed: a business-as-usual or reference scenario, a low gas demand scenario, a high gas demand scenario and a deferral of investment scenario (representing an uncertain investment climate in which investments in infrastructure are postponed) and are used to assess the needs for infrastructure in the long-run.

Pipelines are expected to remain the most dominant means of gas transport in Europe in the next decades. According to the model simulations, pipelines should represent 83% (low demand), 81% (high demand and reference scenario) or 77% (deferral) of transport capacity in 2030, the remaining shares being covered by LNG. This LNG is expected to arrive from Qatar (33%), Nigeria (25%), Algeria (17%), Egypt (15%) and others (10%) and mainly supplying the UK (28%), Spain (19%), Italy (18%), France (15%), Benelux (13%) and other countries (7%) in Europe.

According to the different scenarios, total investment needs from 2005 to 2030 are estimated between €90 billion (low demand) and €164 billion (high demand). In the reference scenario, the requirements are €126 billion (Figure 2.5). These figures include pipelines, storage facilities and liquefaction and gasification terminals.

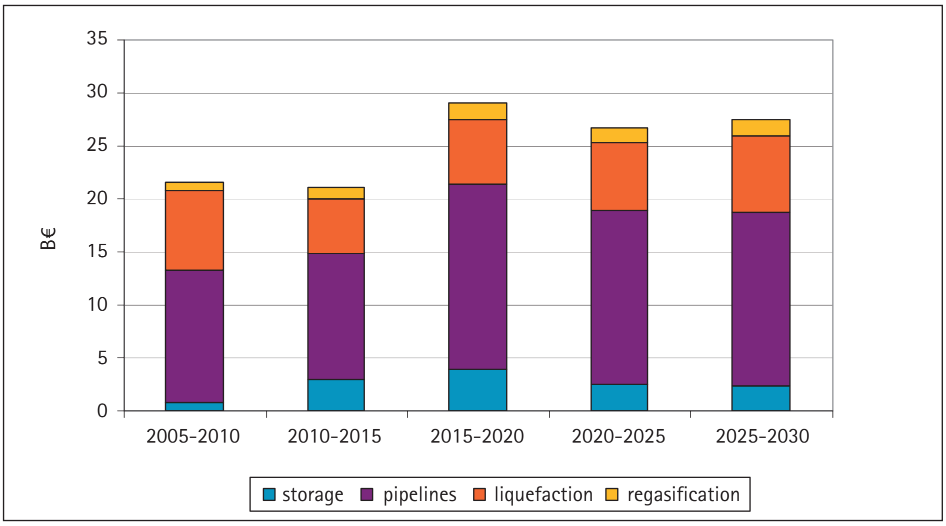

Figure 2.5 *Investment requirements in gas infrastructures (European Union, Switzerland, Balkan countries and Turkey) - reference scenario*

The model results of the reference scenario show that the pipeline connections from North-Africa to Southern Europe, Norway to the UK and Turkey to the Balkans and to Central Europe need to get the highest priority, because the resulting capacities are already needed around 2010. Second priority connection is the Turkey to Italy project needed around 2015. Third priority concerns reinforcements of the Norway to EU and Russia to Turkey-Balkan corridors, because these pipeline links are needed around 2020. It is assumed that the Russia to Germany connection across the Baltic Sea is built and operational according to plan around 2010.

Moreover, based on the reference scenario, several other pipeline connections within Europe also need to be realized or reinforced as soon as possible. These concern mainly pipelines from the South to the North (connecting Italy, Spain and the Balkans to the rest of Europe) and connecting Germany to the Baltic countries. This is needed in order to avoid that the intra-EU gas network becomes a major bottleneck for the expansion of the gas supplies from outside the EU. In fact, realising these intra-EU gas connections, if completed in the next decade, should lead to a more efficient trading between the different European gas markets and therefore allow for lower end-user prices in the EU.

It is particularly interesting to note that in case of investment postponement (deferral scenario), gas border prices would be driven up by around 25% compared the reference scenario. It seems therefore very important to put in place the right incentives for infrastructure projects to be implemented in due time.

As Figure 2.6 shows, several gas corridors are at reinforcement stage or have to be developed. The traditional routes to Europe are being strengthened. Furthermore, six new pipelines are currently under development, namely the pipeline from Norway to the UK (Langeled pipeline), from Russia to Germany across the Baltic Sea (Nord Stream), from Algeria to Spain (Medgaz) and to Italy (Galsi) across the Mediterranean Sea. Another important route under study is the gas corridor from the Middle East and the Caspian region across Turkey, further prolonged by pipelines across Greece (Turkey-Greece-Italy interconnection) or across the Eastern Balkan to Austria (Nabucco pipeline). This so called fourth corridor would allow Europe to considerably diversify its supply sources.

Several LNG gasification terminals are also currently under development or have been announced to be built in the coming years in different European countries. LNG penetration is particularly spectacular in the UK and is expected to become substantial in Italy as well. However, some of these projects are exposed to many administrative obstacles, especially in Italy.

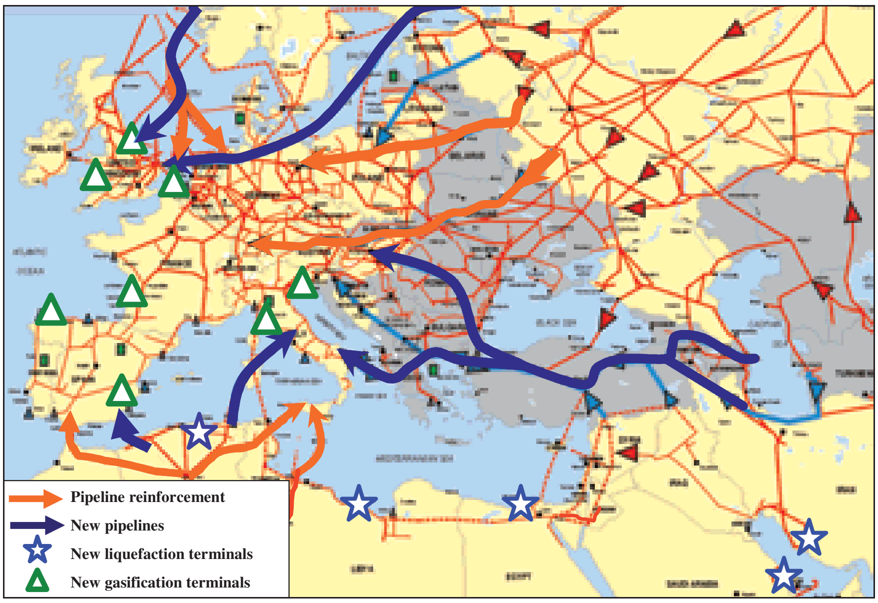

Figure 2.6 *Ongoing and future gas corridors developments in Europe*

Source: EC DG TREN and OME

Table 2.1 *Main Greenfield pipeline projects to Europe*

Project	Supplier	From	To	Capacity [bcm]	Investment [M €]	Foreseen Start-up
Medgaz	Algeria	Hassi R'Mel	Spain	8 to 10	1300	End 2008
GALSI	Algeria	Hassi R'Mel	Italy	8 to 10	1200	2009-2010
ITG-IGI	Caspian	Greece	Italy	8 to 10	950 (IGI)	2011
Nord Stream	Russia	Vyborg	Germany	2x 27.5	4000	2010
Langeled	Norway	Ormen Lange	UK	22 to 24	1000	2006-2007
Nabucco	Caspian	Turkish border	Austria	25 to 30	4600	2010
Total additional supply capacity to Europe				**98.5 to 139**		

The realisation of the above mentioned pipeline projects could provide an additional 100 bcm/yr import capacity to Europe by the beginning of the next decade, see Table 2.1. It should be noted, however, that these projects mainly focus on carrying more gas into the European market, but fewer operators are keen on developing the needed interconnections inside Europe. While not in the scope of this study, it might be useful to investigate the incentives for 'de-bottlenecking' the internal EU gas market. Moreover, the announced LNG projects would represent an additional import capacity of about 100 bcm/yr by the beginning of the next decade.

The number of proposed projects could therefore support the idea that there is no problem of investment in international gas infrastructure to Europe. It should be underlined, however, that many of these projects have been around and announced for quite a while and require often a long lead-time for completion. Ultimately, not all projects will be realized and it is therefore necessary to ensure that at least the required additional supply will be made available in due time.

2.3 Obstacles to investment

At the heart of the investment financing issue is the relation between uncertainty, cost of investments and profitability. The four examples presented hereafter show that some projects remain sustainable by themselves, while others are more difficult to achieve and may need a political or regulatory support.

- The **Nord Stream** is a big offshore pipeline (2x27.5 bcm) across the Baltic Sea, directly linking Russia and Germany. While E.ON, Wintershall and Gasunie are now official partners, it was designed and decided without any supply agreement with importers. Promoted by Gazprom, it aims at bypassing transit countries like Ukraine and Belarus. Supported by a few big promoters, this project does not seem to face any important obstacle.
- The **Medgaz** project (8 bcm) from Algeria to Spain was first proposed by CEPSA and Sonatrach to secure gas supply to Spain. Rapidly, several partners entered the project, including the main Spanish utilities as well as Total, GDF and BP. In fact, Medgaz also targets France and the European market. Promoted by importers, the investment decision has been taken at the end of 2006 and the pipeline should be operational by 2009.

- The **Galsi** pipeline (8 to 10 bcm) from Algeria to Italy via Sardinia, is a joint initiative of Sonatrach, Enel, Edison and several other partners, all booking a small part of the shipping capacity. The shipping agreements will decide of the timing of the project. Contrary to the Nord Stream, the Galsi does not benefit from the support of one or two big importers which could provide some guarantees about the future throughput.
- The **Nabucco** project is a big pipeline (25-30 bcm) which aims at directly connecting the Caspian and Middle East gas resources to the EU gas markets. While the potential benefits of this project are very significant in terms of diversification of supply and stimulation of competition, it remains difficult to complete so far because of the complexity of transit issues and difficulties in coordinating investments in production and transit infrastructure.
- Some **LNG gasification projects** advance rather easily when supported by incumbents or large producers (like the Fos terminal developed by Gaz de France, and gasification terminals in Spain and UK), while some, promoted by new entrants (like Brindisi terminal developed by British Gas as well as several other terminals in Italy), are regularly delayed because of administrative obstacles and commercial risks.

In fact, the level of the barriers to investment in these capital intensive gas infrastructure projects can be related to the exposure of these investment to three different types of risk, namely market risk (uncertainty on price and volume), regulatory risk (impact of market rules and regulation) and political risk (uncertainty relating to international relations and often involvement of several transit regimes). These risks influence the expected profitability and therefore the decision to invest.

Risk exposure and the investors' capacity to hedge them have a direct impact on long term projects' sustainability and investment incentives. As presented in Table 2.2, three categories of projects can be identified to be more or less vulnerable to different risks: exporter promoted projects (e.g. Nord Stream), importer promoted (e.g. Medgaz, Fos LNG terminal) and midstream promoted (e.g. Galsi, Nabucco, most LNG terminal projects). Exporter and importer promoted projects are relatively the least difficult to complete due to large market shares and financing capacity of investors.

The most difficult to realise are 'midstream promoted' projects, both pipelines and LNG gasification terminals, which are aimed at penetrating markets rather than consolidating a downstream or upstream-based position. This category is more vulnerable to risk and may require a political support given that these projects promote competition and diversity of supply. As the Galsi project shows, a political involvement can be an efficient facilitator. Indeed, on the occasion of a visit of Mr Prodi in Algiers, November 15, 2006, some shipping contracts were signed between Sonatrach and Italian partners, including Enel and Edison, booking three quarters of the capacity. This project has therefore shifted from 'midstream' promoted to both 'exporter' and 'importer' promoted corridor.

Table 2.2 *Main characteristics of import projects by category*

	Exporter promoted	Importer promoted	Midstream promoted
Exporting companies	Leader	Partner	Partner/ not involved
Importers (incumbents)	Partner	Leader	Partner/ not involved
Private producers/shippers	Partner (sometimes)	Partner	Leader/Partner
Entrants	Very rare	Partner	Leader/Partner
Number of partners	Small	Small	High
Vulnerability to market risk	Low	Low	High
Type of regulatory risk	Few risks	Incumbent market share	Third party access
Main political dimension	International relations	Security of supply	Competition

Source: OME

Furthermore, 'midstream-promoted' projects can be developed under a **regulated** operating regime or a **merchant**-operating regime. Realization of regulated gas investment projects can be hindered by policy and regulatory risks, whereas the realization of merchant gas investment projects suffers more from market risks. Below we focus on improvements regarding so-called **midstream** investment projects, which are crucial for gas supply security and flexibility.

2.4 Recommendations to improve the investment conditions

The question we address here is how we can mitigate the investment risks of gas infrastructure projects connecting the EU with its neighbouring suppliers. Current European gas markets can still be generally characterised by the incompleteness of their competitive regime. It is therefore important to improve the functioning of the market, the regulatory system and the international political framework to reduce investors' risks and improve the investment climate. It should also be noted that international gas infrastructures are made of different sections starting at the production fields going all the way to consumers, thereby often connecting regions with different market regimes. Markets and regulation must therefore enable the development of commercial agreements to secure a fair sharing and hedging of investment risks from upstream to downstream partners.

Therefore, to promote investment in gas corridors, the action of policy makers should in particular focus on reducing market risks, regulatory risks and political risks. Hereafter we give some recommendations which have been developed in special ad-hoc workshops and bilateral discussions with all the main stakeholders (gas industry, regulators, investors, traders, policy makers, etc):

Market risk mitigation

Unbundling the gas chain, reducing downstream market protections and developing competition have raised risks which have to be covered by operators. To facilitate that coverage, it is recommended to:

- **Complete the Internal Market** as soon as possible to help wholesalers and corridor developers hedging market risks and to improve the quality of market signals. That involves a broader access to the national markets and pipeline capacity by developing interconnections, homogenising regulation in Europe, improving gas hubs liquidity, etc.
- **Remove the barriers to entry** related to the excessive market power of incumbents and the lack of transparency on infrastructure capacity usage and allocation.
- Provide a **specific status to upstream arrangements such as joint ventures** involving several partners. To facilitate gas commercialisation, such joint ventures should be considered as a "single" gas supplier and not as a consortium of individual gas producers.
- **Allow long term contracts** between upstream/midstream operators and downstream companies in order to create an efficient breakdown of risks between upstream operators, mainly carrying technical risks, and downstream companies, mainly carrying commercial risks. However these long term contracts should be implemented, including open season procedures and market based allocation mechanisms for capacity reservation and usage
- At the same time, the **creation of liquid spot markets and secondary financial** markets should be encouraged in order to allow proper hedging of volume and price risks, and to render long-term contracts more compatible with a competitive and integrated European gas market.

Regulatory risk mitigation

Regulation is regularly adapted to the evolution of unwanted market conditions (third party access, pricing, etc.). Regulations should be transparent on capacity, create risk mitigation instruments and be predictable for investors (regulation changes should not introduce additional uncertainty). To mitigate regulatory risks it is recommended to:

- Address **third party access regulation to new infrastructure on a case by case basis**. Project developers take a risk and cannot always afford opening the door to free riders. This risk must be recognised by regulators, providing third party access exemptions compatible with the internal market rules and explicitly formulated exemption rules by the regulator to avoid abuse. Open season procedures are a helpful instrument for a fair allocation of capacity.
- **Clearly define the limits of the European internal gas market and improve coordination of projects across the borders** in order to address the different regulation regimes, interests, risks and revenue of an investment project for the countries involved. It is notably important to address the status of the EU parts of international corridors.
- Make **regulation more predictable**. Regulatory uncertainty can lead investors to delay their investments. It is therefore important to make regulation dynamics more transparent by clearly stating the long term political priorities (competition versus security of supply for instance).

International political risk mitigation

In addition to the uncertainty related to European markets and regulation, the international dimension of gas trade increases its exposure to political risks, in particular institutional instability in producing and transit countries, conflicts between governments, etc. Improving the pan-European political context can enhance the investment climate; when corridors are key for security of supply but hindered by political uncertainty, the EU can play an important political and economic role. The following actions are recommended:

- Remove the **local institutional and legal obstacles to the development of new projects**. This is particularly true for gasification terminals, often delayed or postponed for administrative and political reasons.
- **Financial support to priority corridors:** when investments, which are considered important for security of supply, cannot be completed exclusively on the basis of commercial market considerations (e.g. lack of throughput guarantees), they should be supported by institutional loans (EIB, EBRD) or sovereign guarantees.
- **International dispute settlement bodies:** having credible referees to arbitrate international disputes provides additional security to investors. Further developing the actions of the Energy Charter Treaty and other supra-national bodies should be supported by the EU.
- **Develop dialogue to improve international stability and confidence between importing, producing and transit countries** and taking into account the interest of all the involved parties. It is recommended to develop strategic partnerships between the EU and the major gas supply and transit countries, i.e. extending the EU-Russia dialogue also to other vital energy suppliers for Europe.

3. Electricity corridor assessment

3.1 Introduction and methodology

The European institutions emphasized over recent years the importance of a greater development of interconnection capacity for the implementation of an open and competitive European Union (EU) internal electricity market. In the Green Paper on a "European Strategy for Sustainable, Competitive and Secure Energy" [8] the development of a 'priority interconnection plan', in order to increase interconnection capacity, has been suggested as a priority issue for EU energy policy for the coming years. One of the key factors for the development of a pan-European interconnected system could be the potential expansion of the current UCTE [9] synchronous area eastwards and southwards, in response to requests coming from other systems (e.g. Turkey, Ukraine, Northern Africa). This expansion could determine the opportunity to increase electricity trades and transmission capacity as well.

In the study, first we define an electricity corridor as each point of the system where transmission (interconnection) capacity risks being not adequate, in other words each point of the pan-European system where there could be an additional net socio-economic benefit from additional investments in transfer capacity. With this definition, and considering the historical development of European electricity systems, the electricity corridors are normally located at the borders between countries, at the borders among different EU power pools and, obviously, at the borders between European Union and the neighbouring countries, which are the main focus of this study.

Second, for each electricity corridor we estimate the costs of possible reinforcement projects and we calculate through an optimisation analysis (least-cost dispatch) the benefits which can be gained with each proposed reinforcement. The benefits of transmission reinforcement are calculated referring to the effect of substitution of expensive generation with cheaper one and including the economic effect of reduction of greenhouse gas emissions. Benefits in terms of system reliability and adequacy, which are normally low in strong systems as the European one, are not taken into account. Benefits in terms of increased competition among market participants – which could be significant in some cases – are also not considered. Benefits in terms of improved security of supply for the EU countries, export diversification and creation of internal value for the neighbouring countries (which are exporters of natural gas) are not explicitly considered, because the translation of these concepts into monetary value is difficult and questionable. Therefore, the interconnection development resulting from cost-benefit analysis could be considered to be based on a relatively conservative estimation of benefits.

8 Commission of the European Communities, "Green paper - A European Strategy for Sustainable, Competitive and Secure Energy", COM(2006) 105 final, 8 March 2006. http://ec.europa.eu

9 UCTE is the Union for the Co-ordination of Transmission of Electricity, the association of transmission system operators in continental Europe. IPS/UPS consists of Independent Power Systems of Baltic States (Latvia, Lithuania, and Estonia), Armenia, Azerbaijan, Belarus, Georgia, Moldova, Kazakhstan, Kyrgyzstan, Tajikistan, Ukraine and Uzbekistan and of Unified Power System of Russia. NORDEL (NORDic ELectricity system) comprises transmission system operators from the following countries: Denmark, Finland, Iceland, Norway, and Sweden.

Using results of the aforementioned model calculations we performed a traditional social cost-benefit evaluation of the economics of (in other words, net benefit achieved by) selected reinforcements of the interconnection corridors. The evaluations support us to draw conclusions, which could be useful to support the part of the EU priority plan concerning interconnection corridors between European Union and the neighbouring countries.

3.2 Electricity demand and other main assumptions

Two sets of model simulations are performed to assess and optimise the transfer capacities between EU and the neighbouring countries:

- A mid-term (year 2015) assessment, that takes into account the presence of existing major internal bottlenecks in the EU electricity transmission system (e.g.: Spain – France, the Italian border, Belgium – France, etc.), which will influence the electricity exchanges between EU and neighbouring countries.
- A long-term (year 2030) assessment. For this year it is assumed that the development of the Internal Electricity Market is completed and that the transmission network is not hampered by major congestion in cross border interconnections among EU countries.

The basic idea of the optimisation analysis is to simulate the operation of the electricity systems in the European Union and in the neighbouring countries in order to evaluate economically optimal configurations for the potential electricity corridors. One of the basic assumptions is that, at least in a long-run perspective, the market prices, which are considered to be the main drivers of electricity exchanges among countries and regional systems, will primarily be based on production costs. Therefore, the evaluation of the future energy exchanges is performed by means of a multi-area production optimisation tool that determines the least-cost dispatch of generating units taking into account the limited transfer capacities among the areas in which the full system is subdivided.

The total energy cost to be minimised includes the energy production cost for thermoelectric generators and the cost of load shedding. To take into account the effect of greenhouse gas emission constraints, an opportunity cost approach is adopted. We add to the fuel cost an extra-cost defined for each type of generator, related to the future price of emission trading allowances in the EU-ETS (Emission Trading Scheme).

The 44 countries of the study are grouped in areas: UCTE (Albania, Austria, Belgium, Bosnia Herzegovina, Bulgaria, Croatia, Czech Republic, France, Germany, Greece, Hungary, Italy, Luxembourg, Macedonia, the Netherlands, Poland, Portugal, Romania, Serbia and Montenegro, Slovakia, Slovenia, Spain), BRITISH ISLANDS (Ireland and United Kingdom), NORDEL (Denmark, Finland, Norway and Sweden), BALTIC STATES (Estonia, Latvia, Lithuania), NORTHERN AFRICA (Morocco, Algeria, Tunisia, Libya and Egypt), EASTERN EUROPE (European part of Russian Federation, Belarus, Ukraine and Moldova) and TURKEY. In 2015 analysis, major current bottlenecks in EU were taken into account and therefore the UCTE area was separated into smaller 'blocks': Iberian Peninsula (Spain and Portugal), France, Italy, the German block (Germany, Benelux, Switzerland and Austria) and the Central European block (the other countries). Note that this separation in smaller blocks is conducted on the basis of the presence of congestion within the EU, which influences often the electricity exchanges of the EU with the neighbouring countries.

The interconnection of the islanded systems of CYPRUS, ICELAND and MALTA is investigated in the long term analysis. System model and electricity corridors for year 2030 are displayed in Figure 3.1, which also presents the electricity demand forecasts and its growth in the period 2005-2030. The remarkable growth of electricity demand in some neighbouring regions, such as Northern Africa and Turkey, is expected to stimulate the massive installation of new power plants and strongly influence the potential electricity exchanges between EU and these regions in the long term.

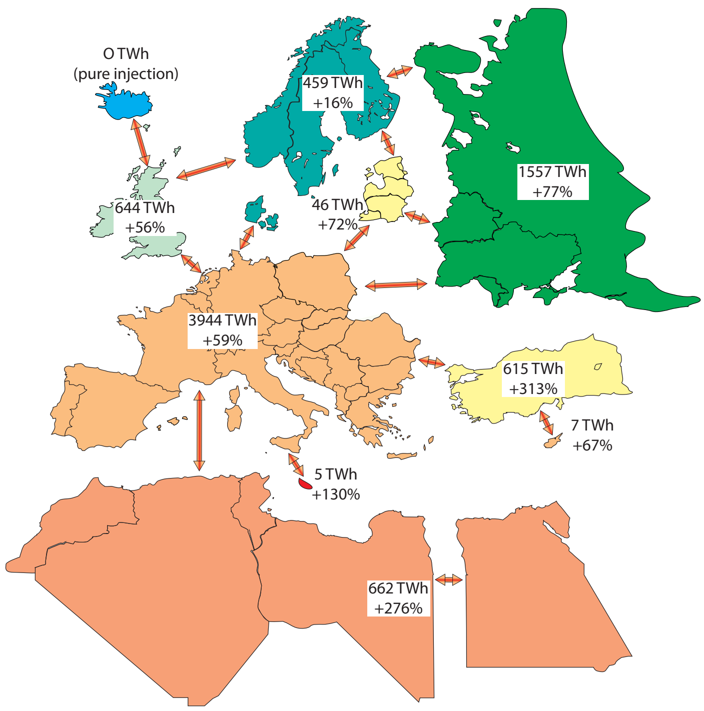

Figure 3.1 *Electricity demand 2030 and percentage growth 2005-2030 in each area of the system*

3.3 Optimal development of electricity corridors between EU and neighbouring countries

Exchanges

The assessment of optimal corridors, performed by a multi-area model, gave the following insights. Regarding the 'dimension of electricity trades', a significant growth is expected for future cross border exchanges at EU-borders, with respect to current trades at borders Finland – Russian Federation, Central Europe – Ukraine, and Spain – Morocco (total about 20 TWh/year). Nevertheless, the total exchanges at the 'main borders' (South border with North Africa, South-East border with Turkey, East border with IPS/UPS system) will represent a relatively small percentage of electricity demand in the EU and neighbouring regions.

The exchange volumes are estimated to range from 110 TWh/year up to 180 TWh/year (from 10 Mtoe to 15 Mtoe), which correspond to 2-4% of total electricity demand in EU-27 (about 4700 TWh/year in

2030) or 1-2% of total electricity demand in the 44 countries investigated in the study (8000 TWh/year in 2030).

Figure 3.2 presents the overall electricity exchange values for each 'main border', based on the base case scenario with a moderate reinforcement of transfer capacities.

Finally it is stressed that the assessed potential for electricity exchanges must not be considered as a substitute of gas imports for the European Union. These trade volumes will only have a limited and complementary role compared with the gas imports. The exchanges of electricity have a different role and are motivated by different drives than the large imports of natural gas.

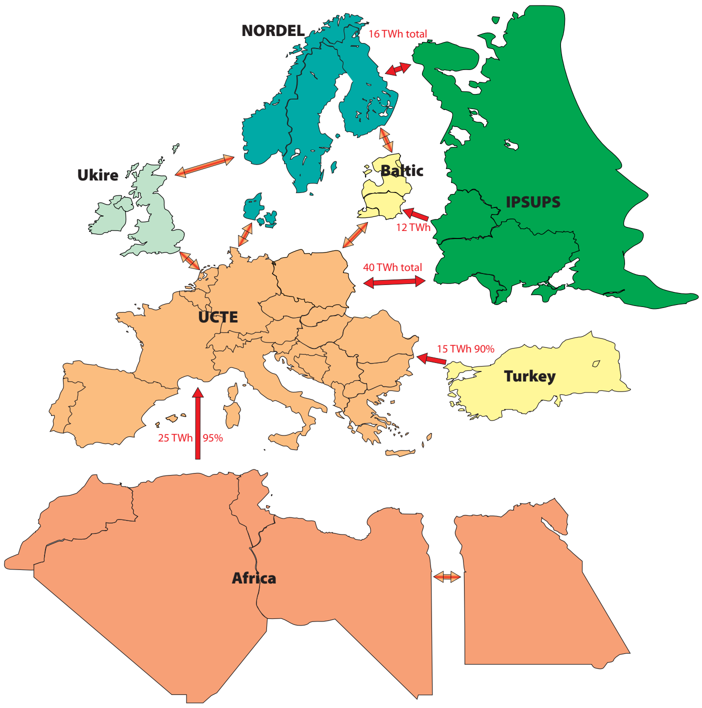

Figure 3.2 *Synthesis of the electricity exchanges (volumes, directions and percentage utilization 2030, reference scenario)*

Transfer capacities

Regarding the optimal development of electricity interconnection capacity between EU and neighbouring countries, the main results of the study are:

Need of new cross border capacity between Turkey and South-Eastern Europe

Large exports from Turkey (85-100% utilisation of the capacity) are foreseen. A 2000 MW short-term transfer capacity is expected for the next years, while currently the interconnection is out of operation due to technical reasons. An increase of transmission capacity up to 5000 MW is economic-efficient in the long run, using AC (alternating current) overhead lines, whose estimated costs are about €70 million for each connection.

Need of new interconnection capacity between Northern Africa and Southern Europe

Despite the high investment costs (e.g. €400 million for a 1000 MW submarine link), large benefits are expected by means of large electricity exports from Northern Africa, as the 90-100% utilisation rate of the available capacity suggests. The benefits could justify an increase of the interconnection capacity up to about 5000 MW in 2030 (the current transfer capacity is 800 MW). The expected future economic-optimal exchanges of electricity with Africa will take place if investment plans for generation in Northern Africa will be fulfilled by the countries (plans: +300% in the period 2005-2030) and if sound operational mechanisms for cross-border transactions (e.g. extension of existing EU regulations and policies) will be set up and realised.

Expectation of bi-directional electricity trades at the 'Eastern Europe' border

Thanks to already existing lines, a 5100 MW transfer capacity is theoretically available at both borders Ukraine+Belarus - UCTE and Russian Federation - Ukraine+Belarus, even if the first one is not fully utilized today due to non-synchronous systems and consequent 'island mode' operation. The opportunity to interconnect the IPS/UPS and UCTE systems and to exploit these existing capacities is emphasized by large trades (40 TWh/year) in both directions foreseen by the study. A similar result is obtained for the borders Baltic Countries - Russian Federation and Finland - Russian Federation, with 30 TWh/year exchanges.

The bi-directionality of the expected electricity trades is characterised by remarkable seasonal variations. Especially in the cold period, UCTE and NORDEL are expected to supply electricity to the IPS/UPS system, contributing to face severe peak loads in Russian Federation and Ukraine and reducing the need of electricity production from obsolete power plants. This 'unexpected' phenomenon suggests the need and the importance of interconnection capacity expansion for the neighbouring countries too.

However various uncertainties about developments in Russia in the long term, e.g. the level of fuel prices, the future of nuclear energy, the level of renewal of the fossil-based generation capacity, create large uncertainties on the need and direction of future trades at EU-IPS/UPS borders. In particular, if the current lack of investments in the Russian generation sector will continue and if gas price in Russia will increase up to market-based values, we foresee a net electricity exports from the EU towards the Russian Federation. Clearly based on these uncertainties, the need and the economic efficiency of developing further the cross border capacity at the border between UCTE and IPS/UPS systems (in addition to the aforementioned value: 5100 MW) is difficult to assess precisely in the long term.

Need of connections with the Mediterranean island countries in the long-term

The model analyses evidenced the opportunity to interconnect the Mediterranean island countries to the pan-European system (a connection Cyprus – Turkey rated about 500 MW and a connection Malta – Italy rated about 300 MW) in a long-term horizon. Especially for these possible interconnections, we remind that the aim of the ENCOURAGED project is to give a wide system overview, covering a very large area. This result should therefore be seen a preliminary analysis pointing out the need of detailed feasibility studies on specific projects, which will better take care of the technical issues.

Investments

Based on the analysed expansion of connections at the EU borders the total investments needed for the realisation of these economic optimal infrastructures are estimated as:

- at least €300 million to realise four new alternating current (AC) lines between Turkey and EU;
- about €2000 million to realise four submarine high voltage direct current (HVDC) links between Northern Africa and Southern Europe (rating: 1000 MW each cable);
- about €200 million to realise a submarine HVDC link connecting Turkey and Cyprus.

The investments needed for a "first-step" future interconnection between the Eastern Europe countries (European part of Russian Federation, Belarus, Ukraine and Moldova) and the UCTE system were not quantified, because these figures are strongly dependent on the technical solutions which will be adopted. The list of necessary investments and their associated costs to be made on both sides of the investigated electrical interface are one of the main objectives of the ongoing feasibility study "Synchronous Interconnection of the Power Systems of IPS/UPS with UCTE", financed by the European Commission [10]. This study is also expected to present in 2008 an open outlook on other non-synchronous system coupling possibilities with the aim at a global benchmark in terms of economic efficiency for the investigated system coupling.

Finally, it is worth to remind that assumed system compatibility and future interconnection development in the neighbouring regions and the energy price levels in medium and long term in these regions are large uncertain factors in the study. Not to mention the development of generation mix and capacity in Russian Federation, Northern Africa and Turkey.

3.4 Obstacles and recommendation for implementation of corridors

The consultation process with stakeholders during the ENCOURAGED project revealed a number of barriers for the exploitation and development of electricity corridors. The major obstacles, different in nature at the various borders, are:

- Between Turkey and South East Europe, the current obstacle for the exploitation of existing and under-construction interconnection capacity is mainly technical (i.e. the need of adaptation of the Turkish power system to UCTE standards, especially concerning the improvement of frequency control);
- At the 'Eastern Europe' border, the main technical barrier is the asynchronous operation of the large power systems IPS/UPS, UCTE and NORDEL. This issue determines the need of relatively large investments, whose allocation among countries remains a point of discussion;
- Between Northern Africa and Southern Europe, national Transmission System Operators (TSOs), and their countries, are interested in new interconnection projects as is clearly demonstrated by various feasibility studies. But the possible impact of very high investments on national tariffs is today an important drawback. For this reason Red Eléctrica de España (Spain) and Terna Rete Elettrica Nazionale (Italy) do not include interconnection projects with Northern Africa in their present national

[10] UCTE IPSUPS Study, "Feasibility Study: Synchronous Interconnection of the Power Systems of IPS/UPS with UCTE - Summary of Project Status", December 2006.

transmission planning. The alternative to regulated investment, namely a 'merchant' [11] approach with private investors, is now under investigation by some companies and seems to be a feasible alternative option.

The discussions with stakeholders revealed that the financing of electricity corridors is not considered to be a major barrier for the regulated investments by the Transmission System Operators (TSOs). The TSOs are prepared to undertake the necessary investments in interconnection capacity provided that this is done within a stable regulatory investment climate and this is supported by the TSO of the neighbouring country.

However, the lack of a stable and coherent legal and regulatory framework for interconnection corridors (revenues of TSOs are often regulated through different national regulatory schemes) acts as a barrier to investment and as a delaying factor. In addition, long approval procedures, hinder grid development too. Conclusion is that regulation frameworks should be made more transparent, stable and predictable and as much as possible harmonised between the different systems. Also the authorisation procedures should be faster and more efficient than today.

According to some discussants, there could also be a conflict of interest between electricity generating companies and the 'social' objectives of TSOs regarding connection investments. This could also create a barrier to investments of the TSO, if generation companies have a certain 'control' on the investment decisions of the TSO. Even if there is no general consensus on this statement, it could be recommended to improve the unbundling of TSOs to secure its independence from major electricity companies.

While policy and regulatory risks hamper the realisation of regulated electricity corridors, market risks are mainly associated with merchant corridors. These market risks stemming from inefficient and flawed price signals can be mitigated through the acceptance of long-term contracting [12] and supporting instruments for international joint-ventures. In order to minimise the negative impact of long-term contracting on wholesale market competition attention should be given to the presence of competitive elements in these long-term contracts. In case of merchant joint-ventures it should be recognised that a proper evaluation and sharing of project costs/risks and of project revenues among the involved companies is a basic precondition to the development of interconnection corridors. Furthermore, the role of regulators and TSOs in merchant electricity corridors should be clarified. Regulators should provide guidelines on exemption from third party access, in compliance with the Regulation 1228/2003/EC, to potential merchant developers and, with the support of TSOs if needed, ensure their compliance. The potential role of a 'public' TSO in merchant projects is questionable and should be clarified too.

In either regime, regulated or merchant, the risk of 'wasting' public or private money can be reduced by improving the reliability of the investment signal provided by the liberalised electricity markets. Therefore policy-makers and regulators should improve the investment conditions for interconnections between EU and neighbouring countries by removing wholesale market price distortions (e.g. through market

11 The dominant regime for electricity transmission investment in the EU is currently a regulated regime in which a TSO is responsible for system operation and development, and where transmission tariffs and remuneration of infrastructures are regulated. Under exceptional circumstances, e.g. very high costs and risks, electricity corridor investments can be realised under a non-regulated regime, which is named "merchant".

12 Long-term here refers to a time horizon longer than e.g. 4-years-ahead contracts currently negotiated in the Nordpool Scandivian market.

concentration, market captivity etc.), if present and implementing market-based mechanisms for capacity allocation at the borders that can assist electricity corridor investors providing more reliable price information signals for investment.

Finally increasing the coordination of TSOs on a regional level would enhance the transparency and feasibility of both regulated and merchant electricity corridor projects. Regional coordinated planning should be further improved to optimise the total system for the benefit of all consumers in the region.

The recent decision on European energy priority projects [13] proves an increased EU awareness of the importance of electricity corridors between EU and its neighbouring countries: two [14] out of the 31 electricity projects of European interest concern the 'main borders' of the European Union and involve an EU Member State and a (current) neighbour. These are the lines between Greece and Turkey (priority axis EL.4) and the 'electrical connection to link Tunisia and Italy' (priority axis EL.9). It is recommended that this awareness will be increased in the future. A more explicit role for social cost-benefit analysis can assist the national, regional and EU governmental and regulatory bodies in the assessment of the impact of the proposed projects on sustainability, competition and security of supply. When an interconnection project is evaluated as beneficial for the country and for EU, proper financial support schemes need to be defined to favour its development. Furthermore, new mechanisms for monitoring the status, the progress and the possible problems in development of electricity projects should be enforced at national, regional and EU level.

13 Decision No 1364/2006/EC of the European Parliament and of the Council of 6 September 2006 laying down guidelines for trans-European energy networks and repealing Decision 96/391/EC and Decision No 1229/2003/EC.

14 The border between Denmark and Norway (and the related project of submarine cable Skagerrak 4) is not included in our definition of 'main EU borders'.

4. Hydrogen corridor assessment

4.1 Introduction, objectives and approach

Today's energy and transport systems are mainly based on fossil energy carriers, which need to be changed in the future to become more sustainable. Concerns over energy supply security, climate change, local air pollution, and increasing price of energy services have a growing impact on policy decisions throughout the world. Increasingly, hydrogen is seen as offering a range of benefits with respect of being a clean energy carrier, if produced by "clean sources". So creating a large market for hydrogen as an energy vector could offer an effective solution to meet both the goals of emission control and the security of energy supply: hydrogen is nearly emission-free at the point of final use, it is a secondary energy carrier that can be obtained from any primary energy source and it can be utilized in different applications (mobile, stationary, and portable). Since EU domestic energy resources are limited the question is valid whether it is an economic efficient and sustainable option to produce hydrogen outside the EU and import it over very long distances to consumers inside the EU?

4.2 Potential demand for hydrogen in the EU

To estimate the development of hydrogen demand in the long term in Europe two scenarios were used; one with a low and one with a high hydrogen penetration share, with a time horizon up to 2050. The assumptions and scenarios are based on studies of the HyWays project, an integrated project of the EU aiming at developing a European roadmap for hydrogen. [15] In HyWays, the hydrogen demand is assessed for 6 European states: Germany, France, Italy, the United Kingdom, the Netherlands and Norway. For our study in the framework of the project Encouraged, the hydrogen demand of the 6 states is extrapolated to the hydrogen demand of the EU-25, proportional to the population ratio. Further is assumed that hydrogen is mainly used in the transport sector. Figure 4.1 shows the hydrogen demand assumed for the EU25 according to the high and low penetration scenarios up to 2050. For comparison, the official scenarios of the European Commission [16] for natural gas and electricity demand for EU-25 in 2030 are also included. From this comparison it becomes clear that the assumed hydrogen demand becomes relatively large from 2030 onwards.

Of course, assumptions about future hydrogen demand are subject to uncertainties because it is not yet certain whether hydrogen will become a substantial part of the energy system at all. In the official reference energy scenario for the European Commission, hydrogen is not included to as important energy carrier. Other projects, such as WETO H2, which forecasts the world energy outlook for the period to 2050 [17], or the World Energy Outlook of the International Energy Agency ([18]), only assume hydrogen penetration in scenarios with a strict climate policy and high oil and gas prices and more over a breakthrough in the technology development of fuel cells and hydrogen storage.

15 For more information on HyWays, see http://www.hyways.de/

16 European Energy and Transport Energy Trends to 2030, 2003

17 Compare http://ec.europa.eu/research/ fp6/ssp/weto_h2_en.htm

18 IEA 2004

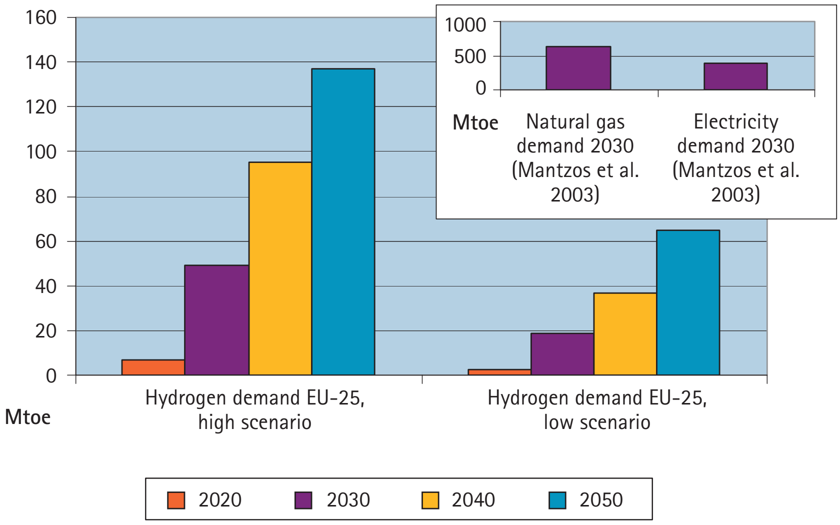

Figure 4.1 *Different Long-term hydrogen, natural gas and electricity demand projections for the EU25*

4.3 Potential hydrogen sources outside EU

Based on the analysis of existing studies, and looking at the hydrogen vision of several stakeholders and policy makers, eight hydrogen production centres outside the EU25 and six type of feedstock are selected for further in-depth analysis. In the feedstock selection focus is on clean sources or renewable energy sources, namely solar thermal energy, wind power, geothermal power, hydropower and biomass. As an exception, one hydrogen corridor based on lignite is also included in the study, because abundant sources of cheap lignite exist and transport of the lignite itself is no viable alternative due to the low heating value of this energy carrier. Converted to hydrogen, lignite might also contribute to increase the supply diversity and in a way to the security of energy supply in Europe. The selected hydrogen production centres outside Europe are Morocco, Algeria, Iceland, Norway, Romania, Bulgaria, Turkey and the Ukraine. The corridor options are shown in Figure 4.2.

For the selected eleven hydrogen production options outside Europe, a detailed analysis is performed of the additional feedstock or electricity potential that if exploited might be used for hydrogen production in the supplying country. Calculated is also the amount of hydrogen that could be produced annually. The additional potential is defined as the realisable potential (equal to theoretically feasible potential in a certain year under the assumption that all today's existing barriers are overcome and all drivers are effective) minus the achieved potential (equal to today's gross inland production of the considered energy source). North Africa has the largest additional potential (wind and solar), followed by Turkey (biomass) and Norway (hydro). In Figure 4.3 the total potential of the twelve hydrogen production centres outside Europe meets the total hydrogen demand of the low hydrogen penetration scenario in 2040 and nearly half the demand of the high hydrogen penetration scenario. Or in other words the total production could power half the European vehicle fleet (if these are completely driven by fuel cells).

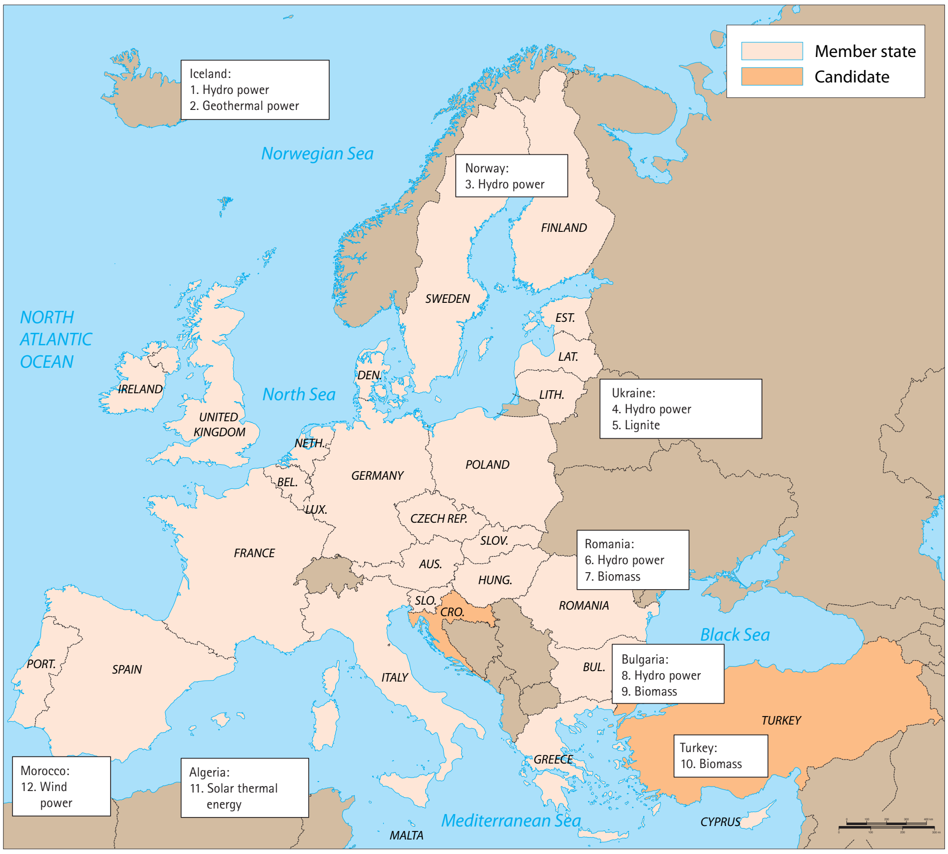

Figure 4.2 *Selected hydrogen production centres*

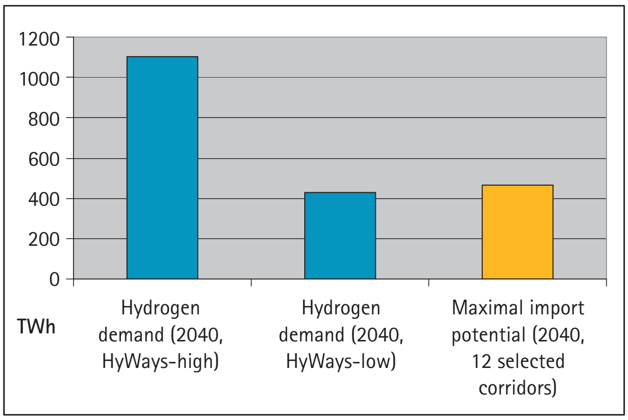

Figure 4.3 *Hydrogen demand according to HyWays scenarios and maximal import potential in 2040 for 12 selected hydrogen corridors*

4.4 Identifying the feasibility of long distance hydrogen supply?

To identify more precisely the need for hydrogen corridors we must assess and compare the hydrogen supply costs of the different production sources outside and inside the EU. Figure 4.4 illustrates the costs of supplying hydrogen via different corridors within Europe till 2040. These European data are used to benchmark the feasibility of hydrogen corridors. The corridor costs include production costs and long-distance hydrogen transportation costs. As solar hydrogen production in Algeria is considered a option of solar thermal water splitting and not via electrolysis. Thus no electricity is needed and no feedstock costs are incurred in this case. In the case of transportation by ship, liquefaction costs are also included. Electricity transmission via high voltage direct current lines and production in Europe is calculated for one corridor option. The hydrogen production options in Europe include only production costs. Due to the large variability of cost of feedstock and electricity sources in Europe, a (low and high) cost range is assumed. The distribution in Europe and the conditioning at the place of use (compression/liquefaction) are not included because these costs are not relevant when comparing these hydrogen corridors with the option of domestic hydrogen production.

As a next step the costs of selected hydrogen pathways are compared with conventional transport fuels, namely gasoline, see Figure 4.5. The figures are shown without taxes and assets in order to have a fair basis for comparison and it can be assumed that the taxes and earnings of different fuels are very similar and therefore not decision relevant.

For the comparison, the costs of hydrogen distribution in Europe and compression at the filling station are added. Furthermore, the negative effects of carbon emissions are included in monetary terms for fossil fuel-based paths at a cost assumption of 20 €/tCO_2. At present, the transport sector is not covered by the European emissions trading scheme, but its future integration into this scheme or other climate policy instruments cannot be excluded. Furthermore, the European Automotive Manufacturers Association (ACEA) has made a voluntary commitment to the European Commission to reduce CO_2 emissions from transport fuels (ACEA 1998).

In summary and on the basis of the analysis of the potentials and the economic feasibility of different hydrogen corridor options with sources in the neighbouring countries, including a cost comparison with domestic hydrogen production in the EU25 (as benchmark) the following conclusions can be drawn:

- Hydrogen import supply routes are particularly attractive if based on renewable energy sources and can significantly contribute to the EC policy goals of securing energy supply and reducing greenhouse gas emissions if sustainability is the key objective.
- Importing renewable hydrogen could start first with some selected corridors after the introduction of hydrogen as a transport fuel, expected from 2015 onwards. Sources could be in Norway and Iceland.
- When a significant level of hydrogen demand (as a transport fuel) is reached. i.e. more than 10% hydrogen vehicles in the total vehicle stock around 2030/2040, a wide supply portfolio is possible. For example including the imports of mostly renewable-based hydrogen as well as from EU sources. This could contribute to reduce the trend of a rising dependency of EU on imported fossil fuels.
- Even when renewable feedstock is used, the supply cost (without tax) of many pathways is within a range of double the current cost of gasoline and hence only economically viable under similar terms as presently applied to bio-fuels.

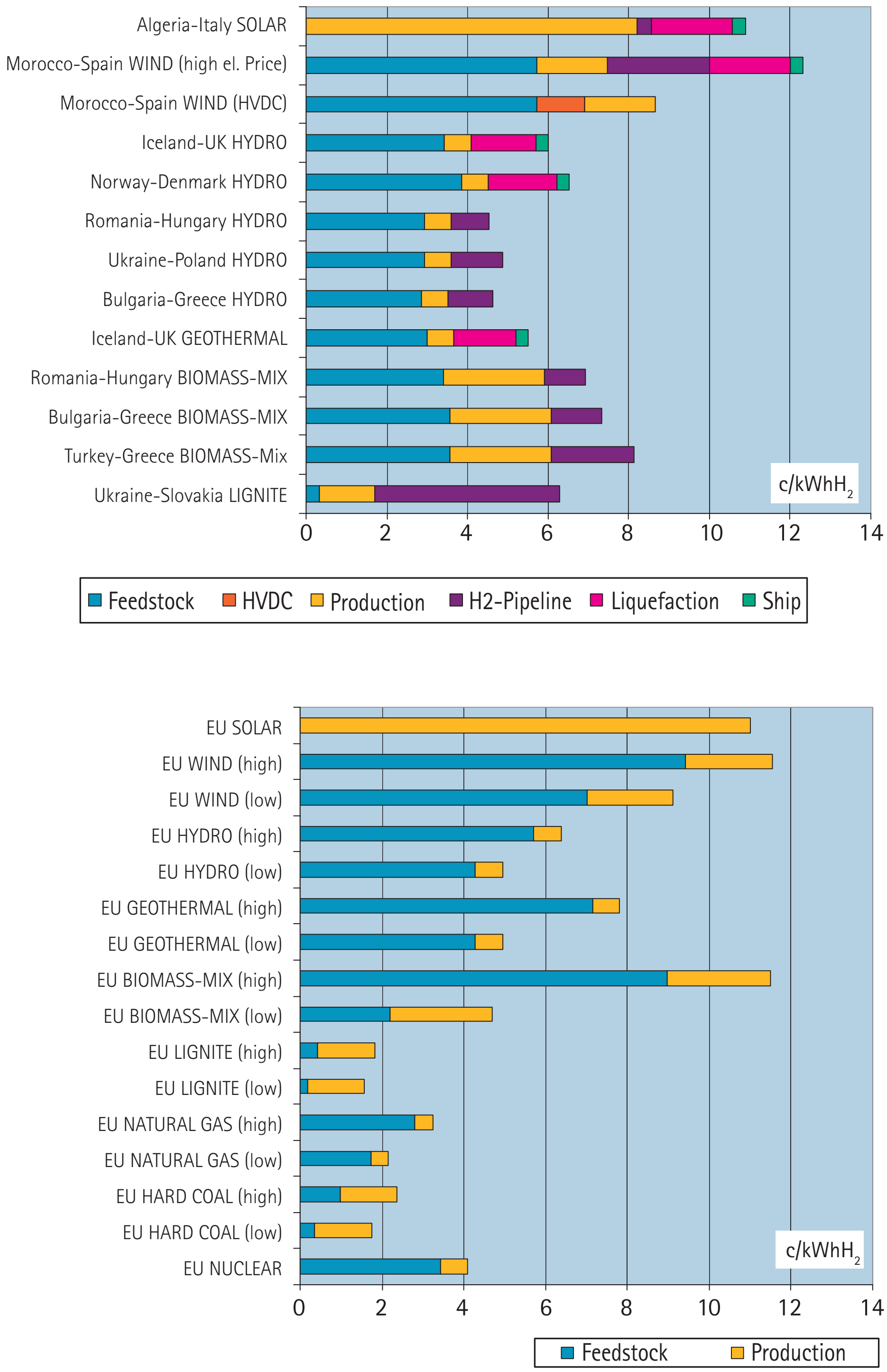

Figure 4.4 *Comparing the costs of hydrogen production and long-distance transportation from selected neighbouring countries to Europe with European hydrogen production from domestic sources with a time-perspective till 2040*

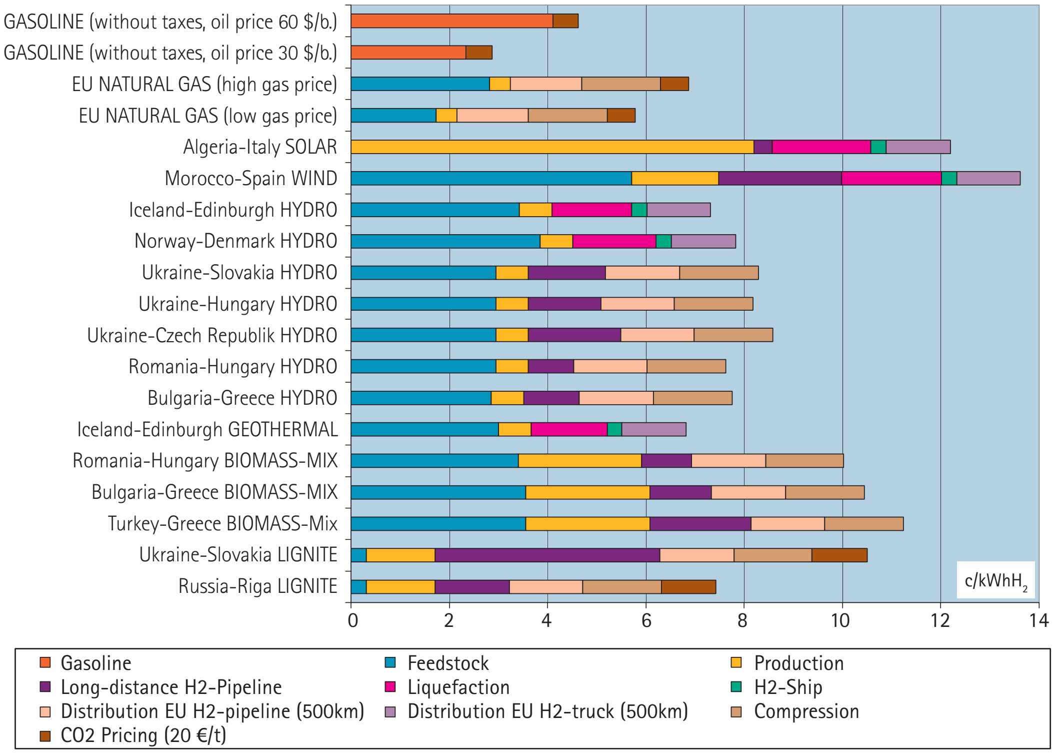

Figure 4.5 *Comparison of hydrogen with conventional fuels*
Time-perspective: 2040

- Due to the relevant influence of transport costs on the economics of hydrogen corridors, it is important to consider only large-scale solutions in order to exploit economies of scales to lower the relative high specific costs today.
- Of all corridor options analysed, hydrogen from hydro or geothermal power from Iceland offers the cheapest hydrogen and the lowest barriers with respect to competing alternative use of it. This is followed by hydrogen from hydropower in Norway and Romania. The following corridors are promising but have certain limitations, e.g. hydrogen from wind power and solar radiation in North Africa (high potential, but also relative high cost) and hydrogen based on biomass from Romania, Bulgaria and Turkey. Are comparatively cheap, but these options meet various alternative very competing applications too.
- Hydrogen is not an attractive transport medium for electricity. If electricity is the desired as end product, transmitting electricity is usually more economic viable than the production, transport and re-electrification of hydrogen, e.g. in fuel cells, due to electricity's better overall efficiency and lower costs.
- If a fossil feedstock like gas, nuclear or coal is used as an source for hydrogen production then the energy carrier should be transported directly (or in case of nuclear via electricity), because of the lower energy density of hydrogen and because the infrastructure for gas and coal transport already exists.
- Using nuclear power as production option for long distance hydrogen transport in Europe has limitations such as it is cheaper to transport uranium or enriched uranium or even electricity instead of hydrogen. Also the political acceptance of using nuclear power in some countries might raise insurmountable problems.

The study analysed the potential of different corridor options covering a fairly large number of feedstock/electricity options for the production of hydrogen. But hydrogen from ocean power or from offshore wind in North Africa cannot be excluded in the very far future. Therefore it is recommended to continue the RTD on analysing the potential production cost of different new sources.

5. Conclusions

Before we give a final summary of the main conclusions it is important to point out the differences between the functions and characteristics of the three categories of energy corridors (gas, electricity and hydrogen) we studied in ENCOURAGED. Such differences indeed lead to various objectives, drivers and needs for transport infrastructure and priorities regarding results, policies and recommendations. The three types of energy corridors can be generally characterized as follows:

Gas corridors have to be developed to satisfy the growing imbalance between demand and supply in Europe. The current trends can be translated into increasing import needs in Europe and hence require important flows of gas (and infrastructure) from producing countries outside the region. Gas corridors are large international infrastructures reaching lengths of several thousand kilometres, thereby representing huge investments with long lead times.

Electricity corridors mainly consist in interconnections between Member States at the periphery of the European Union and the neighbouring countries outside the EU. First, these allow optimising the power demand and supply balance at both sides of the interconnection and, second, these contribute to developing energy interdependences among countries. On the 'technical side', distances of electricity corridors are shorter than those needed for connecting gas production sites with consumer markets inside the EU. Electricity flows can be bi-directional and are important for optimisation and enhancing stability of both connected systems. Volumes of electricity exchanges are low, compared to gas transport volumes.

Hydrogen can be produced from environmentally benign sources (located including outside the EU), and hydrogen can be a useful energy vector (contrary to electricity as it can be stored) to bring environmentally benign energy into Europe. However, hydrogen and therefore hydrogen corridors are more an option for the very long term, and even in the long term these are associated with many difficulties, as the relative high costs of such a long distance transport and domestic priority for local use.

Gas corridors

By nature, gas corridors to Europe consist of large international infrastructures including upstream (exploration and production), midstream (gas treatment, high pressure transportation or LNG) and downstream activities (transportation and distribution within the EU). In addition, natural gas issues now directly involve global EU security of energy supply, including electricity. As a consequence, the drivers for building gas corridors are very different from those for electricity and hydrogen. The growing EU dependency on gas supplied by foreign producing countries and the increasing distance from new gas fields pose different challenges related to the cost of projects' development, the transit across several different countries and the coordination of all involved parties.

The recommended priorities specified within the ENCOURAGED project address the development of gas pipelines from Norway, Russia, North Africa and from the Caspian/Middle-East region via Turkey, as well as several LNG chains mainly from the Middle East and Africa. At the heart of the conclusions is the relation between long term dynamics of the European gas market, risk and investment decision making. Not surprisingly, the issues of market uncertainty, regulatory instability and international political risk have been addressed. The challenge for policy makers is, indeed, to provide enough security to investors while keeping the coherence of the competitive structure of downstream gas markets. That can be achieved through the implementation of specific regulations ensuring that investors can get the benefits of their initiatives; the development of the EU internal market in a way providing sound risk hedging possibilities; the establishment of clear regulatory guidelines making the rules sound and stable; and the promotion of an international dialogue enhancing stable relations between producing, transit and importing countries.

Electricity corridors

We performed a traditional social cost-benefit evaluation of the economics of (in other words, net benefit achieved by) selected number of potentially interesting reinforcements of the interconnection electricity corridors. The evaluations support us to draw conclusions, which potential option could be useful to support the part of the EU Priority Interconnection Plan concerning the electricity corridors between European Union and the neighbouring countries.

A thorough analysis of expected demand, supply, electricity costs and prices in 44 countries of the pan-European system in the long run demonstrated and quantified that further expansions of interconnection capacity (till about 5000 MW at the South border with North Africa, till about 5000 MW at the South-East border with Turkey, up to 5100 MW at the East border between UCTE and IPS/UPS systems) would provide net benefits for EU and its neighbours.

As a consequence of this possible transmission capacity expansion, the total electricity exchanges at the 'main borders' are expected to grow up to about 150 TWh/year. These expected trades and the potential benefits of the identified corridors depend however on several important assumptions regarding e.g. development of generation capacity and its fuel mix, regulation and environmental policies, especially in the neighbouring countries, whose development is more uncertain.

We investigated the barriers and obstacles for the implementation of corridors, concluding that these are various and of a different nature at each border. Nevertheless, the discussions with stakeholders revealed also that the financing of electricity corridors is not considered to be a major barrier for regulated investments by the Transmission System Operators (TSOs). Generally the TSOs are prepared to undertake the necessary investments in interconnection capacity provided that these are executed within a stable regulatory investment climate. For the interconnection between Northern Africa and Southern Europe (characterised by very high upfront investments), the alternative 'merchant' approach with private investors is now under investigation by some companies and could be a feasible option in the future.

Hydrogen corridors

Finally a few words on the results of ENCOURAGED regarding the need and feasibility of Hydrogen corridors. Again the characteristics, drivers and particularly the timing of such corridors are quit different from the gas and electricity corridors. Because it is expected that around 2030 the demand volumes in the EU will sufficiently rise to levels that might be interesting for supplying these by large supply and thus low cost hydrogen production centres, the need for long distance transport must be placed in a period probably beyond 2030 and therefore the focus must on a clean production sources for hydrogen production such as renewables. This poses extra uncertainties on the availability, costs and likelihood of using these sources for that purpose. The options of using renewables for satisfying the domestic energy demand instead of producing hydrogen for long distance and relatively expensive transport to EU member states is attractive and likely. In short the uncertainties surrounding the interesting results of this study in ENCOURAGED are also large. But the findings nevertheless show that with relative high prices and lowering of hydrogen production and transport costs (not unlikely in the very long term) several options are feasible to bring hydrogen to the EU markets. However the study provides a complete overview and comparison of different competing options and underlying assumptions.

Final concluding observations

Our studies concerning the key factors influencing the implementation (investment in) of the recommended economic optimal energy corridors with the neighbouring countries of the EU clearly demonstrated that EU actions and policies are urgently required to speed up the realisation of a well functioning the Internal gas and electricity market, e.g. by enhancing the coordination between TSOs, creating a stronger EU foreign energy policy, intensify the dialogue and cooperation with the EU neighbouring countries.

Note that since the liberalisation of electricity and gas markets in the EU, which generally resulted in the current unbundling of electricity transmission and gas transport from the supply and demand of electricity and respectively gas, the role and responsibilities of the TSOs for the timely infrastructure investments and consequently the realisation of the key EU policy objectives such as realising competitive markets, supply security and a sustainable development has enormously increased. At the same time we experience a delay in implementation of investments in the as socially necessary identified cross border exchange capacities.

Conclusion is that more research into the underlying factors of investments in the energy infrastructure and more policy actions supporting the role of the TSOs and market for facilitating investing is required in the next years. Last but not least issues such as the expected increasing shares of intermittent renewable energy resources and the need for more energy trade should be analysed on their impacts in the next decades on the required energy infrastructure in Europe.

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Annex

Overview of Stakeholders in relevant Seminars

ENCOURAGED has organised in the period from February till December 2006 a number of workshops and seminars to present the study results and discuss these with respectively the electricity, gas and hydrogen stakeholders (representatives from industry, regulators, investors, traders, policy makers, etc). Seminars were held in Frankfurt, Milan, Paris, Algiers, Ankara and finally in Brussels. The consortium benefited in these seminars from the participation and comments of the following experts.

Hydrogen stakeholders workshop in Frankfurt 21 February 2006:

M. Altmann (LBST), Andersen, O. (Western Norway Research Institute), M. Arguminosa (INTA), A. Avadikyan (BETA-ULP), S. Avril (CEA Saclay), M. Ball (DFIU), S. Berger (Adam Opel), W. Borthwick (EC DG RTD), U. Bünger (LBSR), R. Carta (GE Oil and Gas Nuovo Pignone S.p.A.), E. Chacon (INTA), R. Ewald (Hydrogen and fuel cell initiative Hesse), R. Fernandes (IDMEC – IST), E. Girón, J.-E. Hanssen (1-Tech), U. Hasenauer (BSR-Sustainability), G.P. Haugom (DNV), M. Innocenti (GE Oil and Gas Nuovo Pignone), J. Jäger (SERI), O. Johnsen (DNV), S. Jokisch (ZEW), M. Krail (TH Karlsruhe), U. Langnickel (VGB Power Tech e.V.), D. Lorbach (Infraserv Höchst GmbH), R. Macário (CESUR – IST), C. Machens (Hydrogenics Europe), A. Martino (TRT), G. Martinus (ECN), J. Matheys (Vrije Universiteit Brussel), H. Meinel (DaimlerChrysler), A. Mattucci (ENEA), T. Mennel (ZEW), H. Meinel (DaimlerChrysler), T. Mennel (ZEW), S. Mohr (Fhg-ISI), E. Molin (Deft University of Technology), H. Mostad (Hydro), B. Nykvist (Stockholm Environment Institute), E. Patay (Air Liquide), S. Peteves (EC DG JRC), A. J. Purwanto (EC DG JRC), M-M. Quemere (EDF), A. Radlmeier (DaimlerChrysler), S. Rameshol (Wuppertal Institu), W. Schade (FhG-ISI), A. Scholz (TH Karlsruhe), P. Seydel (FhG-ISI), H. Seymour (IDMEC – IST), A. Simonnet (Total), A. Stein (Hessen Agentu GmbH), C. Stiller (LBST), S. Strasser (SERI), L. P. Thiesen (Adam Opel), J.S. Thon (Statkraft), F. Toro (BSR-Sustainability), V. Tsatsami (BP), G. Vaughan (Department of Trade and Industry (UK), H.-C. Wagner (BMW), M. Walter (HyGear B.V.), P. Weaver (University of Durham), L. Whitmarsh (University of East Anglia), M. Wietschel (FhG-ISI), R. Wurster (LBST), L. Zachariah (Delft University of Technology) and M. Zirpel (DENA)

Seminar on the first study results regarding the "Assessment of the electricity interconnections in the European Union and with the neighbouring countries", Milan, 9 May 2006:

Pavel Svejnar (CEPS), Romano Ambrogi, Cristina Cavicchioli, Angelo Invernizzi, and Nikola Kuljaca (CESI RICERCA), Daniele Canever, Sefkija Derviskadic, Luca Imperiali, and Uberto Vercellotti (CESI), Jan Strunc (Czech Energy Regulatory Office), Yves Schlumberger (EDF), Marco Bottoni, Mario Cumbat, Antonella Garavaglia and Clara Risso (EDISON), Fabio Caiazzi, and Raffaella Porri (EDISON Trading), Domenico Rossetti di Valdalbero (European Commission, DG RTD), Francesco Scarpamattachini

(ENEL Produzione), Domizia Novati (Enipower), Eva Hoos (EURELECTRIC), Matti Tähtinen (Fingrid), Sami Demirbilek (Ministry of Energy, Republic of Turkey), Rime Bouaroudj (Sonelgaz), Simone Autuori, and Pier Filippo Di Peio (Sorgenia), Claudio Di Mario, Claudio La Ianca, and Mario Valente (Terna Rete Elettrica Nazionale) and Fabio Zanellini (Università degli Studi di Pavia).

Seminar on first study results regarding the assessment of "Supply potential and corridor needs for future EU gas supply: priority infrastructure and policy recommendations" – Paris, 29 May 2006

Carine Swartenbroekx (Banque Nationale de Belgique), Enrique Iglesias (CEPSA), Olivier Choffrut (Commission de Régulation de l'Energie – France), Georg Krude (E.ON Ruhrgas AG), Frédérik Boujot and Vincent Gabrion (EDF), Nicola Monti (Edison Gas), Ahmed Abdrabo Mohsen (Egyptian Natural Gas Holding Company-Egas), Stéphane Hecq (ELECTRABEL), Jesus Saldana (ENAGAS), Erik Sorensen (Energy Charter Secretariat) Miroslav Maly (ENVIROS), Alfonso Vigre Maza (Gas Natural) Sybren De Jong (Gas Transport Services), Robert Gould (HELIO International), Stevo Kolundzic (INA), Johann Gallistl (OMV Gas), Youcef Abchi (SONATRACH), Pier Filippo Di Peio (Sorgenia), Ottar Skagen (STATOIL), Fatma Bergaoui (STEG), Jacques Chambert-Loir and Olivier Gouraud (TOTAL).

Regional seminar on "Electricity and gas inter-connections from North Africa to the EU" – Algiers, 16 November 2006

Amadou Thierno Diallo (African Development Bank), Farid Rahoual, and Mohand Sand Taibi (CREG), Jacques Schutz (EDF), Mario Cumbat (EDISON), Fabio Caiazzi, and Raffaella Porri (EDISON Trading), Nehal Abdel Aziz Mobarak (Egyptian Electricity Holding Company), Fabrizio Scaramuzza (ENEL), Cristobal Burgos Alonso (European Commission, DG Energy and Transport), Youcef Abchi, Arabi, Madina Benhamouda, Mohamed El-Faït Bensalah, Mahdi Bichari, Ghezali, Ahmed El Hachemi Mazighi, and Mohamed Nait-Cherif (Sonatrach), Abdelhafid Adnane, Abdelali Badache, Rime Bouaroudj, Merouane Chabane, Kamel Dermoune, Tahar Djouambi, Fergani, Daouadji Kinane, Djamila Mohammedi, Tarar Ouaret, Kamel Sid, El Hachemi Touaouaza, and Chérif Zeghoud (Sonelgaz), Lakhdar Chouireb (Sonelgaz and COMELEC), Rabah Touileb (Sonelgaz GRTE), Alaoua Saidani (Sonelgaz GRTG), Abderraouf Ben Mansour (STEG), Michelangelo Celozzi and Angelo Ferrante (Terna Rete Elettrica Nazionale).

Regional seminar on "South-East Europe gas and electricity corridors" – Ankara, 5 December 2006

Gokhan Yardim, (Anadolu Natural Gas Consultancy), Erjola Sadushi (Albanian Regulatory Commission), Adriatik Bego, Eda Gjergji, Agim Nashi, and Elis Sala (Albanian Regulator for Electricity), Mehmet Akif Duman, Kubilay Aktan, Ozden Alp, Mesude Arabacioglu, Eda Ceuheroglu, Ozlen Dudukcu, Hüseyin Saltuk Düzyol, Mr. Eker, Emre Engür, Erdem Getinkaya, Erdem Gordebak, Orhun Kanik; Vicdan Kayi, Mehmet Kosker, Sinar Ozcar, Selim Ozdemir, Erdinc Ozen, Cenk Pala, Bora Sokal, Murside Taymaz, Gokhan V. Toker, and Yavuz Yilmaz (BOTAS), Zeyno Basak Elbasi Akkol (BP Turkey), Pinar Yapanoglu (British Embassy in Turkey), Philippe Saintes (ELECTRABEL), Mete Baysal (Enerco Enerji), Gürbüz Gönül (Energy Charter Secretariat), Fatih Bilgic, Gökhan Efe, Hulusi Kara, and Bagdagül KAYA, (Energy Market Regulatory Authority – Turkey), Nilgün S. Acikalin, Begum Babali, Sinem Caynak, Kenan Erol, Jülide Gültekin, Ciydem Hatinoglu, and Halime Semerci (Ministry of Energy and Natural Resources of Turkey), Gülsun Erkal (Ministry of Foreign Affairs of Turkey), Haygrettin Acar, Mehtag Emri, and Mehmet Zeyrec (EÜAS), Roman Igelpacher (EVN), Peter Graham and Murat Orekli (International Power), Emir Asadollahi (Islamic Republic of Iran Embassy in Turkey), Nurey Atacik, Orhan Remzi Karadeniz, Nuri Dogan Karadeniz, Yasin Suudi, and Ali Can Takunyaci (KARTET), Dimitrios Mavrakis (KEPA-NKUA), Nenko Gamov (NEK EAD), Alesa Svetic (PETROL), Nusret Cömert and Ayhan Kirbas (SHELL Turkey), Mahdi Bichari (SONATRACH), Rachid El Andaloussi (SONELGAZ), Simone Autuori (SORGENIA), Per Myrvang and Ilknur Yenidede (STATOIL), Mounir Ben Hamida (STIR), Joe Mcclintock (Stratic Energy), Yildiz Durukan and Yusuf Bayrak (TEIAS), Vedii Yesilkilic and Filiz Yurdakul (TEDAS), Cem Duygulu and Bumin Gürses (TEKFEN), Ayhan Isen, Azmi Kücükkeles, and Serpil Serdar (TETAS), Jacques Chambert-Loir and Olivier Gouraud (TOTAL), Aysegul T. Bali, Serdar Demiralin, Bureu Gunal, Kutluhen Olcay, Murat Ulu, and Hüseyin Yakar (TPAO), Reha Gülümser (TURUSGAZ), Aysem Sargin and David Kenan Young (US Embassy in Turkey), Graham Freedman and Tim Lambert (WOOD MACKENZIE), Mustafa P. Kokcu and Yurdakul H. Yigitguden.

Final stakeholders' seminar on "Energy corridors between the EU and neighbouring countries" – Brussels, 12 December 2006, with contributing experts among others

Carine Swartenbroekx (Banque Nationale de Belgique), Enrique Iglesias Barbero (CEPSA), Frédérik Boujot (EDF), Jean-Claude Dorcimont (Electrabel NV), Giuliano Basso (Energy Solutions), Miroslav Maly (ENVIROS), Manuel Coxe (ETSO), Juho Lipponen (EURELECTRIC), Peter Nagy (European Commission, DG RELEX), Domenico Rossetti di Valdalbero and Raffaele Liberali (European Commission, DG RTD), Jean-André Barbosa, Cristobal Burgos Alonso and Jean-Paul Launay (European Commission, DG TREN), Alfonso Vigre (Gas Narural) Yasin El Suudi (KARTET), Enrique Iglesias Barbero (Gas Natural CEPSA), Yasin El Suudi (KARTET), Dimitrios Mavrakis (KEPA, NKUA), Robertas Alzbutas (Lithuanian Energy Institute), Johann Gallistl (OMV Gas International), Souad Allagui (STEG), Olivier Gouraud, and Olivier Ricard (TOTAL), Jean-Michel Glachant (University Paris Sud). J. Thon (Statkraft), J. Wind (DaimlerChrysler), S. Berger (Opel), J. Reijerkerk (Linde), M. Innocenti, R. Carta (GE-Nuovo Pignone), T. I. Sigfusson (IPHE co-chair).

From the European Commission, particularly constructive participation and presentations were given by Cristobal Burgos Alonso and Jean-Paul Launay, from DG Transport and Energy.

European Commission

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The European Union is concerned by the competitiveness, security and sustainability of its energy system.

This publication presents the main results of the ENCOURAGED project that assessed the potential energy corridors between the EU and its neighbouring countries addressing in particular the issues on natural gas, electricity and hydrogen.

The EU neighbouring countries are the main suppliers and transit countries of oil and natural gas. The dependency of the EU on imported gas supplies is largely increasing in the next years. Therefore, the role of neighbouring countries will grow significantly in the next decades and will probably extend to electricity exchanges and perhaps, in the next decades, to hydrogen supply.

Three main points are of particular importance for the integration of the energy markets of the EU and neighbouring countries: to get compatible interconnections, compatible market framework and compatible environmental policies.

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