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'Captive' and 'Open Sea' Energy Import Framework

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1 INTRODUCTION

The objectives of the REACCESS work package 2 (“Identification and detailed description of ’captive’ energy import corridors and framework”) and work package 3 (“Identification and detailed description of ‘open sea’ energy import corridors and framework”) were the identification and characterisation of relevant resources, production and transportation infrastructures of the corridors that supply energy to EU27+. The two work packages applied a systematic approach to collect the main characteristics of the whole energy chain of each commodity, starting from mining activities in exporting regions up the input to EU27+ countries. In some cases the corridor enters into EU, feeding more than one country.

The activities were implemented in two phases:

In **Phase 1**, all available information on existing and planned or potential developments were collected and organised in database tables (summarised in the annexes) and task reports (technical notes). A database framework and centralized access structure, defining in detail all the relevant information to be covered, was developed with the cooperation of all task groups involved in the two work packages as well as of modellers and risk experts. For each commodity taken into consideration (oil, gas, electricity, coal, biomass, nuclear fuels and hydrogen) a detailed **Technical Note** giving a complete overview on assumptions, data sources, methodological approaches and results was performed. By using suitable GIS tools, all the identified and defined energy supply routes were represented graphically and analysed with reference to their spatial characteristics and interactions with the crossed territories.

In **Phase 2**, the collected data are aggregated coherently with the Reference Energy Corridors (RECOR) scheme, with the purpose to give a consistent and suitable input to the energy system modelling and risks analysis activities of the other work packages of the project.

According to the general **Data Base Template structure**, the data collection covered a set of data-gathering categories:

- energy fields characteristics (proven and probable resources)
- installed and planned infrastructures for commodities’ production and transportation (technology, capacity, usual operational load, costs, emissions, …)
- technological potential for upgrading the capacities of existing infrastructures (contribution of new technologies)
- past trends and development programs of infrastructures
- economic, financial & political framework

The framework for data collection refers to the usual concepts adopted by the Energy System modelling tools to describe the essential components of a Reference Energy System (RESy) and its inter-connectivity in the TIMES modelling approach.

In order to simplify the data collection and the modelling phases, the same framework was adopted for all resources, identifying the following four steps/processes:

- **Resources:** all primary sources are described with their costs, cumulative amounts and maximum yearly output.
- **Primary production:** including, in addition to the basic extraction activities, also *in-situ* processing (natural gas purification, coal beneficiation, separation of associated gas, uranium ore purification, etc.) (with or without storage). These activities are located in the producing regions. A single process may collect the output of several mining activities of the same region; its input comes from mining (plus additional energy consumed in the process), while the output are the resources ready for transport or (partly) for feeding secondary production facilities. CO_2 emissions, flow losses, flared and vented fractions, costs and efficiencies are accounted for.
- **Secondary production** (with or without storage): refineries for crude oil before the shipment of oil products, liquefaction plants for natural gas, biofuel production plants, yellowcake conversion to UF_6. These facilities are described like normal technologies, located in the supplying regions
- **Transportation** processes (with or without storage), involving pipelines, cables/lines, trains, trucks, ships and related infrastructures (loading and unloading facilities), pumping stations, voltage transformers.

Through user constraints or by adding new features to the TIMES modelling approach, the trade flows in both directions are associated to the corridor processes.

Chapter 2 and **Chapter 3** of this Deliverable give an overview of the methodological approach adopted, the main information sources utilised and the essential results obtained for each commodity, referring to the above mentioned steps of the energy import chain.

Chapter 4 summarises the political and financial framework conditions and **Chapter 5** summarises the work done for the spatial analysis of import corridors. **Chapter 6** provides final conclusions regarding the EU27+ import situation, developments and perspectives.

Detailed information was reported for each energy commodity in **Technical Notes** whose circulation is only admitted among partners, EU officers and advisory members. These working papers were prepared by the different Task groups involved in the collection of resources and corridor data.

An *ad hoc* **Data Base Template** was designed for the collection of standard sets of data for each commodity finalised to be the required input for the pan-EU27+, TIAM and RECOR TIMES models. The main parameters describing the characteristics of resources, primary and secondary production activities, corridor paths and features, with past trends and planned or possible developments were filled in.

In the **Annex I** and **Annex II** the more detailed but non sensible data for resources, production capacities and corridors are reported for each commodity, in addition to the full list of the oil and natural gas corridors.

Annex III provides the definition of abbreviations for the world regions and supply countries used in the models and **Annex IV** provides a glossary.

Notice

The time horizon of the analyses that are performed by the modelling tools (the adapted PanEU27+ and TIAM TIMES models and the RECOR model) starts from the 2005 (base year) and reaches the year 2050.

In general, the time evolution of energy systems and infrastructures is not particularly fast; however, there are exceptions. One of the most relevant is related to the very rapid development of the LNG trade, particularly in Middle East countries: until 2007 there were no LNG plants in the area, while in 2009 Qatar alone is the main world LNG exporter and its tanker fleet is becoming the largest one. In the same sector, floating re-gasification units are presently (and even more in the future) enhancing the open sea trade in natural gas.

While the calibration of the modelling tools requires the knowledge of the situation at the base year, the scenario analyses require a complete vision of the energy systems' boundaries along the whole time horizon: for these reasons the information collected by work packages 2 and 3 teams (and reported in this Deliverable) mainly focused the situation at the year 2005 and all the planned or expected developments (at least, those available in the energy related literature). The data have been collected and organised in a wide set of worksheets and implemented in order to easily feed the input shells of the TIMES procedure. This Deliverable documents the methodologies, presents the energy corridors that have been identified and reports the main figures for the energy commodities analysed, mainly in the context of the 2005 base year.

2 IDENTIFIED RESOURCES AND PRODUCTION

The characterisation of each resource considered as supplying EU energy corridors provides a description of the source area (country, basin, representative field or area), a distinction of proven, probable and possible stocks with their energy content and exploration costs.

The characterisation of each production process includes plant type and capacity, energy consumption and losses, quantities produced in past and base years, possible capacity extensions, investment and operating costs, technical lifetime and onsite storage capacities and costs. Each production process is numbered by a commodity code and linked to one or several energy corridors to EU27+.

Two alternative options can be taken into consideration for identifying the starting points of these commodity chains (i.e. the "origins" of the corridors and/or the representative locations of resource and production facilities):

- it is possible to identify and collect data with reference to a well defined location (coal and uranium ore mine, oil and gas field, biomass harvesting field, solar plant);
- it is necessary to assume (and describe, in an aggregated way) a virtual source point, where a given commodity starts to be available.

Since the information available at the most granular level (i.e. individual oil and gas fields) is very often limited and in order to reduce the number of processes to be characterised as suitable input for the models, a standard aggregation procedure of the detailed data has been defined and performed for each commodity. Resources and production data are provided mostly at national level and, for some commodities, at sub-national level (as for oil and gas basins in Russia and some areas in African countries).

Representative starting points of the corridors have been associated to spatial coordinates referring to the locations of source fields, main stations/plants, ports/terminals or areas/land used for biomass production or solar power generation. A summary of identified resources, production quantities and capacities for each commodity is presented in the following Table 2.1.

Resource and production data refer to the sources feeding the identified EU corridors. The same data are reported for each commodity in more detail in Chapter 2.1 to 2.6 with reference to the main energy supply regions.

Table 2.1: Aggregated list of identified resources, production quantities and capacities in possible energy supply regions outside EU27+.

	Resources identified			Primary and secondary production				
Commodity	**Resources proven**	**Resources probable/ possible**	**unit**	**Quantity in 2005**	**Capacity in 2005**	**Estimated import to EU27+ in 2050**	**Import to Europe/EU27+ in 2005**	**unit**
Natural gas	172,200 equal to 6,544,500	349,700 equal to 13,287,300	bm³ PJ	2,493 equal to 94,740		ne	205 equal to 7,795	bm³/yr PJ/yr
LNG				137,905 equal to 7,179		ne	34,745 equal to 1,810	kt/yr PJ/yr
Crude oil	1,171,000 equal to 7,166,800	1,997,100 equal to 12,222,500	mbl PJ	27,474 equal to 168,143		ne	3,846 equal to 23,538	mbl/yr PJ/yr
Oil products			mbl PJ	56.43 equal to 345		ne	994 equal to 6,084	mbl/yr PJ/yr
Unconventional oil: - oil shale - natural bitumen - tar sands & extra heavy oil	 16,813,600 15,150,900 15,951,700		 PJ PJ PJ			ne		
Hard coal	20,656,900	94,463,000	PJ			ne		
Lignite	2,149,650	8,152,400	PJ			ne		
Solar electricity		4,666,380 equal to 1,936,800	km² land PJ/yr	0	0	2,520 (1)	0	PJ/yr
Biomass – energy crops scenario 1 (2)	712 equal to 209,000		Mha land PJ/yr	(3)	(3)	ne	(3)	
Biomass – agricultural and forestry residues	49,000		PJ/yr	(3)	(3)	ne	(3)	
Biomass – wood resources	26,000		PJ/yr	(3)	(3)	ne	(3)	
Biodiesel				17	36	ne	0.33 (but 40.72 in 2007)	PJ/yr
Bioethanol				677	658	ne	8	PJ/yr
Wood pellets				na	29	ne	23	PJ/yr
Nuclear fuel (4)	4,743,000 equal to 1,897,200		tU PJ	26,081 equal to 10,432				tU/yr PJ/yr
Hydrogen from lignite	5.1		PJ/yr	0	0	2.88	0	PJ/yr
Hydrogen from biomass/solar & wind power	811.9		PJ/yr	0	0	275.19	0	PJ/yr

(1) Assumption: 0.13% of calculated maximum technical generation potential of ~538,000 TWh/yr in the seven MENA supply countries considered to be achievable by 2050 (corresponding to about 15% of expected electricity demand in EU27+ in the year 2050).

(2) A lower scenario for energy crops is also proposed: Total world = 136 EJ in 2050, 166 EJ in 2100 (EUR = 0.5 EJ only).

(3) Only trade in secondary biomass commodities (biodiesel, bioethanol and wood pellets) is represented.

(4) Reasonably Assured Resources plus Inferred Resources, to US$ 130/kg U. Assumed conversion ratio of 0.4 PJ/tU.

Other conversion factors assumed: biomass energy crops: 294 GJ/ha; natural gas: 0.038 GJ/m³; crude oil and oil products: 6.12 GJ/barrel

ne = not estimated

2.1 Oil and natural gas

2.1.1 Resources

Conventional oil and natural gas resources are divided into reserves, undiscovered resources and future reserve growth. Reserves are exploitable deposits that are profitable and approved for production. Reserves must be discovered through one or more exploratory wells, be recoverable using existing technology, be commercially viable and remaining in the ground. Reserve estimates are uncertain, depending on the available geological and engineering data and the interpretation of this information.

Various organisations report oil and natural gas reserve data, using national and company sources. The Oil and Gas journal (O&G-journal, www.ogj.com), British Petroleum (BP, 2008a) and the Organisation of Petroleum-Exporting Countries (OPEC) (OPEC, 2008) are examples of sources that produce annual reserve data by country. In the REACCESS project reserve data from BP are used as it has a well arranged format on a country level. There are doubts regarding the reliability of reserve data due to the fact that such information is considered confidential in countries like the OPEC member countries and Russia (Yenikeyeff, 2006; Whaley, 2007).

In 2005 the world oil reserves were estimated to be 1277 bbl (billion barrels = 10^9 barrels) according to the O&G-journal, 1194 bbl according to BP and 1178 bbl according to OPEC. One reason for the difference between the O&G-journal and the other sources is that this source includes estimates of oil sand in the reserve data. BP includes an official estimate of the Canadian oil sands that is proven while OPEC includes crude oil estimates only.

In 2005 the world natural gas reserves were estimated to be 171 Tm^3 (Tm^3 = Tera cubic metre or 10^{12} m^3) according to the O&G-journal, 179 Tm^3 according to BP and 181 Tm^3 according to OPEC. There are minor differences between BP and OPEC while the O&G-journal has about 5% lower reserves compared to BP.

The chance of an undiscovered resource (from fields that are not yet discovered) to be commercialised is the chance of discovery times the chance of development. Reserve growth refers to an increase in the estimated size of the field that occurs through the time as the oil and gas fields are developed and produced. Reserve growth results from several factors:

- additional reservoir and geologic information,
- discovery of new reservoirs in existing fields,
- improved recovery factor e.g. application of enhanced oil recovery (EOR) and
- economics, i.e. rising oil and gas prices.

In 2000 U.S. Geological Survey (USGS) published a World Petroleum Assessment (USGS, 2000a). The study provided resource estimates of undiscovered oil, natural gas and natural gas liquids (NGL) and reserve growth. Estimated undiscovered resources are given by country level up to 2025 using a probabilistic approach. The mean values of undiscovered resources, except for the United States, were 649 bbl oil, 207 bbl NGL and 132 Tm^3 of natural gas. The potential of reserve growth from 1995 to 2025 was reported at the world level except for the United States and was 612 bbl oil, 42 bbl NGL and 94 Tm^3 of natural gas. Despite the fact that several organisations, such as the American Association of Petroleum Geologists (AAPG), the Committee on Resource and Evaluation and National Academy of Science (NCR) supports the USGS 2000 assessment (Ahlbrabdt, 2000), the particular research has also received plenty of criticism. In the literature several researchers, such as Laherrère (2000), Campbell (2000) and Deffeyes (2008), disagree with regards to the methodology used in the USGS assessment for estimating the remaining oil and gas resources.

In 2007 an evaluation of the USGS World Petroleum Assessment (USGS, 2007) suggested that additional reserves per region for crude oil and natural gas should be included in comparison to the data from 2000. Field sizes used for the reserve growth assessment in (USGS, 2000a) were taken from the international petroleum exploration and production database IHS Energy from 1996 while data from the IHS Database (http://energy.ihs.com/) for 2003 were used to estimate additional resources. The additional undiscovered resources were estimated to be 69 bbl of oil and 13 Tm^3 of natural gas and the additional reserve growth was estimated to be 171 bbl of oil and 48 Tm^3 of gas.

The detailed data on undiscovered resources in (USGS, 2000a) are by country whereas suggested changes from (USGS, 2007) are per region. The same regional distribution of undiscovered resources between countries is therefore assumed for both data sets. The detailed data on reserve growth are at world level in (USGS, 2000a) and at regional level in (USGS, 2007). It is assumed that the regional distribution of proven reserves is equal to the distribution of the estimates of reserve growth.

Oil resources of the world, Saudi Arabia, Iran and Iraq are illustrated in Figure 2.1. In 2005, the total world oil resources were 1194 bbl of proven reserves, 981 bbl of undiscovered fields and 901 bbl of field growth. Saudi Arabia, Iran and Iraq are the countries with the largest proven oil reserves. Saudi Arabia has 22% of worldwide reserves.

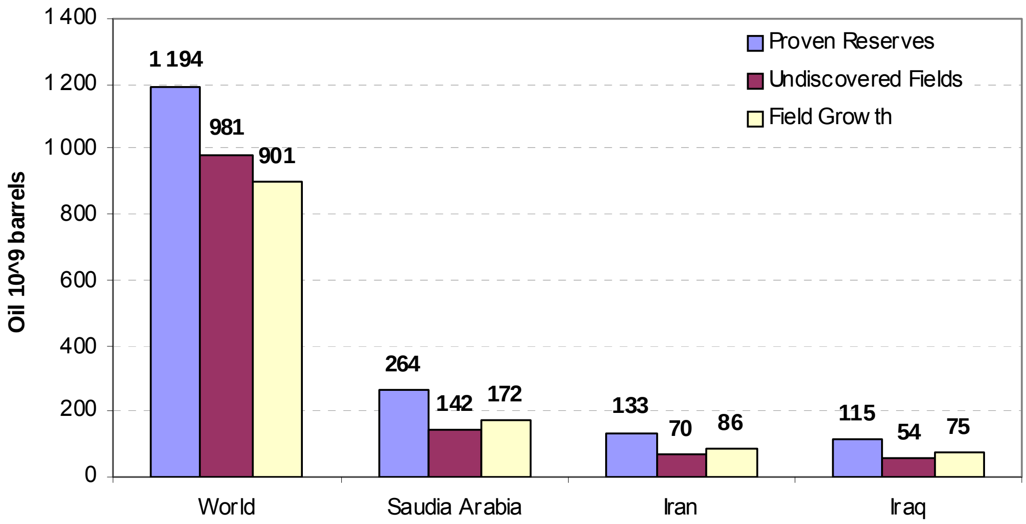


Figure 2.1: Oil resources: proven reserves, undiscovered fields and potential field growth of the world, Saudi Arabia, Iran and Iraq.

Natural gas resources of the world, Russia, Iran and Qatar are illustrated in Figure 2.2. The world natural gas resources in 2005 were 179 Tm^3 of proven reserves, 159 Tm^3 of undiscovered fields and 152 Tm^3 of field growth. Russia, Iran and Qatar are the countries with the largest proven reserves with Russia having 27% of worldwide reserves.

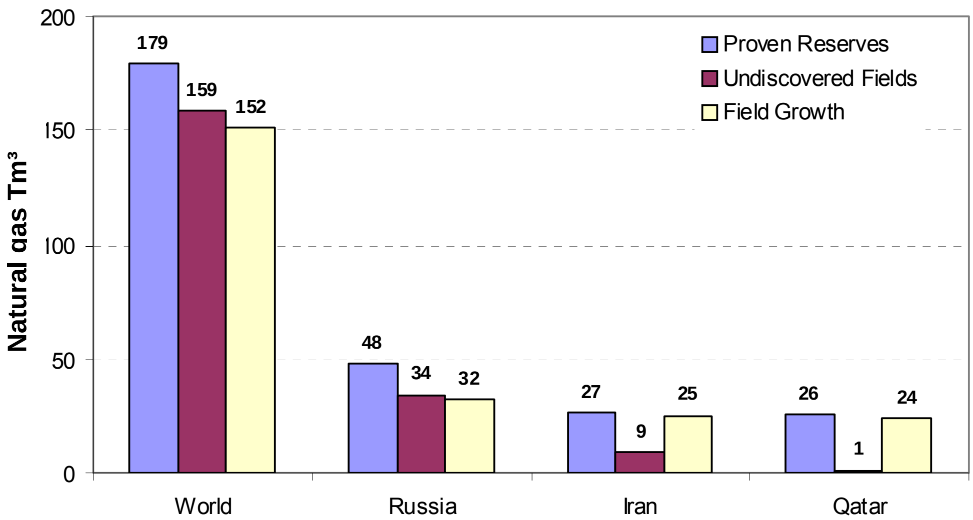


Figure 2.2: Natural gas resources: proven reserves, undiscovered fields and potential field growth of the world, Russia. Iran and Qatar (beginning of year 2005).

Oil and natural production is divided into primary and secondary production. Primary production includes extraction, separation and purification of natural gas and oil from the well head to further processing and export. Secondary production is further processing from primary production. Examples of such processes are liquefaction of natural gas (LNG) and oil refining. Losses from primary oil and gas production are mainly flaring, venting and internal energy consumption. The losses are not included in the presented production figures.

2.1.2 Primary production

The primary production of oil and natural gas is limited by the production capacity. National organisations of producing countries like the Norwegian Petroleum Directorate or national oil companies like Gazprom provide national production data. Information on production data by country or region is provided by various organisations from national and company sources. The O&G-journal, BP and OPEC are examples of sources that provide annual production data by country.

According to OPEC, 2005 worldwide oil production was 71,641 kb/d (kb/d = thousands barrels per day) and according to BP 81,255 kb/d, this represents a 13% difference between BP and OPEC. According to OPEC, 2005 worldwide natural gas production was 2805 bm^3 and according to BP 2776 bm^3 hence the difference between the OPEC and BP production data is minor and corresponds to 1%.

Oil and natural gas production data from BP is used in the REACCESS project, since according to IEA (IEA, 2008) the accuracy of the OPEC production data is questionable:

"Estimates of OPEC crude production are based on information from a wide range of sources with tanker tracking information being particularly useful. Production is generally, but not exclusively, taken as exports plus local consumption of crude oil and hence does not generally take into account any changes in crude oil stock levels within the country."

The reserve over production ratio (R/P-ratio) indicates the duration of the currently estimated reserves, with the current production rate. In 2005 the worldwide R/P-ratio was 48 years for oil and 64 years for natural gas. Even though the R/P ratio indicates regional differences between reserves and production, it is not an appropriate parameter to investigate how long oil and natural gas will last. Firstly, the production rate will not remain constant and secondly new discoveries are probable.

Middle East is the region with largest oil production where Saudi Arabia is the largest producing country. According to BP, Saudi Arabia produced in 2005 11,114 kb/d of oil and had an R/P ratio of 65 years. Russia was the second largest oil producer in 2005 with 9553 kb/d and the United States the third largest oil producer with 6879 kb/d. Russia was the largest natural gas producing country in 1995, 2005 and 2007. Russia produced 656 bm^3 natural gas in 2005 and had an R/P-ratio of 73 years. In 2005, the United States were the second largest natural gas producer with 511 bm^3 and Canada was the third largest natural gas producer with 187 bm^3.

2.1.3 Costs of primary production

There have been significant improvements in the oil and gas technology during the past decades and further new technology can decrease development and production costs and make more oil and gas economical to extract. Development of low cost wells, deepwater production and recovery technologies can reduce costs and lead to an increased oil and gas production. The cost impact of the evolving offshore technology from fixed platforms to floating production solutions has led to considerable decrease in capital expenditures. The recent development of subsea oil and gas production technologies can decrease the production costs further and make more fields economically profitable. Subsea separation and transport to shore are currently applied to some new fields, like the Snøhvit field in the Barents Sea, Norway.

Recovery is the amount of hydrocarbons that it is possible to extract from a field. Extraction of oil in the sedimentary reservoir rocks needs the injection of another fluid. The oil can be replaced with fluids already contained in the reservoir, injected water, gas or complex mixtures. The recovery factor varies widely, dependent on reservoir characteristics. The oil recovery factor is typically between 30 to 50%. Extracting more than 40% usually requires injection of complex mixtures that may not be economical. The gas recovery factor is much higher, typically at 70 to 80% (IEA, 2005a). Numerous techniques for enhanced recovery have been developed, but they have a high cost. Hydrocarbon gas and CO_2 injection have the advantage that they can be immiscible with oil, dependent on reservoir pressure and temperature. Research on inter alia rock-fluid interfaces can lead to cost reduction for recovery processes. The oil price also affects the profitability of recovery by injection. For example the Stat fjord field in the North Sea has increased its recovery from 49% in 1986 to 68% in 2007 (Statoil, 2001).

The Financial Reporting System (FRS) was established by the Energy Information Administration (EIA) in 1977 with the goal to implement a data reporting program on energy financial and operating information for major energy-producing companies. The FRS basically includes US owned companies but also non-US companies like BP and Shell. In 2005, 29 companies provided data to the FRS. The company information is aggregated to regional level and published in an annual data and analysis report (EIA, 2007). The FRS provides production (lifting) and exploration (finding) costs by region. Production (lifting) cost are the costs of operating and maintaining wells and related equipment and facilities per barrel of oil equivalent (boe) of oil and gas produced after the hydrocarbons have been found, acquired and developed for production. Exploration (finding) cost cover the costs of adding proved reserves of oil and natural gas through exploration and development activities and by the purchase of properties that might contain reserves. Oil and natural gas are often produced together and therefore single production cost data are often not available.

The United States show the highest increase in lifting cost between 2005 and 2006 from 5.56 to 6.83 US$/boe. Canada had the highest level of production cost in 2006 at 8.29 US$/boe. The Other Western Hemisphere (OWH) had the lowest production cost in 2006 at 3.21 US$/boe. Three regions, the Former Soviet Union, Middle East and Africa had declining lifting costs from 2005 to 2006 resulting from production increases and economy of scale. From 2000 to 2006 the lifting costs in the USA have increased by 92% while in the rest of the world have increased by 42%.

Finding cost is calculated as a weighted average over three years. All regions had increasing finding costs between 2003 to 2005 and 2004 to 2006. The regions with largest proportional increase in finding costs are Europe, US onshore, OWH and Africa. Only the Middle East had a finding cost below 10 US$/boe in the period 2004 to 2006 with an average of 5.26 US$/boe. The largest finding cost is found in the United States (offshore) at 63.71 US$/boe. Factors that can cause increased finding costs includes fall in reserve additions from oil and natural gas extensions and discoveries and growing development expenses

Offshore oil production accounts for 30% of the total oil production and 50% of the total natural gas production worldwide. The lifetime of an oil rig is about 20 years. At the end of the life, unless it is re-used or re-developed, the rig must be decommissioned. A challenge for decommissioning is that there is no standard method because of the wide variety of oil and gas offshore structures and equipment. The United Kingdom has 470 offshore installations and it is estimated that a 90% decommissioning of the UK infrastructure will cost between 10 and 20 billion pounds (Oil & Gas UK, 2008).

2.1.4 Emissions during primary production

The International Association for Oil and Gas Producers (OGP) consists of 31 member companies working in 60 countries worldwide. All members submit data on their environmental performance to the E&P Industry annual report (OGP, 2007). The report for 2006 includes data covering about 33% of the global oil and natural gas production. Information on emissions from primary oil and gas facilities are provided in this report. The regional coverage is uneven, ranging from 100% of the production in Europe to 17% of known production in the Middle East and 5% in the Former Soviet Union (FSU). Global averages are calculated using data from all regions, including those from the FSU and the Middle East.

CO_2 emissions from primary production are a result of flaring or fuel combustion for energy production. They are a function of the burned fuel type and quantity. In 2005, Africa had the highest CO_2 emissions with 274 tonnes per 1000 tonnes oil and Europe had the lowest emissions with 65 tonnes per 1000 tonnes oil.

Methane (CH_4) emissions are caused by venting and by incomplete combustion of hydrocarbons. CH_4 has approximately 20 times higher global warming potential compared to CO_2. In 2005, Africa had the highest CH_4 emissions with 1.73 tonnes per 1000 tonnes oil and Europe had the lowest emissions with 0.24 tonnes per 1000 tonnes oil (OGP, 2007).

Emissions of nitrogen oxides (NO_x) occur mainly from combustion of hydrocarbon fuels. Thermal NO_x emission is a function of the maximum combustion temperature and is varying with operation and type of the combustion device. In 2005, America had the highest NO_x emissions with 0.46 tonnes per 1000 tonnes oil and the Middle East had the lowest emissions with 0.16 tonnes per 1000 tonnes (OGP, 2007).

2.1.5 Losses during primary production

Flaring occurs when natural gas is produced in association with oil and there is no use, market or infrastructure to sell the natural gas. Venting and flaring of natural gas also occur during start-up, shut-down and off-design operations of primary production facilities. The World Bank Global Gas Flaring Reduction Initiative estimates that 150 Gm^3 of gas were flared or vented in 2005 (World Bank, 2008).

There are efforts worldwide to reduce flaring of natural gas. For example, Algerian government has announced the banning of natural gas flaring after 2010 (Mbendi, 2005).

Nigeria is the country with largest amounts of flared and vented gas in the world. The amount of flared and vented gas has been reduced from 27 Gm^3 in 1993 to 22 Gm^3 in 2007 (OPEC, 2008). Investments in natural gas infrastructure can result in increased natural gas production and reduced flaring and venting of natural gas. The ratio between flared and vented gas depends on the field characteristics and the operation regime.

The energy needed for the primary production of oil and gas covers a wide range of activities. These include pumps for oil extraction, production of process heat for oil separation and steam for enhanced oil recovery (if any), pumps for re-injection of water and the transport of produced oil through pipelines, compressors for re-injection of gas or for transport through pipelines and turbines to generate electricity needed for the operations and for living quarters (e.g. at offshore platforms).

The energy is often obtained from locally produced gas burned in gas turbine. When the supply of local natural gas is limited, energy for oil and gas production is delivered from external suppliers. According to OGP, North America is the region with highest energy consumption with 2.36 GJ per tonne oil produced in 2006 and Africa has the smallest energy consumption with 0.93 GJ per tonne in 2006.

2.1.6 Secondary production

Liquefied Natural Gas (LNG) is produced by cooling natural gas to -162 °C in a refrigerant cycle. The efficiency of the process is primarily dependent on the efficiency of heat exchangers and turbo machinery. Energy losses of the current liquefaction plants are approximately 15% of the natural gas input and future plants are expected to be 11% (Pyrdol & Baron, 2006).

The liquefaction plant is the largest cost component in the LNG value chain but the costs have decreased significantly during the past decades because of improved technology and increased train size.

The average cost of a liquefaction plant in 2003 was 3.8 US$ per MMBtu/yr (Shively & Ferrare, 2005) and the future cost is expected to be 2.9 US$ per MMBtu/yr (Alexander, 2003).

Table 2.2 shows LNG production per region for 1998, 2005 and 2007. Asia Pacific is the largest LNG producer with 63.6 Mt_{LNG} in 2007. Worldwide LNG production increased by 66% from 73.8 to 122.8 Mt_{LNG} in the period from 1998 to 2007. More detailed data on LNG plants and capacities are shown in Annex I.

Table 2.2: LNG production by region for 1998, 2005 and 2007 (BP, 2008a).
(figures in Mt_{LNG})

Region	Production 1998	Production 2005	Production 2007
Africa	18.8	33.2	45.0
Middle East *	0	0	0
Asia Pacific	53.7	61.3	63.6
North America	1.3	1.3	0.9
Latin America	0	10.2	13.2
Total world	**73.8**	**106.1**	**122.8**

* In 2009, six LNG liquefaction marine terminal sites are in operation in the Persian Gulf (three in Qatar, two in Oman and one in UAE). Twelve additional LNG liquefaction terminals projects are proposed or under construction in this region.

LNG needs to be re-gasified before it can be used by the importing countries. Table 2.3 gives an overview of existing European regasification terminals. Total regasification capacity is 183 Gm^3/yr and total storage capacity is about 6.4 Gm^3.

Refineries convert crude oil, condensate and NGL to products as gasoline, naphtha, jet fuel, diesel, residual fuel oil, etc. Table 2.4 shows refinery capacities by region for 1995, 2000 and 2005. The data shows increasing capacities for nearly all countries except Russia. Global refinery capacity increased from 76,000 kb/d in 1995 to about 86,000 kb/d in 2005. More detailed refinery capacities are listed in Annex I.

Table 2.3: Existing European regasification terminals (King & Spalding, 2006).

Existing EU regasification terminals		Storage capacity [10^3 m^3]		Capacity [10^9 m^3/yr]		Start-up year	
		present	expansion	present	expansion	present	expansion
Zeebrugge	Belgium	3 x 87	140	4.5	9	1987	2007
Montoir	France	3 x 120		10.2		1982	
Fos-sur-Mer	France	2 x 35 + 80		4.55		1972	
Fos Cavaou	France	3 x 110		8.25		2007	
Revithoussa	Greece	2 x 65		2.26	6.5	2000	2007
Panigaglia	Italy	2 x 50		3.5		1971	
Isola di Porto. Levante	Italy	2 x 125		8		2008	
Sines	Portugal	2 x 120	140	5.2	8.5	2003	NA
Bilbao	Spain	2 x 150	150	7	10.5	2003	NA
Barcelona	Spain	2 x 80 + 2 x 40	2 x 150	10.5	14.5	1969	2005
Cartagena	Spain	55+127+105	150	7.9	9.2	1989	2007
Huelva	Spain	60+100+150	150	7.9	11.8	1988	2006
Sagunto	Spain	2 x 150	2 x 150	6.6	11.4	2006	NA
El Ferrol (Mugardos)	Spain	2 x 150		3.6		2006	
Marmara Ereglisi	Turkey	3 x 85		5.2		1994	
Aliaga	Turkey	2 x 140		6			
Grain	UK	4 x 50	3 x 190	4.6	9.3	2005	2008
South Hook	UK	3 x 155	2 x 155	10.5	21	2008	2010
Dragon	UK	2 x 168	1 x 168	6	9	2007	NA

NA = not available

Table 2.4: Refinery capacities (BP, 2008a).
(figures are kb/d = thousands barrels per day)

Region	**1995**	**2000**	**2005**
Africa	2910	3034	3311
Middle East	5826	6362	7179
Asia Pacific	17295	21435	22694
North America	17125	18456	19262
Latin America	6054	6544	6763
Russia	6123	5351	5412
Total world	**75978**	**81955**	**85702**

2.2 Solar electricity

2.2.1 Introductory remarks

Recent studies, such as ENCOURAGED, analyse strategies for and benefits of improved energy interconnections between UCTE transmission grid (HVAC – High-Voltage Alternate Current) and neighbouring regions. However, the scenarios in ENCOURAGED show only relative low import potentials for EU27+, less than 3% of the future electricity demand, as a result of the expected strong increase of demand in possible supply countries and the high losses of a long range power transmission via the HVAC grid. Complementary to this, Task 2.3 of REACCESS analysed solar electricity import potentials via High-Voltage Direct Current (HVDC) lines as an additional and virtually unlimited energy resource. Concentrating solar power (CSP) plants equipped with high temperature heat storage and HVDC overhead lines and submarine cables for bulk power transmission represent the key technologies for implementing this most promising option for the import of renewable energy to EU27.

The German Aerospace Center (DLR) has developed a method that models the optical transparency of the atmosphere to calculate the direct normal irradiance (DNI) on the ground at any time and any site, by detecting and quantifying those atmospheric components that absorb or reflect sunlight, such as clouds, aerosols, water vapour, ozone, gases and others. Most of this information is derived from satellite remote sensing (Schillings et al., 2004). The DNI is the natural energy source for concentrating solar power plants (CSP). The resulting solar resource data were uploaded to a Geographic Information System (GIS) and processed together with spatial data on land use, topography, hydrology, geomorphology, infrastructure, protected areas etc. excluding sites that are not technically feasible for the construction of Concentrating Solar Power Plants. The methodologies and results of the studies MED-CSP (Trieb et al., 2005) and TRANS-CSP (Trieb et al., 2006) commissioned by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) were used as a basis for this Task. Figure 2.3 shows the result of this analysis as non-excluded areas in the MENA (Middle East North Africa) region which is the technical potential for CSP generation in the future. The remaining sites are in principle potential CSP project sites with respect to the following exclusion criteria applied:

- slope of terrain > 2.1%
- selected land cover (sea, inland water, forest, swamp, agriculture, rice culture)
- hydrologic criteria (permanent inland water, non-permanent inland water, regularly flooded area
- geomorphologic criteria (shifting sand plus security zone of 10 km, dunes, salt pans, glaciers plus security zone)
- selected land use (settlement, airport, oil or gas fields, mine, quarry, desalination plant, protected area, restricted area)

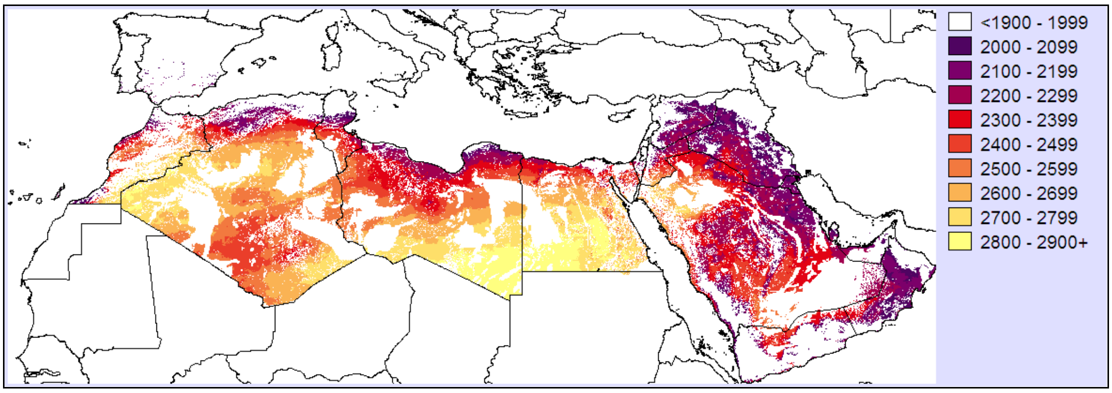


Figure 2.3: Annual direct normal irradiance on non-excluded areas in MENA.
(figures are in kWh/(m² · yr))

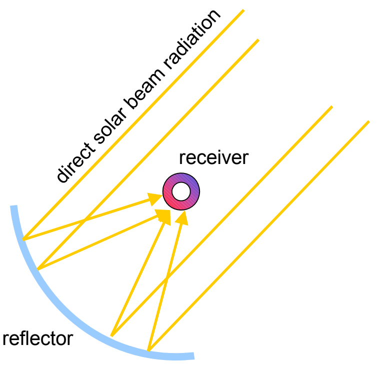
2.2.2 The technology

Figure 2.4 shows the principle of a Concentrating Solar Collector and of a Concentrating Solar Thermal Power Station. The CSP performance model considers current oil-cooled parabolic trough technology with molten salt storage and a steam cycle power block with a dry cooling tower as the reference. Today, CSP plants without thermal energy storage at sites with annual DNI higher than 2000 kWh/(m² · yr) would have capacity factors of 20 to 25%, equivalent to about 2000 full load operating hours per year, with the perspective to expand their time of solar operation to base-load using suitable thermal energy storage facilities and larger collector fields.

A standard solar field with solar multiple SM1 defines a collector field with an aperture area of 6000 m² per installed MW of power capacity. Each storage unit has a capacity of 6 full load operating hours. For REACCESS analysis, a CSP plant with a solar multiple 4 was assumed as the future technology having a 4 x 6000 = 24,000 m²/MW solar field aperture area and thus in addition 3 x 6 = 18 hour's storage capacity. This model considers current technologies with an annual net solar electric efficiency of 12% as reference. An overall land use efficiency of 4.5% was assumed referring to a typical parabolic trough power station with respect to the solar energy irradiated per year on the total land surface required by the plant. The cost of concentrating solar power plants was modelled as function of time individually for the different components of such plants. For each component (solar field, power block, storage), a separate learning curve and progress ratio for future cost development is assumed.

Figure 2.5 shows overall learning curves for the investment of CSP plants and resulting electricity costs as function of DNI for CSP reference plants with SM4. For a DNI of 2700 kWh/m² per year, resulting levelised CSP electricity production costs are decreasing from 14 €ct/kWh to 5.5 €ct/kWh.

A more detailed technical note documents approach and data base which were used for the identification and characterisation of potentials and corridors provided for REACCESS (Trieb et al., 2009).



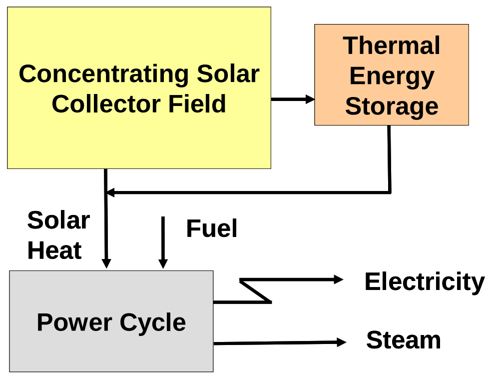
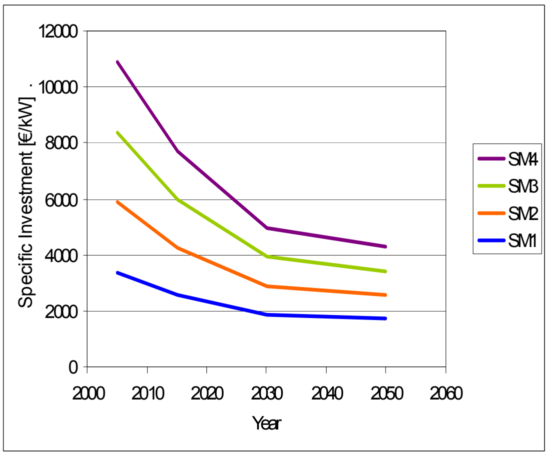


Figure 2.4: Principle of a concentrating solar collector (left) and of a concentrating solar thermal power station for co-generation of electricity and process steam (right).



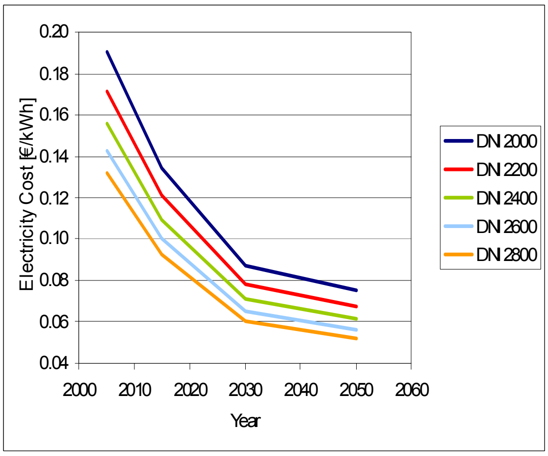


Figure 2.5: Learning curves for the investment of CSP plants as function of the solar multiple until 2050 (left) and resulting electricity costs in €/kWh as function of DNI in kWh/(m² · yr) for CSP reference plants with SM4 (right).

2.2.3 The energy potentials

Table 2.5 summarises identified solar power resources and power generation potentials of possible energy supply countries in the MENA region. The technical potential for CSP generation is huge and only a small portion would be required to satisfy a significant fraction of the electricity demand in EU27+.

Table 2.5: Summary of identified solar power resources and power generation potentials in energy supply regions.

Country/region	Resources calculated (suitable land area)	Unit	Technical power generation potential calculated	Unit
Morocco	171,724	km²	19,915	TWh/yr
Algeria	1,422,344	km²	168,336	TWh/yr
Tunisia	79,761	km²	8,597	TWh/yr
Libya	1,184,870	km²	138,303	TWh/yr
Egypt	598,439	km²	72,840	TWh/yr
Jordan	59,315	km²	6,394	TWh/yr
Saudi Arabia	1,149,927	km²	123,296	TWh/yr
Total	**4,666,380**	**km²**	**537,680**	**TWh/yr**

The current development of CSP projects is very dynamic and therefore difficult to assess. At the end of 2008 commercial plants with a capacity of about 482 MW were in operation of which almost 419 MW was installed in the USA, 63 MW in Spain and another 0.36 MW in Australia. The most frequently used concept is parabolic trough mirrors, except a tower project in Spain with 11 MW, a Fresnel reflector system with 2 MW in Spain and another one in Australia with 0.36 MW.

As the use of renewable energies became more important in the recent years and several governments adopted promotion schemes, the use of CSP is experiencing a revival. In 2007 three installations with a total capacity of about 75 MW went into operation followed by another installation with 52 MW in 2008. Another 16 projects were under construction at the end of 2008 adding up to a capacity of 540 MW. Again Spain with 389 MW and the USA with 86 MW are the largest contributors to this development. The remaining projects are being constructed in Egypt (25 MW), Algeria (20 MW) and Morocco (20 MW). Overall, 5975 to 7415 MW of planned capacity of CSP plants could be identified on a project level that was announced up to the end of 2008. The countries that account for the majority of these projects are once again the USA and Spain.

2.3 Coal

2.3.1 Introductory remarks

As an important input to the European transformation sector, Europe had to import about 200 million tonnes of coal in 2005. Hard coal imports correspond to more than 80% of coal consumption (see Figure 2.6). This ratio is rising since the end of the 70s. Import dependency increased with a decreasing domestic coal production. Coal imports increased in particular from former Soviet republics, while imports from the United States decreased steadily over time.

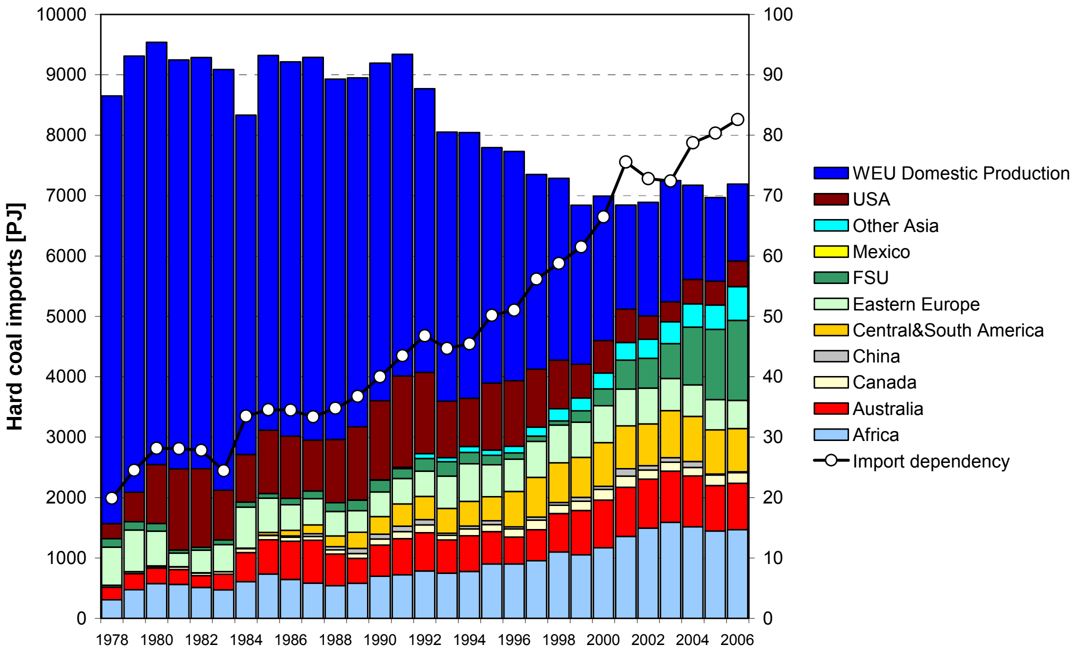


Figure 2.6: Development of European Coal Imports [source (IEA, 2007a)].

South Africa is the most important coal supplier to the European Union with 51 Mt, followed by Russia with 47 Mt, Australia with 27 Mt and Colombia with 23 Mt. These four countries make up about three quarters of all European coal imports (see Figure 2.7).

2.3.2 Identified resources

Table 2.6 lists identified main coal resources of the world based on work done by Remme et al. (2007). The Table provides proven reserves and location of the fields. Main European resources are located in Czech Republic, Poland and Germany. Largest global reserves are located in USA, Russia, Australia, China, Japan, and South Africa.

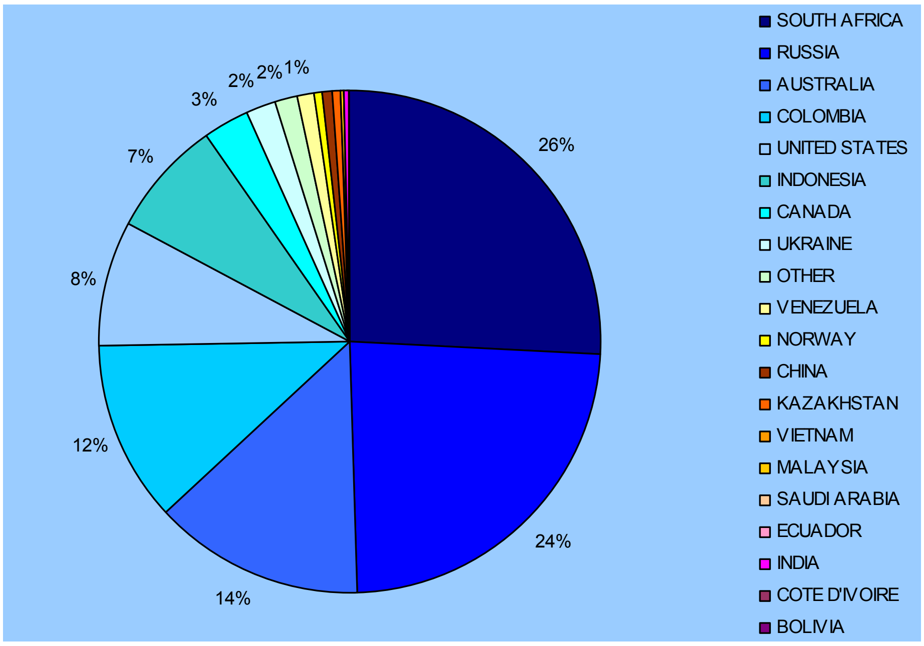


Figure 2.7: Origin of coal imports to EU27 in 2005 [source (Eurostat, 2008a)].

Table 2.6: Summary of identified coal resources.

World region	Country/region	Field location	Proven reserves
			GJ
AFR_P	Nigeria, Nassarawa	Lafia-Obi area	4.56E+09
AFR_N	South Africa, Mpumalanga province	Karoo basin	1.24E+12
AUS	Australia, New South Wales	Singleton	1.61E+12
AUS	Australia, Queensland	Moranbah	1.61E+12
CAN	Canada	British Columbia Vancouver	9.03E+10
CHI	China, Shanxi	Shenhua	2.52E+12
CSA_P	Venezuela	Guasare	1.26E+10
CSA_N	Colombia	La Guajira - El Cerrejón	3.58E+11
EUR	Czech Republic	Ostrava-Karvina Basin	3.17E+11
EEU	Poland	Upper Silesian Basin	3.17E+11
EUR	Germany, North Rhine-Westphalia	Ruhr Basin	9.99E+09
JPN	Japan, Kyûshû	Karatsu	2.20E+12
IND	India, West Bengal	Raniganj	8.85E+09
MEA_P	Iran, Alborz	Tazreh	1.02E+10
MEA_N	Turkey	North-West Anatolia Zonguldak	2.52E+10
MEX	Mexico, Coahuila	Sabinas-Saltillito-Monclova basin	2.16E+10
ODA_P	Indonesia, Kalimantan	Barito basin	6.51E+10
ODA_N	North Korea	Pyongyang Province	1.05E+11
RUS	Siberian Federal District Novosibirsk	Kemerovo, Kuznetsk Basin	3.54E+12
SFS	Kazakhstan, Pavlodar	Karaganda Basin	7.10E+11
UBM	Ukraine, Donets Basin	Donets Basin	4.03E+11
USA	USA, Pennsylvan., Appalachian region	Lackawanna county	6.13E+12

2.4 Biomass

2.4.1 Introductory remarks

The literature shows a large range of worldwide bio-energy potentials (e.g. from 34 to almost 3600 Mha (Mega hectares) suitable land area and from 0 to almost 1300 EJ crop potential), dependent on many assumptions possible for such an evaluation:

- Agriculture and animal system production, having an impact on the yields: level of mechanised agriculture systems, optimised varieties with higher harvest indexes or not, irrigation or not, level of utilisation of fertilisers and pesticides, landless industrial animal production system
- Factors having an impact on the yields and the energy content: type and size of land considered such as arable, grassland, fallow, set-aside, marginal/degraded land; Type of biomass and conversion technologies (secondary generation or not)
- Food and feed demands: population growth and eating patterns.

Behind these factors lie two major aspects. On one hand, the demand for food (and therefore, the demand for feed), which must be satisfied first. On the other hand the sustainability of the biomass production that is now at the heart of the debate about the use of bio-energy. The recognized sustainability issues which might modify the total available potentials are deforestation, biodiversity, greenhouse gas emissions, quality and erosion of the soils, nutrient, pesticides and water scarcity.

2.4.2 The evaluation of the biomass potentials

The evaluation of the biomass potentials for REACCESS was based on the work done with Quickscan by Smeets et al. (2004, 2007). Initially, a new database developed by the International Institute for Applied Systems Analysis (IIASA - Agro-Ecological Zones system) should have been used for REACCESS as this source was already used for EU27 in the previous panEU27 (PET) model and an upgrading on global scale was expected by the end of January 2009. However, given some delay in the delivering of these data, it was decided to use the second best source of information, based on the works done by Smeets. The estimated biomass resources cover the following categories (organic urban wastes were not included because of the lack of data):

- dedicated bio-energy crops from surplus agricultural land (cropland & pastures, after satisfaction of food & feed);
- agricultural and forestry residues and waste;
- forest growth potential, including wood fuel.

The lowest scenario for energy crops proposed by Smeets et al. was used, given the very optimistic technology assumptions presumed by the authors. One prerequisite for the availability of the bio-energy potentials identified by the authors is the implementation of improved agricultural practices, agricultural management systems and technologies, what might be unrealistic in some developing countries. The scenario does not require irrigation. This represents a possible criterion regarding the sustainability assessment of energy crops.

The crop potentials were divided in two categories in order to represent the part of the resources which is possibly located far from consumption centres and which is therefore more expensive. A second scenario for energy crops with lower potentials is also proposed, based on some evaluations from VTT (Lehtila, 2009, based on Pahkala, 2009, and Hoogwijk, 2004).

As regards the surplus forest growth potential, the ecological potential defined by Smeets et al., is used, including sustainability criteria. The data were reallocated to the world regions in the TIAM model based on the land use database of the FAO (FAOSTAT, http://faostat.fao.org/site/377/default.aspx#ancor) according to the following assumptions:

- **Crops potentials**: split according to the agriculture land.
- **Agriculture and forestry residues**: split according to the agriculture and forest land.
- **Forest growth**: split according to the forest land.

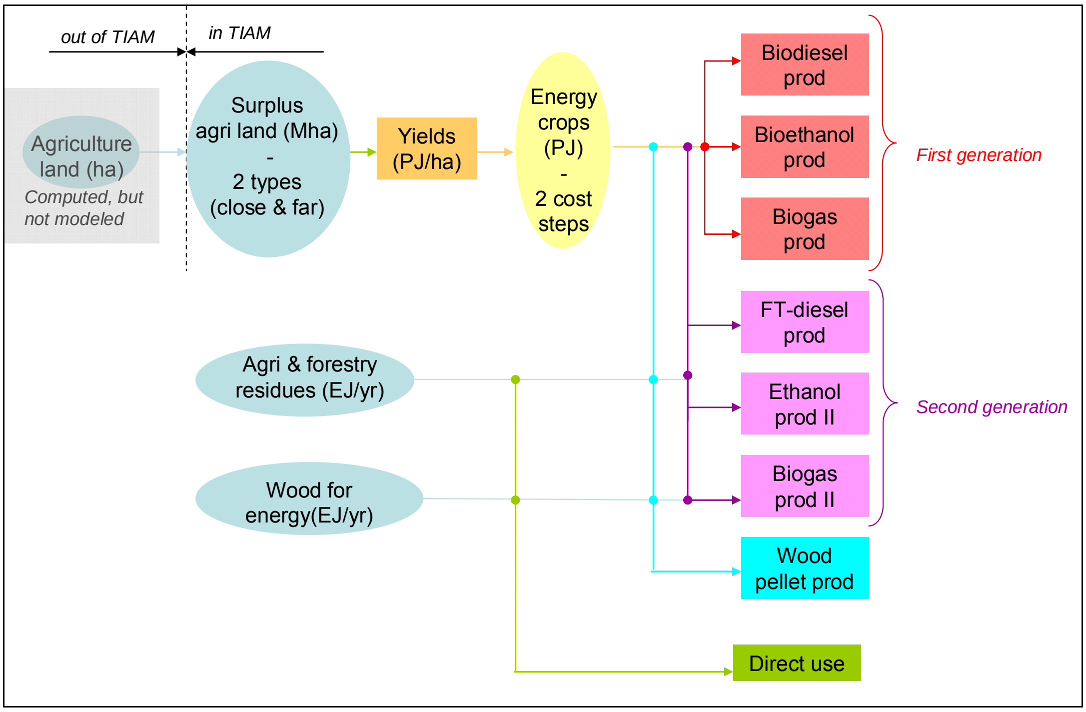


Figure 2.8: Overview of the biomass structure.

Current productions and installed capacities of biomass plants for the production of biodiesel, bioethanol and wood pellets were collected using different official sources. The production data is annual, and the capacity is provided at the beginning of the year when the data were available. Data are provided for recent years, given the rapid changes observed from one year to another.

Most important collected data are presented in Table 2.7 and Table 2.8 below for the world regions. Some differences exist between the installed capacities included in the PET model and the ones found in the literature. Some corrections might be required in the PET.

Table 2.7: Summary of identified biomass resources for TIAM world regions (part 1).

	Agricultural surplus land (Mha)				Agricultural and forestry residues energy potential	Total wood resources available for energy
	Total	***Ratio wrt total agri land***	**<200 km**	**>200 km**	**2050* (EJ/yr)**	**2050* (EJ/yr)**
AFR	104	*10%*	79.4	24.6	15	4.3
AUS	216	*45%*	126.4	89.6	2	0.1
CAC	58.4	*20%*	43.5	14.9	0.7	0
CAN	7.6	*11%*	4.5	3.1	2.4	0.6
CHI	14.9	*2%*	13.6	1.3	3.8	7.3
CSA	129.3	*20%*	93.3	36.0	9.9	7.9
IND	29	*16%*	29.0	0.0	5.7	3.8
JPN	0	*0%*	0.0	0.0	0	0
MEA	23	*5%*	22.9	0.1	0	0.3
MEX	22.7	*20%*	21.8	0.9	1.1	0.6
ODA	7	*15%*	6.7	0.3	1.4	0.7
OEE	10.5	*20%*	10.5	0.0	0.1	0
RUS	43	*20%*	28.1	14.9	2.2	0.1
SKO	0	*2%*	0.0	0.0	0.1	0.02
USA	46.4	*11%*	35.2	11.2	4.6	0.6
EUR	17.1	*8%*	17.1	0.0	4	1.6
World	**728.9**	***15%***	**532.1**	**196.8**	**53**	**28**

It is proposed to use and transfer to TIAM the biomass conversion technologies and their characterisations included in the PET model. Figure 2.8 provides an overview on the approach and data structure used for the representation of biomass resources and production in the TIAM model.

Table 2.8: Summary of identified biomass resources for TIAM world regions (part 2).

	Energy crop potential in 2050** (EJ/yr)			Alternative potential for energy crops (Lethila, 2009) (EJ/yr)			
	Total	**<200 km**	**>200 km**	**2010**	**2020**	**2050**	**2100**
AFR	31	23.7	7.3	0.2	3.1	9	15
AUS	38	22.2	15.8	0	2.4	13	16.6
CAC	23.3	17.3	6	0.2	6.6	28.7	29.6
CAN	2.8	1.7	1.1	0	1.4	6	9
CHI	10.9	10	0.9	0.2	2.1	5	6
CSA	40	28.9	11.1	2.7	9.6	17	22
IND	12.1	12.1	0	0.2	1.9	5	7
JPN	0	0	0	0	0	0.1	0.1
MEA	2	2	0	0	0.4	1	1.5
MEX	7	6.7	0.3	0	0.7	2	3
ODA	3	2.9	0.1	0.8	3.1	6	6.5
OEE	4.2	4.2	0	0.0	1.2	5.2	5.3
RUS	17.1	11.2	5.9	0.1	4.9	21.1	21.8
SKO	0	0	0	0	0	0.1	0.1
USA	17.2	13	4.2	0.7	6.9	16.4	22
EUR	8.4	8.4	0	0.0	0.1	0.5	0.5
World	**217**	**164.3**	**52.7**	**5.3**	**44.6**	**136**	**166**

* More details about 2005 and 2100 potentials in the Technical Note 3.4.1 (CIEMAT, 2009).

** Potentials in 2100 considered the same as 2050. Based on (Smeets et al., 2004, 2007). More details in the Technical Note 3.4.1 (CIEMAT, 2009).

2.5 Nuclear fuels

2.5.1 Introductory remarks

The full nuclear chain involves several processes, starting from the uranium ore resource availability. The most important are:

- **mining, milling** and **refining** of the uranium ore, **conversion** to UF_6, **enrichment** (for LWR) and **fuel fabrication** (in the so-called **front end** section);
- loading, consumption and unloading (**power plant operating** sector):
- **spent fuel management** in open or closed cycles; in the former option the nuclear wastes are treated and sent to a geologic repository; in the latter option, the spent fuel assemblies are reprocessed and the material is recovered and reused for particular types of fuel elements (MOX) (in the so-called **back end** section)

Since all the uranium resources needed for the supply of the EU nuclear chain are located outside Europe and imported as yellowcake, the primary production processes that include **mining**, **milling** and **refining** of the uranium ore are also located outside of Europe.

The **conversion** to UF_6, the **enrichment** (for LWR fuel elements) and the **fuel element fabrication** are generally made inside EU: the conversion facilities are located at Pierrelatte (France) and Springfields (UK).

The EU gaseous diffusion enrichment facility is located at Tricastin (France), while the centrifuge technique ones are located at Capenhurst (UK), Tricastin and Pierrelatte (France), Almelo (The Netherlands) and Gronau (Germany).

The EU fuel fabrication facilities are located at Romans-sur-Isère (France), Dessel (Belgium), Lingen (Germany), Västerås (Sweden), Juzbado (Spain) and Springfields (UK) for LWR and AGR; VVER plants (in Slovakia, Bulgaria, Finland, Poland) are fuelled by Russian fuel fabrication facilities. The Romanian CANDU fuel elements are fabricated in Romania, while the Lithuanian RBMK fuel elements are fabricated in Russia.

The EU reprocessing facilities are located at Sellafield (UK) and La Hague (France), where also non-EU spent fuel elements are treated (the resulting products are sent back to the owners).

As a consequence, the “corridors” related to the nuclear cycle involve the transportation of several materials from outside and inside EU27+. In the present phase of the REACCESS project, only the yellowcake import is taken into consideration.

2.5.2 Resources

Uranium is ubiquitous on the Earth and it is a constituent of most rocks and even of the sea. The major primary ore mineral is uraninite (basically UO_2) or pitchblende ($U_2O_5.UO_3$, better known as U_3O_8), though a range of other uranium minerals is found in particular deposits).

Some typical concentrations are: (ppm = parts per million)

Very high-grade ore (Canada) - 20% U 200,000 ppm U
High-grade ore - 2% U, 20,000 ppm U
Low-grade ore - 0.1% U, 1,000 ppm U
Very low-grade ore* (Namibia) - 0.01% U 100 ppm U
Granite 4-5 ppm U
Sedimentary rock 2 ppm U
Earth's continental crust (average) 2.8 ppm U
Seawater 0.003 ppm U

Where uranium is at low levels in rock or sands (less than 1,000 ppm), it needs to be in a form which can be easily separated for those concentrations to be called "ore", implying that the uranium can be recovered economically. This means that it needs to be in a mineral form that can be easily dissolved by sulphuric acid or sodium carbonate leaching.

Three categories of uranium resources are used to reflect differing levels of confidence in the resources reported: **reasonably assured resources (RAR), estimated additional resources (EAR),** and **speculative resources (SR)** are described below.

Reasonably assured resources (RAR): The uranium that occurs in known mineral deposits of such size, grade, and configuration that they could be recovered within the given production cost ranges, with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of deposit characteristics. RAR correspond to US - Department of Energy's uranium reserves category.

Estimated additional resources (EAR): The uranium in addition to RAR that is expected to occur, mostly on the basis of direct geological evidence, in extensions of well-explored deposits, little explored deposits, and undiscovered deposits believed to exist along well-defined geological trends with known deposits, such that the uranium can subsequently be recovered within the given cost ranges. Estimates of tonnage and grade are based on available sampling data and on knowledge of the deposit characteristics, as determined in the best-known parts of the deposit or in similar deposits. EAR correspond to US DOE’s probable potential resources category.

Speculative resources (SR): Uranium in addition to EAR that is thought to exist, mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. The locations of deposits in this category can generally be specified only as being somewhere within given regions or geological trends. The estimates in this category are less reliable than estimates of RAR and EAR. The category of SR corresponds to US DOE’s possible potential resources plus speculative potential resources categories combined.

The natural uranium concentrate takes its name (**yellowcake)** from its colour and texture; typically contains 70 to 90% U_3O_8 by weight. It is used as feedstock or uranium fuel enrichment and fuel pellet fabrication.

At world level about 2.3 million tons of uranium has already been produced since 1945. Discovered available reasonably assured resources are somewhere between 1.9 and 3.3 million tons, dependent on the cost class. Estimated additional resources (with lower data quality) are between 0.8 and 1.4 million tons.

Among other criteria, the ore grade plays an important role in determining whether uranium can be easily mined or not. The energy demand for the uranium extraction increases steadily with lower ore concentrations.

Today only one country, Canada, has reasonable amounts with an ore grade larger than 1%. The Canadian reserves amount to about 400 kt of uranium with highest concentrations of up to 20%. About 90% of world wide resources have ore grades below 1%, more than two thirds below 0.1%

Over the last decades several countries have already exhausted their uranium resources: Germany, the Czech Republic, France, Congo, Gabon, Bulgaria, Tajikistan, Hungary, Romania, Spain, Portugal and Argentina. The remaining resources with highest probability are in Australia, Canada and Kazakhstan which together contain about 2/3 of these resources below 40 $/kgU extraction cost.

At present, the production falls short of demand by about 25 kt/yr. This gap was closed with uranium drawn from stockpiles.

A significant amount of the uranium is mined as by-product of the mining of gold, copper or other minerals (e.g. in South Africa), but most reservoirs contain only uranium. At these mines the mining effort increases dramatically with decreasing ore grade due to the amount of material to be processed and the uranium losses during the separation.

Below a certain ore grade (Life Cycle energy balance estimates are around 0.02 to 0.01%) the net energy balance becomes negative.

Known recoverable resources of uranium are estimated at more than 4.7 million tonnes of U, distributed as reported in Table 2.9.

2.5.3 Production technologies, capacities and costs

Presently, the main operating uranium mines are located in Australia, Canada, Niger and Namibia. The ten largest uranium mines in the western world are listed in Table 2.10.

Table 2.9: World distribution of U resources.

Country	**Resources (tU)**	**Share (%)**
Australia	1,143,000	24
Kazakhstan	816,000	17
Canada	444,000	9
USA	342,000	7
South Africa	341,000	7
Namibia	282,000	6
Brazil	279,000	6
Niger	225,000	5
Russian Federation	172,000	4
Uzbekistan	116,000	2
Ukraine	90,000	2
Jordan	79,000	2
India	67,000	1
China	60,000	1
Other	287,000	6
World total	**4,743,000**	

(Reasonably Assured Resources plus Inferred Resources, to US$ 130/kg U, 1/1/05, from OECD NEA & IAEA, *Uranium 2005: Resources, Production and Demand*)

Table 2.10: Main operating uranium mines.

Mine	Country	Main owner	Mine type	Capacities (tU/yr)	Share (%)
McArthur River	Canada	Cameco	underground	7,200	17.3
Ranger	Australia	Rio Tinto	open-pit	5,006	12.0
Olympic Dam	Australia	BHP Billiton	by-product (copper) underground	3,688	8.9
Rössing	Namibia	Rio Tinto	open-pit	3,147	7.6
Rabbit Lake	Canada	Cameco	underground	2,316	5.5
McClean Lake	Canada	Areva	open-pit	2,121	5.1
Akouta	Niger	Areva	underground	1,778	4.3
Arlit	Niger	Areva	open-pit	1,315	3.2
Beverley	Australia	Heathgate Res	ISL	825	2.0
Vaal River	South Africa	Anglogold Ashanti	by-product (copper) underground	674	1.6
Total				**28,061**	**67.5**

The **primary production** of uranium materials involves three types of technological approaches:

In **open-pit mining**, overburden is removed by drilling and blasting to expose the ore body which is mined by blasting and excavation via loaders and dump trucks. Water is extensively used to suppress airborne dust levels.

Underground uranium **mining** is in principle no different to any other hard rock mining and other ores are often mined in association (copper, gold, silver). Different methods can be used: “cut and fill”, “open stopping”, shrinkage” and “room and pillar”. Waste rock is produced during open-pit mining when overburden is removed, and during underground mining when driving tunnels through non-ore zones. In some cases uranium has been removed from this low-grade ore by heap leaching. The leaching liquid (often sulphuric acid) is introduced on the top of the pile and percolates down until it reaches a liner below the pile, where it is caught and pumped to a processing plant.

In-situ leaching (ISL) is performed by pumping liquids (weak acid or weak alkaline dependent on the calcium concentration in the ore) down through injection wells placed on one side of the deposit of uranium, through the deposit, and up through recovery wells on the opposing side of the deposit - recovering ore by leaching.

2.5.4 Available information on costs

Information about the costs of the single segments of the front end uranium supply chain (ore exploration, primary and secondary productions and transportations from mine sites to open sea shipping facilities) are available in special literature but, generally, are incomplete or not homogeneous.

2.6 Hydrogen

2.6.1 Introductory remarks

Hydrogen is one of the best choices when it comes to the storage of electricity from fluctuating sources or when the primary fuel has such low energy content in terms of MJ per unit of volume that its transportation over long distances has proven inefficient.

2.6.2 The energy sources

Starting from the work done by the hydrogen task group in the ENCOURAGED project, four energy sources were identified as consistent with REACCESS purpose of analysing hydrogen supply corridors from outside EU into EU. They are: lignite, biomass, solar power and wind power.

Lignite reserves exist in different areas of the world: among them, the Ukraine reserves were chosen as they are one of the largest in a region adjacent to the EU. Proven recoverable reserves of lignite in Ukraine total about 2 billion t.

Table 2.11: Summary of identified lignite potential, production quantities and capacities in the identified supply region (Ukraine).

	Resources identified			Primary production - lignite		
TIAM Region	**Resources proven**	**Resources probable/ possible**	**unit**	**Quantity in 2005**	**Capacity in 2005**	**unit**
Other East European countries	1940	2893	Mt	360	360	kt/yr

The area where lignite mines are more concentrated is the Donetsk basin. The production capacity of the area, according to data from (IEA, 2005b) and (WEC, 2007), is assumed to be 360 kt/yr (2005 reference data) and it has constantly decreased in the last years. It can be assumed that for the years when hydrogen is expected to affirm, lignite production in the region will set at about 300 kt/yr. To avoid long distance inefficient transportation, lignite can be gasified. Only the more precious product of the gasification process, hydrogen, would then be delivered to the final EU users.

Hydrogen (H_2) can be separated, purified, compressed and shipped via pipeline towards its final destination. A gasification plant which can process the present Ukrainian lignite annual production is described by cost and performance data listed in Table 2.12.

Table 2.12: Parameters for gasification plant (Wietschel et al., 2006).

Parameter	Unit	Value
Capacity	MW (H_2)	100
Investment cost	€/MW (H_2)	1000
Lifetime	years	20
Efficiency	%	56
Utilisation factor	hours/yr	8000
O&M costs	% investment	2

Concerning **biomass** potential in countries adjacent to EU27+ area, as stated in the ENCOURAGED project, Turkey represents an interesting option.

Table 2.13: Summary of identified biomass potential, production quantities and capacities in the identified supply region (Turkey).

	Resources		Primary production - biomass				
TIAM Region	**Potential**	**unit**	**Quantity in 2005**	**Capacity in 2005**	**Capacity growth**	**Import to EU27+ in 2005**	**unit**
Middle East countries	174,000	GWh/yr	87,000	87,000	0	0	GWh/yr

The reported potential at year 2020 is estimated at around 174,000 GWh (Wietschel et al., 2006), mainly consisting of agricultural production and residues. However in (Ozturk & Bascetincelik, 2006) a fairly low value was obtained as the energy content of agricultural residues, namely around 84,000 GWh, from field crop and fruit residues (reference years 2002-2003). In REACCESS it is made the assumption that the supposed annual resource used for the hydrogen corridor capacity from Turkey towards the EU equal to about 87,000 GWh, that is one half of the projected potential in ENCOURAGED. Biomass is spread throughout the country and it seems reasonable to foresee a distributed generation network for hydrogen, locating medium-size steam reforming plants in barycentric areas. A network of 100 plants with a capacity of 50 MW (H_2) is envisaged. The assumed parameters for the steam reforming plants are listed in Table 2.14.

Table 2.14: Parameters for the steam reformer plant (Wietschel et al., 2006) (except for the efficiency figure).

Parameter	Unit	Value
Capacity	MW (H_2)	50
Investment cost	€/MW (H_2)	2000
Lifetime	years	20
Efficiency	%	40
Utilisation factor	hours/yr	8000
O&M costs	% investment	3

One of the most looked after future **solar power** basins for Europe is Algeria, which has in excess of 2,300,000 km^2 of irradiated land. The ENCOURAGED project foresaw the exploitation of about 1/10,000 of the Algerian land area for installing solar power plants (about 195 km^2) for hydrogen production. This is also the resource allocated also for the REACCESS project.

It was chosen to locate the hydrogen production plant next to Chott Ech Chergui, a large endorheic salt lake situated in the Saharan Atlas. According to DLR (Trieb et al., 2009) evaluations, the chosen area has a DNI ranging from 2100 to 2250 kWh/(m^2 · yr).

Table 2.15: Summary of identified solar power potential, production quantities and capacities in the identified supply region (Algeria).

	Resource - Land		Primary production – thermal energy				
TIAM Region	**Potential**	**unit**	**Quantity in 2040**	**Capacity in 2040**	**Capacity growth**	**Import to EU27+ in 2005**	**unit**
Africa	195	km^2	40,950	40,950	0	0	GWh/yr

It can be assumed that central receiver solar towers should be installed in the area, with a land use factor comprised between 20 and 25%. Thus, the solar energy really incident on the plant can be quantified as about 82,000 to 102,000 GWh/yr. For central receiver towers, the reported efficiency of the “thermal” section is between 40 and 45%. The potential thermal energy which can be used for thermo-chemical water splitting then, from the considered area, would be about 33,000 to 46,000 GWh/yr.

Hydrogen could be produced by thermo-chemical water-splitting, a chemical process that features the multi-step decomposition of water. Water and heat are the inputs; hydrogen and oxygen are the only outputs (see Annex I for detail). Main parameters assumed for the thermo-chemical systems are listed in Table 2.16.

Table 2.16: Parameters for the thermo-chemical water splitting plant (Abanades et al., 2006, Viebahn et al., 2008).

Parameter	Unit	Value
Capacity	MW (H_2)	143
Investment cost	€/MW (H_2)	5.6
Lifetime	years	20
Efficiency	%	40-50
Utilisation factor	hours/yr	6230

The ENCOURAGED project envisaged a huge potential for **wind power** off the coast of Morocco. The area allocated for electricity production from a wind farm should be 10 km wide and 2000 km long. According to measurements of the wind force in that area, the project evaluated the average potential of the area as ranging between 0.1 and 0.15 $TWh_{el}/(km^2 \cdot yr)$. Assumptions detailed in the report (Wietschel et al., 2006) led to the final quantification of an electricity production potential of about 148,600 GWh_{el}/yr. For the REACCESS project, using the criterion of competitiveness among technologies, one quarter of the total was used. Thus the total electric energy available per year for hydrogen production is about 24,700 GWh_{el}/yr. The wind farm should be linked to the coast with a submarine DC cable.

Table 2.17: Summary of identified wind power potential, production quantities and capacities in the identified supply region (Morocco).

	Resource – sea surface		Primary production – electricity				
TIAM Region	**Potential**	**unit**	**Quantity in 2040**	**Capacity in 2040**	**Capacity growth**	**Import to EU27+ in 2005**	**unit**
Africa	20,000	km^2	36,000	36,000	0	0	GWh/yr

Once electricity is transported to the Moroccan coast, it can be supplied to an electrolysis plant. Considering the huge amount of electricity dedicated to the production of hydrogen, it is foreseeable the creation of a cluster (35 units) of electrolysers in the shipping area or in the area where the DC cable approaches the coast. The parameters assumed for one module of the cluster are resumed in Table 2.18.

Table 2.18: Parameters for the electrolyser (Wietschel et al., 2006).

Parameter	Unit	Value
Capacity	MW (H_2)	200
Investment cost	€/MW (H_2)	0.4
Lifetime	years	15
Efficiency	%	70
Utilisation factor	hours/yr	3000
O&M costs	% investment	1.5

Table 2.19 shows a summary of calculated results for identified hydrogen resources, production quantities and capacities in energy supply regions. Predominantly renewable sources may have a high potential for hydrogen import to EU27+. Total hydrogen import potential calculated is about 278 PJ/yr which corresponds to 0.6% of the total final energy demand and 1.8% of the final energy demand for transport in EU27 in the year 2005.

Table 2.19: Summary of identified hydrogen resources, production quantities and capacities in energy supply regions.

	Primary production	Unit	Commodity delivered	Unit	Efficiency of the chain	Origin TIAM region	Percentage per origin
H_2 from lignite	5.1	PJ/yr	2.88	PJ/yr	56%	OEE	1%
H_2 from biomass	313.8	PJ/yr	125.50	PJ/yr	40%	MEA	45%
H_2 from solar power	368.6	PJ/yr	58.97	PJ/yr	16%	AFR	54%
H_2 from wind power	129.6	PJ/yr	90.72	PJ/yr	70%		
Total	**817.0**	**PJ/yr**	**278.05**	**PJ/yr**	**34%**		

3 IMPORT CORRIDORS AND INFRASTRUCTURES

The following Chapter provides a description of overall methodological aspects, assumptions and main references used for the identification and characterisation of EU import corridors for each commodity. Results in terms of number and capacity of corridors are summarised in Tables; more detailed information can be found in the Annex II. The main characteristics of the transport technologies involved are also presented.

3.1 Oil and natural gas

The import routes are divided into captive corridors represented by oil and gas pipelines and open sea corridors represented by ship transportation of liquefied natural gas (LNG), crude oil or refined products.

3.1.1 Captive corridors

The **captive oil corridors** are oil pipelines from Central Asian Countries (CAC) and Russia to EU and the oil pipelines from North Sea and from Africa to EU. The Kazakh oil is also exported by rail and by pipeline to Russia and China. The information was derived from (EIA, 2008a). The Caspian Pipeline consortium exports oil from Kazakhstan to the Russian Black Sea port of Novorossiysk and has a maximum capacity of 800 kb/d. The Atyrau-Samara pipeline exports Kazakh oil to Russia and has a capacity of 600 kb/d. Azerbaijan exported in 2007 about 730 kb/d of oil, mainly by the Baku-Tblisi-Ceyhan pipeline to Turkey via Georgia. **Norpipe** oil is the main oil pipeline from Norway to EU. The pipeline was commissioned in 1975 with a design capacity of 900 kb/d. The operating capacity in 2005 was 810 kb/d (NPD, 2005).

The **captive natural gas corridors** are divided into pipelines from Africa, pipelines from Russia, pipelines from CAC and pipelines from Norway. Figure 3.1 illustrates the natural gas pipelines from North Africa to Europe where the dotted pipelines indicate planned/ foreseen pipelines.

There are three existing export pipelines from Africa and two additional pipelines are planned/ under construction. The **Transmed** pipeline, with a capacity 24 bm^3/yr, transports gas from Algeria via Tunisia to Italy and Slovenia (Hayes, 2004). The **MEG** pipeline, with a current capacity 12 bm^3/yr, transports gas from Algeria to Spain and Portugal via Morocco (Hayes, 2004). The **Greenstream** pipeline, with a capacity of 8 bm^3/yr, transports gas from Libya to Italy (Eni, 2008). The **GALSI** pipeline, planned to be commissioned in 2012, will export around 8 bm^3/yr from Algeria to Italy via Sardinia (Sonatrach, 2006). The **MEDGAZ** pipeline, expected to start-up 2009, will export 8 bm^3/yr from Algeria to Spain (Sonatrach, 2006).

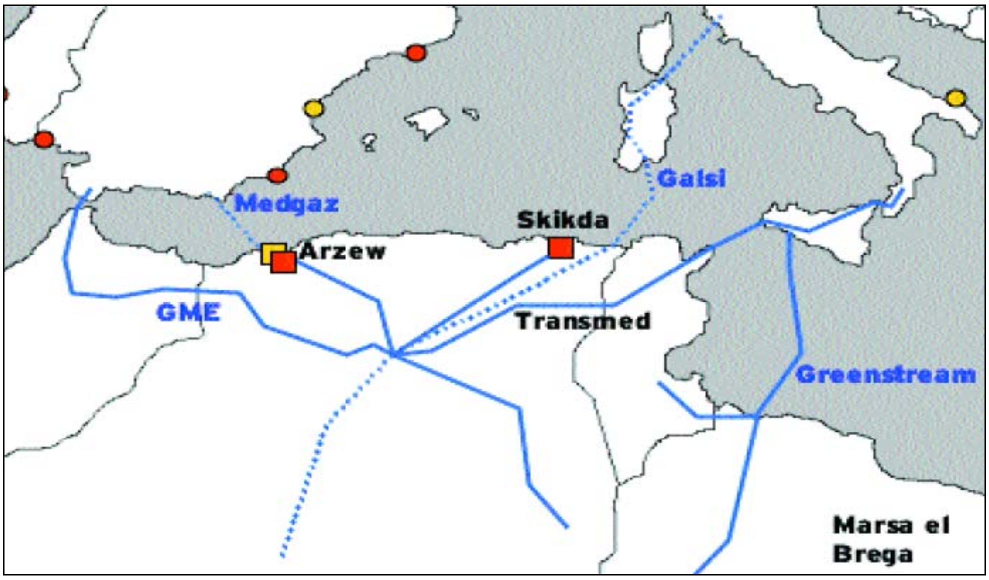


Figure 3.1: Natural gas pipelines from North Africa to Europe (Kingston, 2004).

Russia is the largest exporter of natural gas to the EU, supplying 161.5 bm^3/yr in 2006 (Gazprom, 2008). The majority of Russian gas is transported by pipeline. Germany was the largest importer of Russian gas in 2006 with 34.4 bm$^{3/}$yr (Gazprom, 2008). The existing pipelines with export capacities to the EU are **Yamal** to Poland (33 bm^3/yr), Brotherhood to Slovakia (30 bm^3/yr), **Northern Lights** to Slovakia (28 bm^3/yr) and **Blue Stream** to Turkey (16 bm^3/yr). Figure 3.2 illustrates the full system of Russian-EU corridors.

Figure 3.2: Primary oil pipelines from Russia to EU.

Figure 3.3 illustrates the planned offshore Nord Stream pipeline from Russia to Germany. The pipeline with planned start-up in 2012 will have a capacity of 55 bm^3/yr (**Nord Stream**, 2008). The ongoing work involves international consultants, national permit applications, detailed technical planning, financial concept and dialogue with authorities and the public in the Baltic Sea region.

Figure 3.3: Illustration of the Nord Stream pipeline (Nord Stream, 2008).

The natural gas export from CAC is primarily by pipelines. Figure 3.4 illustrates the Kazakhstan natural gas pipeline system. Major portions of the natural gas exported from Kazakhstan, Turkmenistan and Uzbekistan is transported to Russia via the **Central Asia-Center** (CAC) pipeline consisting of five parallel gas pipelines from the Kazakh-Uzbek border to the Russian compression station at Alexandrov Gay. The pipeline system was built from 1967 to 1986 with a design capacity 60 bm^3/yr. The actual capacity in 2008 was, however, no more than 47 bm^3/yr (Yenikeyeff, 2008). Refurbishment of the pipeline system started in 2004 and it is planned to be finished between 2012 and 2015 with the new capacity estimated to be up to 100 bm^3/yr (Yenikeyeff, 2009).

The main natural gas exports from Azerbaijan are transported by the **South Caucasus Pipeline** (SCP) to Turkey via Georgia. The pipeline started up in 2006 with an annual capacity 7 bm^3/yr (BP, 2008b).

There are no direct pipelines from CAC to EU. This situation will change if the **Nabucco** pipeline is implemented. This pipeline is planned to run from the Turkey-Iran and the Turkey-Georgia border to Austria with a capacity 31 bm^3/yr. Azerbaijan is the only country that has supplied gas to the pipeline (Nabucco, 2008).

There are seven natural gas pipelines from the Norwegian continental shelf to Europe; **Europipe I, Europipe II, Franpipe, Norpipe, Vesterled, Zeepipe** and **Langeled**. In 2005 and 2007, Norway exported 79.5 bm^3/yr and 86.1 bm^3/yr, respectively, by pipeline. The largest importing country in 2005 was Germany with 26.3 bm^3/yr followed by France with 14.2 bm^3/yr (NPD, 2005). Figure 3.5 illustrates the Norwegian natural gas pipeline network.

Figure 3.4: Kazakh natural gas pipeline infrastructure (Source: Kazakhstan Energy Ministry).

Figure 3.5: North Sea natural gas transport to Europe (NPD, 2005).

A list of identified captive oil and gas import corridors between supply countries and selected EU27 member states can be found in Annex II.

3.1.2 Open sea corridors

Open sea transport of oil is currently performed mainly by diesel fuelled tankers. In 2005, Russia exported 600 kb/d to Northern Europe and 700 kb/d to Southern Europe. Open sea export from Kazakhstan starts from the Aktau port of the Caspian Sea and ends at the Baku terminal in Azerbaijan, Naka in Iran and Makhachkala in Russia. Between 40 and 48 kb/d of oil from Kazakhstan is transported through the Caspian Sea to the Black sea ports of Georgia via Baku (Yenikeyeff, 2009). Norwegian open sea oil export has decreased during past years, 660 kb/d was exported in 2005 and 580 kb/d in 2007 (SSB, 2008). The United Kingdom is the largest importer of Norwegian oil, in 2007 about 30% of Norwegian oil tanker exports was imported by the UK (SSB, 2008).

Table 3.1 shows the export and import of oil and refined products in 2005. The Middle East is the largest oil exporter and the largest producer of oil and refined products and Asia Pacific is the largest importer of oil and refined products.

Table 3.1: Oil production, export and import by world region (BP, 2008a).
(figures are in kb/d)

Country/region	Production 2005	Export 2005	Import 2005
North America	9936	1681	10989
Latin America	10658	4157	657
Asia Pacific	7881	1209	14685
Africa	9835	6902	785
Middle East	25392	17329	205
Russia	9551		
Central Asian Countries	2134		
Former Soviet Union		5374	0

Open sea transport of LNG is mainly undertaken by fleet carriers. LNG carriers have historically used steam turbine propulsion fuelled by heavy fuel oil but recent engine technology has made diesel propulsion possible for LNG carriers. It is expected that more LNG ships will have diesel propulsion in the future. Shipping accounts for 10 to 30% of the delivered value of LNG (depending on distance between resource and market) compared to less than 10% for oil because of the high ship manufactory cost (Hayes, 2004). The average price of a new build LNG ship with a capacity of 150,000 m^3 increased from 1985 to 1995, decreased from 1995 to 2003 and increased again from 2003 to 2006. The cost was historically lowest in 2003 with 150 million US$ and highest in 1995 with 245 million US$ (UN, 2007).

Figure 3.6 shows the LNG export-import balance between different world regions 1998, 2005 and 2008. Asia Pacific and EU27+ are the largest importers of LNG from external regions. Asia Pacific region imported in 2005 43.8 bm^3/yr from external regions and 83.5 bm^3/yr was traded within the region. EU27+ imported 42.7 bm^3/yr in

2005, the major proportion of 35.2 bm^3/yr came from Africa. Africa is the world's largest producer of LNG and is the main exporter to EU27+ while the Middle East region is the main LNG exporter to Asia Pacific (BP, 2008a).

A list of identified open sea import corridors between supply countries and selected EU27 member states can be found in Annex II.

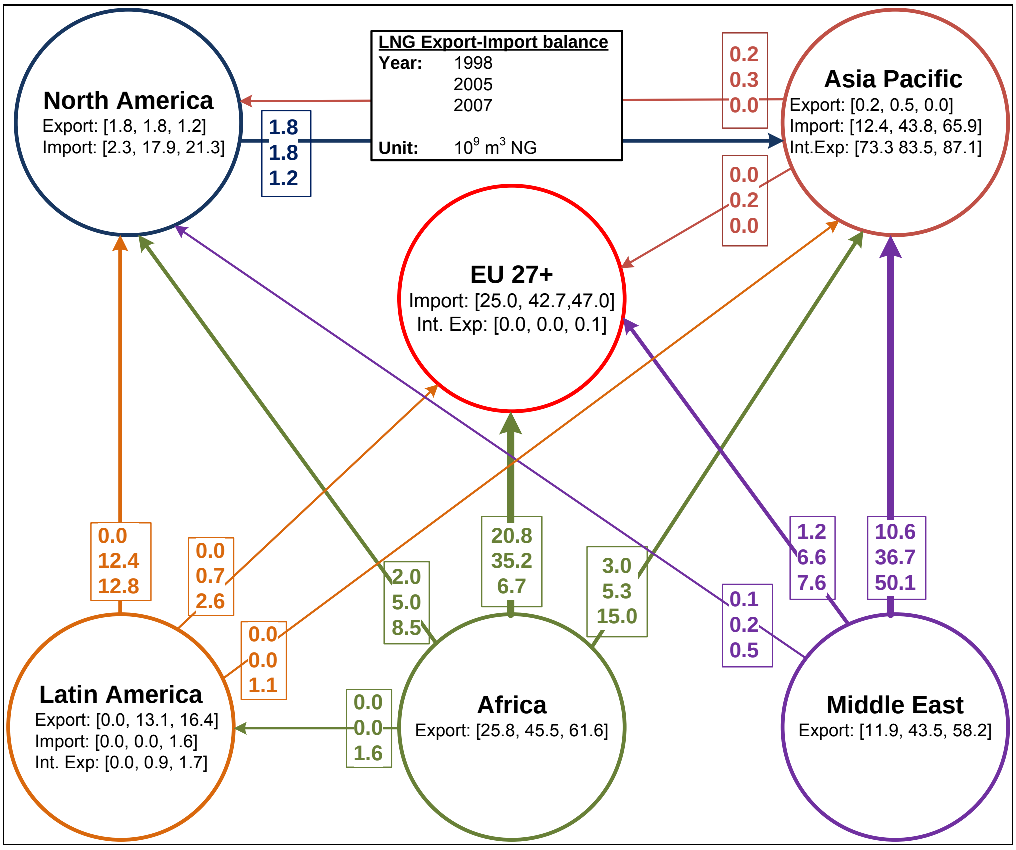


Figure 3.6: LNG export-import balance in bm³ for 1998, 2005 and 2007 (BP, 2008a).

3.2 Solar electricity

Two technical concepts exist for the transmission of electricity. It can be transmitted as either alternating current (AC) or direct current (DC). Both technologies do have their advantages. There are however some good reasons to favour HVDC over HVAC when it comes to the import of bulk electricity over long distances. First of all the **investment costs** of HVDC lines are considerably lower than for HVAC lines. However, as generation plants as well as consumer goods have grown to use the AC technology a conversion from AC to DC is needed on both sides of the line. The costs of these converter stations are considerably larger than those of AC transformer stations. Another aspect is the **lower losses** of electricity in HVDC lines over long distances compared to HVAC lines. For example, for a voltage level of ±800 kV HVDC lines the losses are of 3% per 1,000 km whereas for an 800 kV HVAC line would be at around 7% per 1,000 km. Taking a look at sea cables the differences are even more striking. As losses of HVDC sea cables are in the same range as overhead lines which does not put any limitation to the possible distance, a 750 kV HVAC sea cable does have losses of approximately 60% per 100 km. The converter/transformer stations have only 0.6% - 0.2% of additional losses per station. Taking costs and losses into account, the use of HVDC does become economically feasible at a distance between 600 and 800 km for overhead lines and about 50 km for sea cables (ABB, 2007). The influences on the environment boil down to the use of land. A transmission line with the same voltage level of HVDC is capable to transport significantly more capacity than a HVAC line. Taking again the example used above, a ±800 kV HVDC line can transport a maximum capacity of 6,400 MW whereas an 800 kV HVAC line is limited to 2,000 MW. Also the number of lines differs between the technologies. HVDC lines typically consist of a dipole needing a positive and a negative line. A HVAC line however does consist of three phases and therefore needs to apply tree lines. The pylon construction for a HVAC line therefore needs to be larger than for a HVDC line.

World wide HVDC transmission lines cumulate today to a total capacity of over 75 GW in more than 90 projects. Many of them connect renewable power sources from hydropower (e.g. Inga-Shaba in Congo, Itaipu in Brazil, projects in China) or geothermal power (e.g. Philippines) with distant centres of demand. Others are used to interconnect countries over sea (e.g. SwePol, Baltic Cable, Italy-Greece, and Sardinia-Italy). A list of existing HVDC lines can be found at (ECE, 2008).

For the characterisation of solar power corridors in REACCESS, rather conservative numbers were assumed based on ongoing HVDC projects and without speculative assumptions. Bipolar lines were assumed for both overhead lines and submarine cables, in order to increase security of supply, as half of the capacity is still available, if one line fails. For REACCESS, voltage of a corridor consisting of sea cable(s) and overhead line(s) was assumed to be ±600 kV for all corridor sectors technically possible until 2020. The maximum voltage of the complete line is limited by the sea cable and also by the line capacity which is assumed to be in the range of 3,000 MW per bipolar line, for reasons of supply security in case of a line outage. We did not consider overhead lines with Ultra High-Voltage DC (UHVDC) having lower losses as it is technically not possible to include a DC-DC transformation between sea cable and overhead line and because higher investments in UHVDC are recommended only for bulk power transmission above 5,000 MW which for safety and reliability reasons is not proposed for the import to EU27+. The ±600 kV HVDC classic is also specified by power losses from a transformer/converter station of 0.7%, from sea cables of 2.7%/1000 km and from overhead lines of 4.5%/1000 km. Investment costs assumed are 120 €/kW for stations, for 1.2 million €/km sea cables and 270,000 €/km for overhead lines. Operating costs are assumed to be 1% of investment costs per year. For the future, significant further developments of HVDC technology seem to be possible and also the outage capacity tolerated by the UCTE system may be higher than today. Data assumed for a ±600 kV HVDC corridor with 3,200 MW capacity, 3,000 km land and 200 km sea distance having 6,500 full load hours result in transmission costs of less than 2 €ct/kWh taking into account costs due to the loss of solar electricity with production costs of 6 €ct/kWh. A discount rate of 6% was used for this estimation.

3.2.1 The selection of potential reference sites

The selection of eleven potential reference sites in the MENA region for solar power generation took into consideration all relevant criteria like solar resource and land availability, local risks, available infrastructure and economic performance. The sites selected for analysis and as corridor starting points are a compromise between solar and land resource availability, availability of road infrastructure for access and closeness to the European centres of demand. The findings do not necessarily represent optimal sites – as we did not apply any optimisation function – but *represent reasonably feasible sites for the production of solar electricity*. The eleven sites selected have a solar direct normal irradiance classified between 2500 and 2700 kWh/(m²·yr). With that level of DNI a very good availability for solar power is possible, with 7200 to 7800 full load operating hours per year (for a CSP plant with a solar multiple) which is equivalent to the availability of conventional base-load power stations. Taking into consideration sites with over 8000 full load operating hours per year, performance of the HVDC interconnections could still be enhanced further, if required.

In order to find potential sites for the import of CSP electricity, we have analysed the total electricity demand of the European countries, the population density and the land availability for siting the HVDC headers close to the selected centres of demand. The idea of accessing centres of demand is that large scale electricity imports via HVDC must be fed into the conventional electricity grid at sites with large demand were a powerful infrastructure is available that can cope with the large capacities to be imported. The end of a HVDC power line needs a grid infrastructure capable of absorbing the electricity generated. These places are usually and preferably close to large centres of demand, which are usually the population centres in Europe. The following 27 demand centres were selected as corridor end points (14 finally selected centres provided as input for energy system modelling are in bold letters): **Brussels** (BE), **Sophia** (BG), **Prague** (CZ), **Paris**, Lyon (FR), **Jülich**, Berlin, Mainz, Karlsruhe, Munich, Hamburg, Hannover (DE), **Athens**, Thessaloniki (GR), **Budapest** (HU), **Milano**, Firenze, Rome, Naples (IT), **Appledorn** (NL), **Warsaw** (PL), **Lisbon** (PT), **Bucharest** (RO), **Madrid**, Zaragoza (ES), **London**, Newcastle (UK).

3.2.2 The selection of the corridors

The next step was to find the best corridors for HVDC lines interconnecting the solar power generation in MENA with demand centres in Europe. The corridors should be as short as possible, not create significant environmental impact and not be submitted to significant natural risks. The first task was to create a regional map excluding all sites that would not be suitable for the construction of HVDC lines such as protected, industrial or populated areas, inland bodies of water, sand dunes and salt areas and deep sea areas for sea cables. The methodology is very similar to that used for site exclusion of CSP plants, and applies similar criteria for site exclusion (see Figure 3.7). All remaining areas are weighted differently by means of further features (land cover, population density, visibility, existing grid infrastructure and natural hazards such as earthquakes, storms, volcano eruptions and lightning) in order to identify the least-cost interconnection between supply and demand sites under ecological aspects. To this end, relative costs – so-called friction factors – are assigned to the land area in order to weight concerning its suitability as line location. A friction image was generated containing isotropic features which have the same value in all directions. The slope of the terrain is an additional anisotropic feature dependent on the direction of a corridor pathway. Generally it is assumed that the line costs rise with increasing slope. The ‘Global Land One-kilometre Base Elevation (GLOBE) Digital Elevation Model was used for spatially determine the continental elevation. Finally, a cost-distance image was calculated for the start and end point of each corridor from the isotropic friction image and the anisotropic friction image, taking into account excluded areas. The result consists of identified interconnections with the smallest relative environmental and economic impact. Figure 3.8 shows the map of all HVDC lines interconnecting 11 CSP production sites in MENA with 27 European centres of demand. The 37 corridors finally characterised and provided to the energy system modelling in the frame of REACCESS are listed in Annex II.

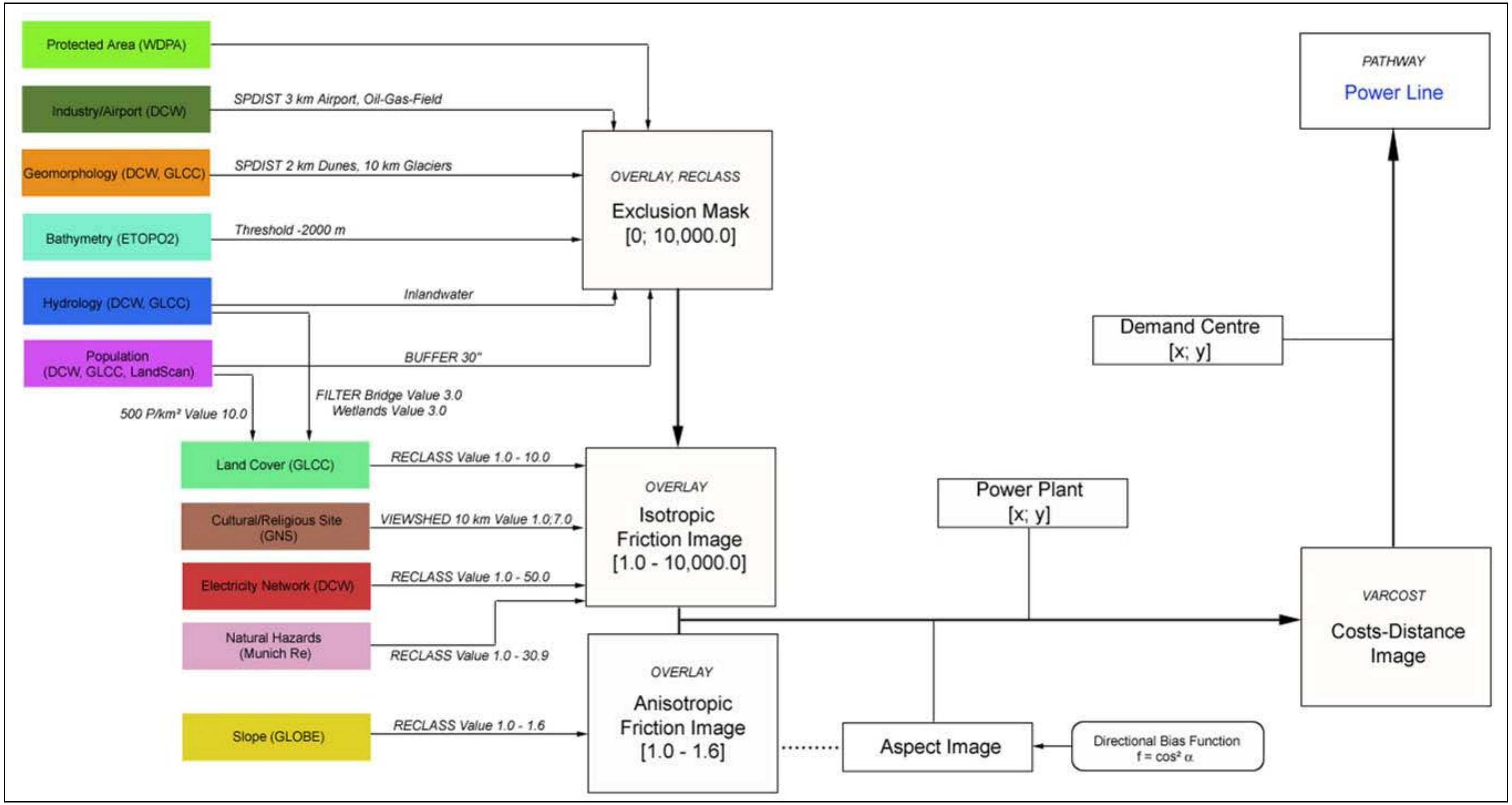


Figure 3.7: Model applied for the identification of least-cost HVDC power lines in terms of economic and environmental impact.

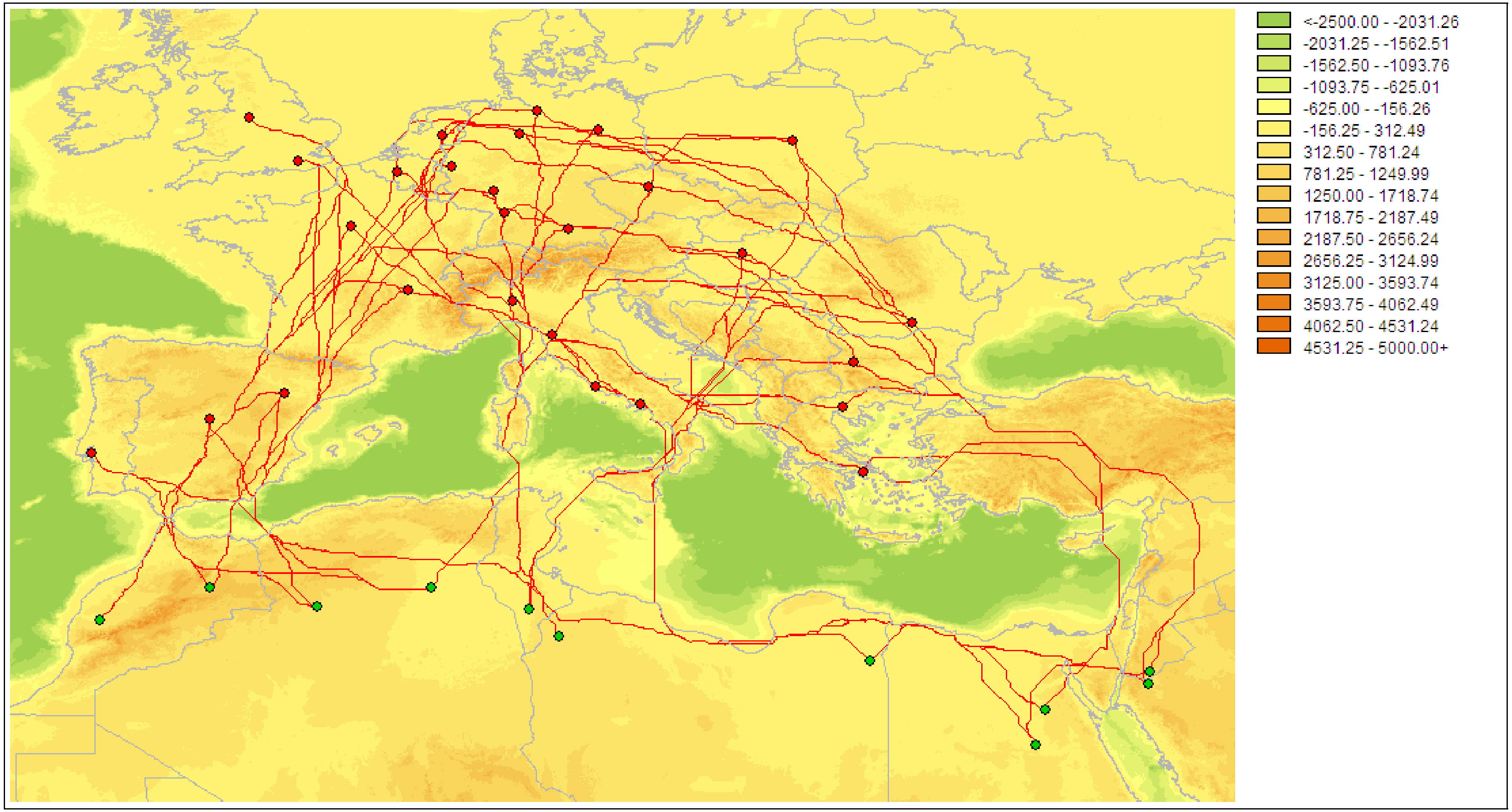


Figure 3.8: All HVDC lines interconnecting 11 CSP production sites in MENA with 27 European centres of demand as identified in the REACCESS project. The background map shows the elevation in metres above/below sea level.

3.3 Coal

3.3.1 Introductory remarks

The most important portion of coal imports are transported via sea to the European Union. About 6% of total coal imports by Europe are transported by means of inland waterways or rail, mainly from East European and Central Asian countries. Railway as a mode of transport is of importance for coal imports from Russia, Kazakhstan and Ukraine with over 6 Mt. Inland water transport is dominant for coal imports from Russia and Ukraine (2.5 Mt), but representing only 1% of total coal imports.

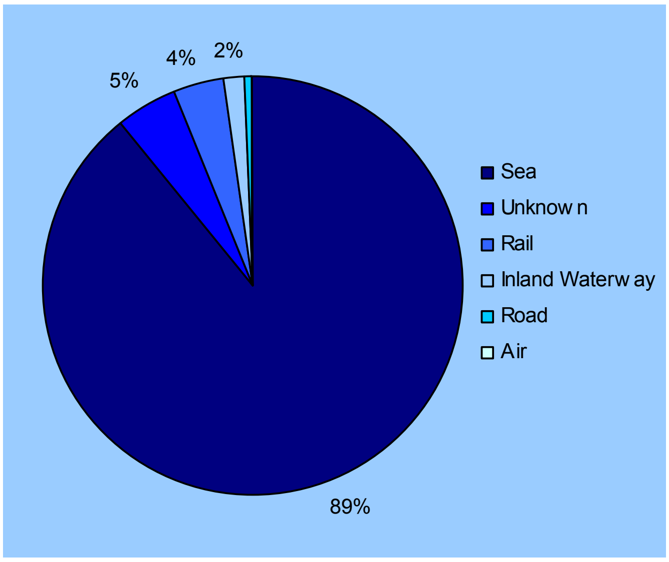


Figure 3.9: Transport Mode of Coal Imports to EU27 in 2005 [source: (Eurostat, 2008a)].

As the majority of coal exports to Europe is transported via seagoing vessels, deep-sea ports play an important role in handling and distributing the imported coal to the final destination. The **ARA** ports (**Amsterdam-Rotterdam-Antwerp**) handle the largest shares of coal imports (see Table 3.2). In the same time they serve as turnover stations for transport to the most important inland waterway in the EU27, the **Rhine**.

Other important coal ports **are Hamburg, Szczecin and Gdansk** in the East-West corridor, **Constanta** as the entrance point for inland water transportation on the **Danube** and **Le Havre** and **Marseille** in France for inland water shipment on the **Seine** and **Rhône**.

Other sea ports play an important role locally, but as they are not connected to major inland waterways, they are deprived of the possibility of cheap further transport into the hinterland.

Therefore, in addition to the supply of domestic energy systems through the ports listed in Table 3.2, it is necessary to take into consideration the four **major inland water corridors** in the EU27 and their cost structure for coal transportation.

Aside from inland waterway transport, railway also plays an important role for the transport of hard coal from the deep-sea port to the consumers. For the calculation of the specific distance-dependant transport costs of hard coal, data on prices and conditions were drawn from (Railion, 2007). Coal is typically transported in block trains, which are used as double trains.

Table 3.2: Total coal throughput in European seaports in 2005.
(source: (VDKI, 2008), different port statistics)

Ports	Throughput 2005 [Mt]	Capacity 2005 [Mt]
Rotterdam	26.50	33.13
Amsterdam	19.00	23.75
Antwerp	9.40	11.75
Dunkirk	8.80	11.00
Gdansk	6.90	8.63
Riga	6.60	8.25
Szczecin	6.40	8.00
Valencia	5.60	7.00
Hamburg	4.70	5.88
Zeeland Seaports	4.10	5.13
Tallinn	4.09	5.11
Marseille	4.03	5.04
Constanta	3.47	4.34
Liverpool	3.00	3.75
Le Havre	2.90	3.63

3.3.2 The main EU Inland waterways

Inland waterways play a significant role in coal transport. For example, 60 to 80% of coal arriving in the ARA-ports is transported via barges to the hinterland (VDKI, 2008).

The Rhine coal corridor

The Rhine corridor covers the whole of the Rhine confluence and the canals in Western Germany, the Benelux countries, Eastern France and Switzerland. In general, the physical conditions on the Lower and Middle Rhine are conducive to waterway transport; however, problems may arise in the case of heavy bulk cargo with low water levels. For example, dry bulk transports (e.g. coal, iron ore) with 6-unit pushed barges are not allowed if the water gauge at Lobith (German-Dutch frontier) drops below 9 metres. During the 2003 summer, the Rhine at Lobith dropped to a historic low of 7.15 metres. These conditions can have significant impacts on costs.

In the case of normal water conditions, pusher trains with up to six push barges can transport the coal from the ARA ports to the Ruhr-Area. That corresponds to a load capacity of up to 18,000 t of coal. For shipments going to the Middle Rhine or up to Basel, 4 pushing units can be used at most with a capacity of 2,000-2,500 t each. For a transport onto further inland waterways the pushing units are usually separated because of the limited draught. For example on the Neckar, only ships with a loading capacity up to 1,800 tons dead weight (dwt) are allowed for freight transport.

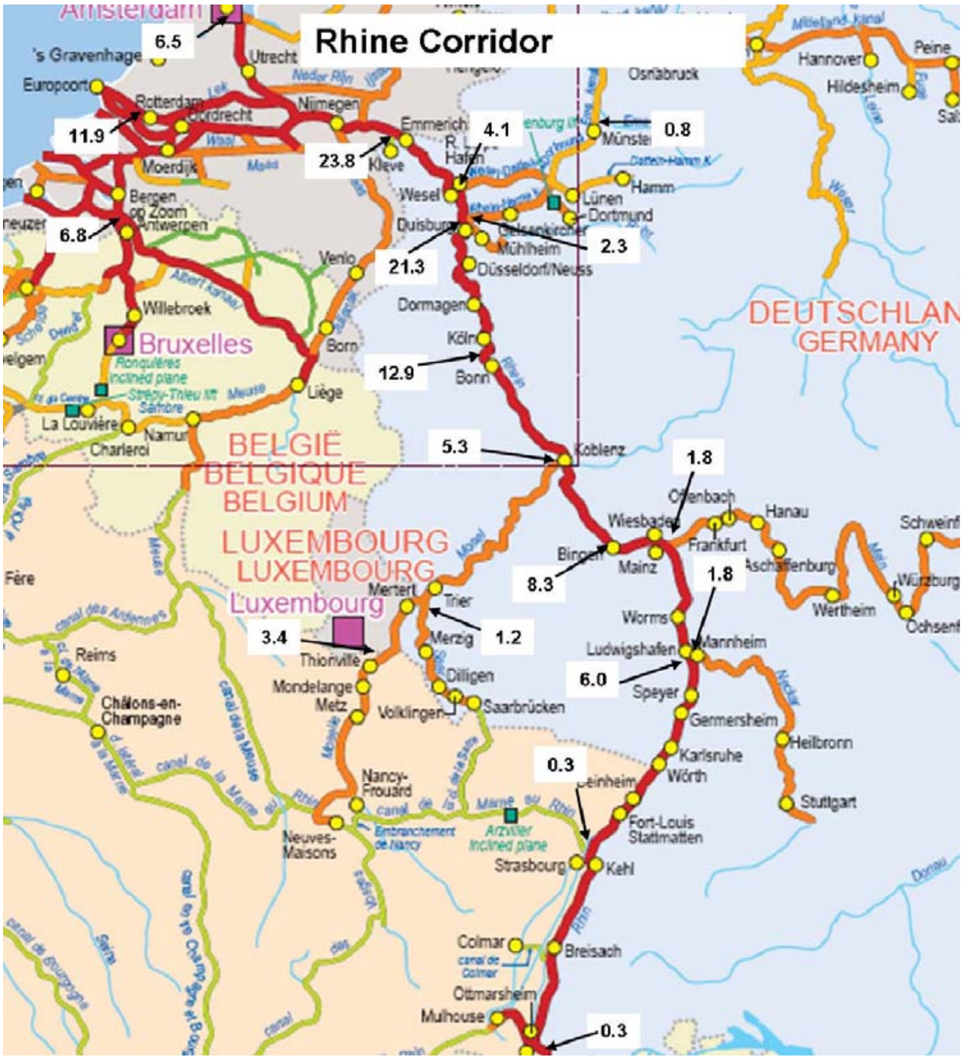


Figure 3.10: Map of the Rhine corridor [source: (ZKR, 2003)].

The Danube coal corridor

The Danube corridor covers the Danube confluence between German Bavaria and the Black Sea with all tributaries including the Main-Danube canal. The Danube is the second-longest river in Europe and represents with the Main-Danube canal and the Rhine the shortest navigable connection between North Sea and Black Sea. It has not only importance for coal importation through the Black Sea port of Constanta, but also for coal importation via inland water transport from Ukrainian Danube ports.

Near the river mouth, the Danube is navigable for pusher trains of up to 9 pushing units. Up to Novi Sad in Serbia the Danube is classified in the highest inland waterway class VII. Further upstream and for the Main-Danube canal the class becomes Vb in Germany meaning that ships of dwt of 3,200 to 6,000 dwt are allowed to pass through the canal. The Main river represents the bottleneck for international waterway transport, because there only one pushing unit is allowed, limiting the load to 3,000 dwt.

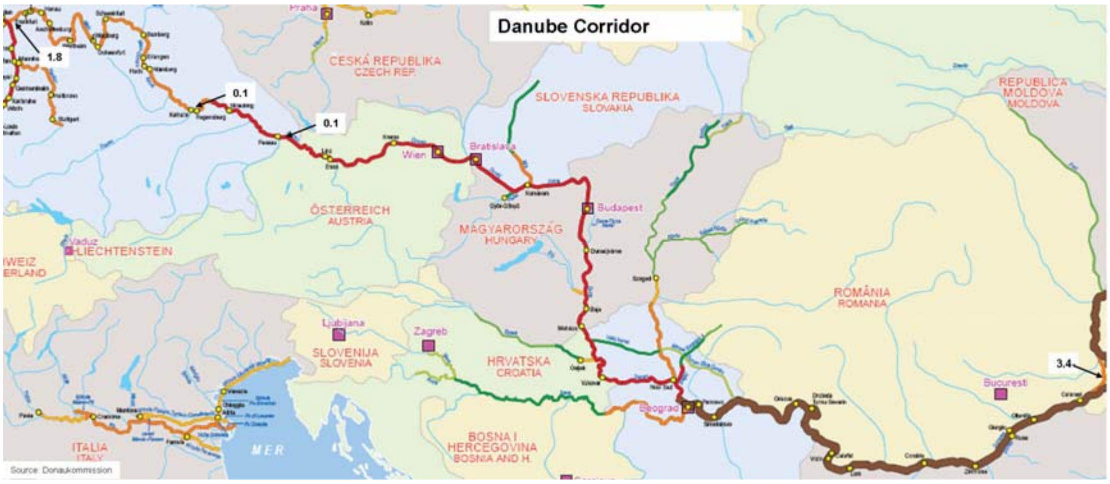


Figure 3.11: Map of the Danube corridor [source: (Donaukommission, 2007)].

The East-West and North-South coal corridors

The East-West corridor covers the Mittelland canal and the confluences of the Elbe, Oder and Wisla. The East-West corridor is connected to the Rhine by a well established network of canals. The improved Mittelland Canal constitutes the main link and offers stable waterway conditions. The Weser, Elbe and Odra are the main waterways of this corridor; but inland navigation on the Elbe and Odra are hindered by fluctuating water levels in the free flowing sections. Generally the East-West corridor only allows the operation of smaller vessels, whilst the middle course of the Odra has unfavourable water conditions and represents the bottleneck for the entire eastern part of the corridor.

Up to 6,000 dwt are allowed on the Elbe from Dörnitz on to the North Sea, reducing to 800 dwt in the Czech Republic. The Weser shows a maximum load capacity of around 6,000 dwt to Bremen. The Wisla is an important main inland shipping route up to Gdansk with a maximum load capacity of 3,300 dwt. Ships of about 3,000 tdw are allowed to navigate from the Baltic Sea on the Oder down to Szczecin, whereafter a load of only 1,000 dwt is possible.

The North-South corridor runs from the Lower Rhine, through Northern France and the Garonne to Marseille via the Loire and Rhône-Saône. Larger ships cannot pass over from the Rhine corridor, nor change the operation area within the North-South corridor itself, for instance between the Seine and Rhône. Consequently, these waterways are only conditionally integrated into the common European Inland Waterway (IWW) network. On the Rhône, ships with a load of 1,300 dwt can transport coal up to Lyon. The Seine is classified as Vb up to Paris, meaning that two pushing units are allowed

3.3.3 The cost structure

The cost of import coal is made up of different parts. The first part is the mining cost and inland transportation in the country of origin. The second part of the price represents the costs for sea transport to Europe. The transfer from a seagoing vessel to a barge or railway, i.e. the handling charges in a deep-sea port, represents the third part of the costs. The last part of the coal transport is made up of the transportation costs from the port to the consumer, i.e. the costs for inland water or railway transportation.

Sea transport to Europe

Sea transportation costs for coal can be taken from Table 3.3, which lists these costs for transportation between world regions. Coal handling in sea ports can be assumed to be in the range of US$ 2 per ton (Konstantin, 2007).

Table 3.3: Coal trade transport cost between world regions in $\$_{2000}$/GJ [source: (Remme et al., 2007)].

		Destination														
		AFR	**AUS**	**CAN**	**CHI**	**CSA**	**EEU**	**FSU**	**IND**	**JPN**	**MEA**	**MEX**	**ODA**	**SKO**	**USA**	**WEU**
Origin	**AFR**			2						44	240		0	73		1217
	AUS				37	146	0		388	2559	44	51	478	639	4	778
	CAN					95				391	24	27	39	168		148
	CHI			5					91	539		0	85	674	0	55
	CSA														82	657
	EEU					4					3					606
	FSU			1			26				155	2		76		287
	IND															
	JPN															
	MEA															
	MEX															
	ODA								311	433				161	19	254
	SKO															
	USA			520			2		1	101	65	12	3	46		572
	WEU										2					

Inland Water Transportation

The cost for inland water transportation consists of costs for the coal transporting barge, costs for the maintenance and infrastructure of inland waterways in the form of waterway tolls, charges at inland ports and follow-up costs from the inland port to the final destination. A good overview of freight rates on the most important European inland waterways is found in (Segerer & Heinecker, 2001).

Typical freight rates for coal transport from ARA-ports to the Ruhr are in the range of 1.8-3.1 €/t, while transport costs to Austria via the Main-Danube canal would typically range from 9.7-11.3 €/t. Coal transport via inland water transportation from Hamburg on the Elbe, the Elbe-Havel canal and the Havel to Berlin costs 3.6-4.1 €/t.

Coal is transported on different types of barges in the various inland waterways across Europe. In each particular corridor, navigational conditions and local market demands determine the characteristic of the fleet units. They can be mainly characterised by the typical unit size (length, breadth, draught, carrying capacity) and the applied technology (self-propelled vessel or pushing technology). For each waterway, typical vessels can be identified which meet the conditions of the corridor. Although it is clear that on large rivers, such as the Rhine and Danube, various units of different sizes and types can be found.

Within the Rhine corridor the Rhine determines the typical vessel size. Typical are single self-propelled ships of different sizes, e.g. a largo cargo motor ship with a draught of 3.5 m and between 2,000 and 3,000 tons capacity (Type 4, 15 and 16) for transports to confluences of the Rhine. They are characterised by a single crew and separate accommodation per permanent residence. Up to the middle Rhine, coal is usually transported in 4-unit pushed barges.

In the Danube corridor the typical vessel for coal transport are pushed trains consisting of 2,4,6 or even up to 9 pushed barges and a push boat of appropriate power, for example a barge train consisting of 4 barges and having about 6000 tons loading capacity at 2.5 m draught (Type 12 and 19). It has a large deckhouse to provide accommodation for a crew of 10 or more necessary for long voyages along the river.

Table 3.4 shows the operation cost per tonnes-year for different vessel types at full capacity utilisation.

For the calculation of the transport costs we took into consideration costs for the vessel transport, infrastructure costs and charges for port handling. Infrastructure costs are calculated for routes in France and on German canals.

Table 3.4: Operational cost per tonne-year for different vessel types at full capacity utilisation [source: (BCI, 2004); (PLANCO, 2003)].

	Type	load capacity [t]	fuel / lubri-ficants cost
PLANCO Consulting GmbH 2003			
Germany	**1**	835	28.0
	2	1080	33.0
	3	1528	41.0
	4	2154	47.0
Belgium	**5**	2121	56.0
Netherlands	**6**	860	31.0
	7	2800	45.0
Poland	**8**	490	48.2
Slovakia	**9**	1529	85.7
Hungary	**10**	1550	75.9
	11	1725	86.7
Romania	**12**	6600	20.5
Buck Consultants et al. 2004			
Rhine corridor	**13**	1280	70.2
	14	1280	70.2
	15	2850	54.3
	16	2850	55.2
Czech Republic	**17**	1190	42.2
Danube corridor	**18**	1280	70.2
Romania	**19**	6000	29.8

Concerning port charges and further handling costs, we assumed on average 0.3 €/t as pier tax, 3 €/t for railway loading in the inland port and 5 €/t as follow-up costs for the transport from the inland port to the final destination. For the routes we chose the vessel types mentioned in Table 3.5 as representative for a coal transporting vessel.

Table 3.5: Chosen vessel type for each route.

Route	**Vessel type**
Le Havre - Vitry	Type 2
Marseille - Chalons sur Saone	Type 2
Antwerp/Rotterdam - Thionville	Type 4
Antwerp/Rotterdam - Linz	Type3
Antwerp/Rotterdam - Basel	Type4
Constanta - Linz	Type 18
Reni - Linz	Type 18
Constanta - Lom	Type 12
Reni - Lom	Type 12
Constanta - Dunajvaros	Type 11
Reni - Dunajvaros	Type 11
Constanta - Galati	Type 12
Reni - Galati	Type 12
Sczcecin - Frankfurt	Type 9

3.4 Biomass

3.4.1 The identification of possible biomass import corridors to EU27

The following methodology was applied for the identification of possible biomass import corridors to EU27+. The existing trade in raw biomass materials and biofuels has been collected for each of the world region. However, only the corridors related to biofuels and wood pellets are modelled as no information was available on which share of traded crops and vegetal oils is currently used for energy purpose. As raw crops and vegetable oils are important for the food sector and energy density is rather low for long-range transport, trade data related to these products are not provided in this synthesis. Future corridors are defined for solid biomass (pellets), bioethanol and biodiesel, between:

- 10 ports in non-European countries for export: AFR, CAN, CHI, CSA (2), ODA (2), RUS (2) and USA
- 2 possible ports in Europe for import: Rotterdam and Marseille, representing a Northern and a Southern access to Europe.

Corridors within Europe (where trucks and train might be used) are not evaluated here. The transport is considered by ship given the large distances (dedicated tankers for bioethanol and biodiesel transportation and non-dedicated bulks for pellets). Pipelines are not considered since the biofuel industry does not expect the large implementation of such pipelines in a well-defined time horizon (uncertainties of the market, characteristics of bioethanol). Costs and energy consumption are provided, based on the distance. They were estimated using the study by Suurs (2002) on long distance bioenergy logistics.

Table 3.6 shows a summary of installed production capacities in energy supply regions. The total capacity for wood pellets was 345 PJ at the beginning of 2008 with the main share in Western Europe. The main source of data for wood pellets plants was the Pellets map published by The Bioenergy International Magazine No. 29 and No. 36 (www.bioenergyinternational.com). Total capacity for biodiesel production was 777 PJ in 2007 (mainly USA and EU27) and 993 PJ for bioethanol (mainly USA and South America). For both products, capacities are expected to increase significantly in coming years. The main data sources for biofuels in Europe was the European Biodiesel Board (http://www.ebb-eu.org/links.php), the European Bioethanol Fuel association, the GAIN Report of the USA Foreign Agricultural Service (http://www.fas.US$a.gov/scriptsw/AttacheRep/default.asp) and information from national biofuels associations.

Current trade in biofuels and biomass feedstock is modest compared to total production, but is growing rapidly. Most trade is between neighbouring countries or regions, but long distance trade is growing (IEA, 2007b). Several studies show that intercontinental trade in biofuels could be economically feasible and does certainly not lead to dramatic energy losses. In fact, biofuel shipping costs are small compared with the total value of the fuel and are not a limiting factor for the development of large bioenergy facilities (IEA, 2007b). However, trade barriers currently prevent large-scale shipments for example to Europe or the USA. Moreover, it is uncertain to what extent the consuming regions will allow imports in the future.

Bioenergy can be transported as raw biomass (chips, logs, bales, pellets and seeds), intermediate energy carriers (oils) or high quality energy carriers (bioethanol or biodiesel). Trade in raw biomass is more costly because of its bulk and lower calorific value, however currently raw materials such as palm kernel shells from Malaysia are also exported to the EU.

Table 3.6: Summary of installed production capacities in energy supply regions.

	Installed capacity of wood pellet plants (PJ/yr)		
Region	**Beginning of 2005**	**Beginning of 2007**	**Beginning of 2008**
AFR			2.76
AUS			4.85
CAC			
CAN	14.35	28.50	35.34
CHI			
CSA			
IND			
JPN			1.24
MEA			
MEX			
ODA			
OEE	0.27	1.65	12.55
RUS	14.40	12.01	21.58
SKO			0.27
USA		30.21	19.30
EUR	89.07	185.48	247.32
WORLD	**118.1**	**257.9**	**345.2**

	Installed capacity of biodiesel plants (PJ/yr)						**Installed capacity of bioethanol plants (PJ/yr)**				
Region	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2005**	**2006**	**2007**	**2008**	**2009**
AFR	0	0	0.00 **	0	0	13.62	0	0	0	0	5.73
AUS	3.44	17.2	17.2	19.83	20.49	20.49	1.6	1.6	12.85	12.85	12.85
CAC	nd	nd	nd	nd	nd	nd	nd	nd	1.52	1.52	1.52
CAN	0.3	1.97	3.18	10.57	10.57	10.57	6.15	8.35	14.84	24.1	38.44
CHI	3.06	44.87	57.31	57.31	57.31	66.53	24.6	34.76	45.73	47.35	47.35
CSA	0	12.01	16.17	175.17	175.17		327.65	344.41	390.92	448.76	448.76
IND	nd	nd	nd	0.07	0.07	55.95	2.12	5.31	6.37	6.37	6.37
JPN	0	0.08	0.15	0.15	0.15	0.15	0	0.0006	0.0306	0.08064	0.7393
MEA	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MEX	0	0.12	0.12	0.12	0.12	0.12	0	0	0	0	0
ODA	1.16	4.01	48.56	58.28	58.28	58.28	2.57	13.09	20.78	29.13	29.13
OEE	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
RUS	0	0	0	0	0	8.21	0	0	4.01	0	0
SKO	0.58	11.19	19.83	19.83	19.83	19.83	0	0	0	0	0
USA	27.96	72.69	229.87	410.03	410.03	410.03	292.96	348.66	441.68	634.24	634.24
EUR	158.18	226.85	384.75	596.76	596.76	596.76	31.29	44.54	54.21	70.2	70.2
WORLD	**194.67**	**391**	**777.13**	**1348.12**	**1348.77**	**1260.54**	**688.94**	**800.71**	**992.97**	**1274.61**	**1295.35**

nd = no data

The availability of statistics on the trade in biomass for energy purpose and biofuels is still very limited since trade statistics don't yet distinguish between biomass for energy and biomass for other uses. Bioenergy trade statistics are hidden and embedded in other more traditional trade flow data, making very uncertain any description of the current situation. The most important sources of data related to biomass and biofuel trade are (USDA, 2008), (FAPRI, 2008), (UN Comtrade, 2008), and Eurostat (http://epp.eurostat.ec.europa.eu) and FAOSTAT (http://faostat.fao.org) statistics. Table 3.7 shows resulting current total bioenergy exports and exports to Europe by region as well as the worldwide trade volume. Values for wood and bioethanol are given for 2005 when production capacities were somewhat lower than today's level. About 30% of wood pellets produced in 2005 were exported (20% to EU27). In 2005, only 1.2% of biodiesel produced worldwide was exported (0.2% to EU27) whereas in 2007 already more than 9% was used for export (5.3% to EU27). Export of bioethanol was about 5% in 2005 (1.2% to EU27).

Table 3.7: Current total bioenergy export and export to Europe per region and worldwide trade volume (in PJ/yr).

	Wood pellets 2005		Biodiesel 2005		Biodiesel 2007		Bioethanol 2005	
Region	**to EUR**	**total**	**to EUR**	**total**	**to EUR**	**total**	**to EUR**	**total**
AFR	0.17	0.18	0	0	0	0	0.10	0.85
AUS	0	0.05	0	0	0	0	0	0
CAC	0	0	0	0	0	0	0.13	0.13
CAN	8.50	17.84	0	0	0	0	0	0
CHI	0	0.45	0	0	0	0	0	1.48
CSA	2.71	2.71	0.06	0.09	2.80	11.19	7.01	31.81
IND	0	0	0	0	0	0	0	0
JPN	0	0	0	0	0	0	0	0
MEA	0	0	0	0	0	0	0	0
MEX	0	0.02	0	0.02	0	0	0	0
ODA	0.07	0.57	0.01	0.58	0.62	22.27	0.66	0.87
OEE	2.91	2.91	0	0	0	0	0.06	0.06
RUS	4.55	5.27	0	0	0	0	0	0
SKO	0	0	0	0	0	0	0	0.02
USA	3.69	4.32	0.26	0.30	37.30	37.30	0.03	0.03
EUR	-	0.29	-	1.31	-	0	-	0.30
WORLD	**22.61**	**34.62**	**0.33**	**2.30**	**40.72**	**70.76**	**7.99**	**35.55**

Table 3.8 lists the defined future biomass import corridors to EU27. Most of the distances between selected ports are in the long range above 6000 km. With the intention of avoiding long distances for truck transportation, which turns out to have the highest costs, two destination ports were selected for the imports of biofuels in Europe, Rotterdam in Northern Europe and Marseille in Southern Europe. Both are, at present, important doors for imports and exports.

More information on corridors can be found in Annex II. Once the bioenergy is in the destination EU27+ ports, it would be distributed to the other countries either by truck or by train.

Table 3.9 and Table 3.10 show cost data applied for the characterisation of biomass transport costs mainly based on (Suurs, 2002) and (Hamelinck et al., 2008). Due to the long distances between EU27+ and the importing regions and the low costs of ship transport compared with the other alternatives, only sea corridors were defined and estimated. Sea transport costs include capital costs, operation and maintenance costs, transfer costs (loading and unloading costs) and port charges as well as fuel costs. From the five vessels analysed by Suurs (2002), two have been chosen:

- Conventional bulk carrier CV-II which carry 30,000 dwt solid biomass (non-dedicated), and
- Chemical tanker for biodiesel and bioethanol transportation, 4,527 dwt (dedicated)

As regards the database, dedicated tankers are considered for bioethanol and biodiesel transportation and non-dedicated bulks for pellets. Biodiesel has lower costs than bioethanol only because of the higher energy content of biodiesel comparing with bioethanol. Transport of wood pellets is more expensive also because of the low energy density.

Table 3.8: Defined future import corridors to Europe and distances in km.

Region/port of origin	Load	Distance to Rotterdam	Distance to Marseille
AFR (Cape Town)	Bioethanol	11,414	10,705
CAN (Montreal)	Solid biomass	6,093	7,167
CHI (Shanghai)	Bioethanol	19,481	16,218
CSA (Sao Paolo)	Bioethanol/Biodiesel	10,056	9,384
CSA (Mar de Plata)	Biodiesel	11,744	11,073
ODA (Penang)	Biodiesel	14,807	11,544
ODA (Karachi)	Bioethanol	11,355	8,091
RUS (Primorsk)	Solid biomass	1,996	-
RUS (Novorossiysk)	Solid biomass	-	3,397
USA (New York)	Biodiesel	6,265	7,215

Table 3.9: Biomass transport costs without energy costs, in € per TJ transported and per km (bold values used for import corridors in REACCESS).

	Solid biomass*	Bioethanol	Biodiesel
By Ship			
1500 km	0.51-1.85	0.247-0.347**	0.177-0.249**
10000 km	0.12-0.51	0.130-0.212**	0.093-0.152**
long range non-dedicated transport	**wood pellets: 0.121**	**0.130**	**0.093**
long range dedicated transport	**wood pellets: 0.161**	**0.212**	**0.152**
By Train			
500 km	0.81-3.42	2.15	1.54
1000 km	0.46-2.33	1.47	1.05
1500 km	0.35-1.97	1.24	0.89
2000 km	0.29-1.78	1.13	0.81
By Truck			
50 km	4.6-15.54	3.66	2.63
200 km	2.84-7.18	3.20	2.29

* The large range of the costs for solid biomass can be explained mainly by the different kind of solid biomass. For example, among the different kinds of solid biomass, which are logs, chips, bales and pellets, the lowest cost corresponds to the pellets while the highest is that for chips for truck transport and bales for ship transport. The reason may be the low density of the bales and chips against the pellets density. The bigger the density of the biomass, the cheapest the transport cost.

** The costs for dedicated transport are higher than the ones for non-dedicated ones (40% higher for short distance, 63% higher for long distance)

Table 3.10: Fuel/electricity consumption by biomass transport in MJ energy consumed per GJ transported and per km.

	Solid biomass	Bioethanol	Biodiesel
By Ship (Heavy Fuel Oil)	0.0038	0.0055	0.0038
By Train (Electricity)	0.0142	0.0079	0.0057
By Truck (Diesel)	0.0330	0.0260	0.0190

Figure 3.12 shows possible bioenergy sea routes in Europe where biomass comes from America and the countries of the Former Soviet Union, entering the destination ports of Rotterdam and Marseille. A possible intermediate stop in the UK has been considered. Once the bioenergy has arrived at the destination EU27+ ports, it would be distributed to the other countries (dotted arrows) either by truck or by train. Ports of origin are shown in Figure 3.13.

Figure 3.12: Future potential biomass corridors to and within Europe.

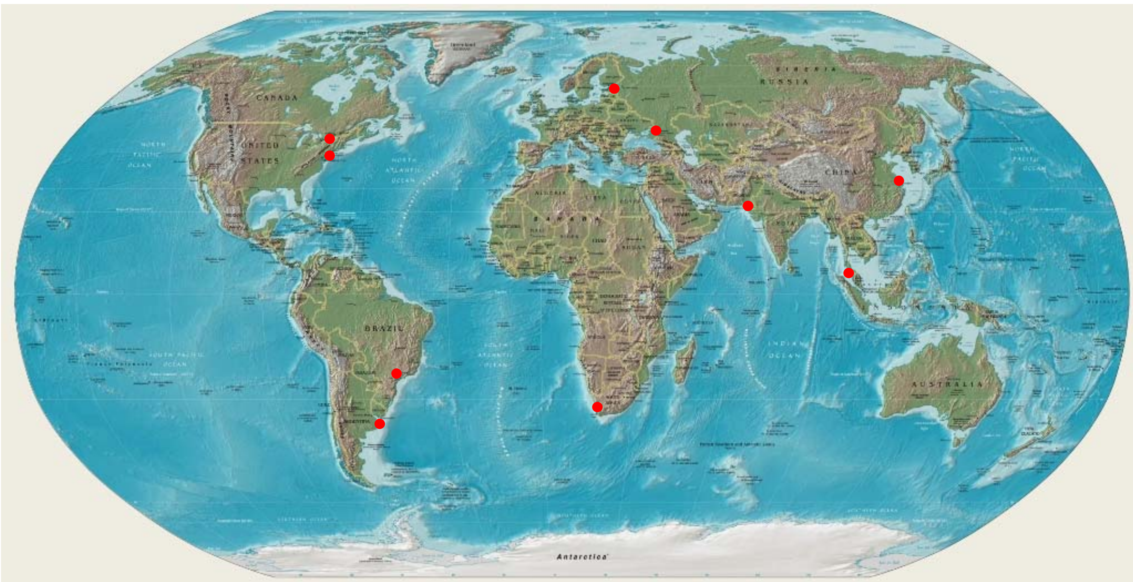


Figure 3.13: Ports of origin for biomass import to EU27+ (world map from www.aquimapas.com).

3.5 Nuclear fuels

3.5.1 The identification of the corridors

Uranium ore is extracted as U_3O_8 from surface and underground mines, concentrated and refined mainly in Canada, Australia, Niger and Namibia; in these countries the first chain phases involve transportation on roads and rails. Then the uranium commodity (U_3O_8 or, in some cases, UF_6) is transported by ship in UK, France, Spain, Sweden, Germany for secondary processes, like conversion, enrichment, fuel fabrication, related to the type of reactor where the fuel elements will be used (light water reactors like PWR, BWR, EPR and VVER, heavy water reactors like CANDU, gas cooled reactors like AGR).

Additional uranium fuel is obtained from reprocessing activities of spent fuel elements and highly enriched uranium (HEU). A limited amount of fuel elements are supplied directly from Russia to VVER and RBMK plants. Four main operating uranium corridors have been identified:

NUC_001_A and NUC_001_B from Canada to UK
NUC_002 from Northern Australia to EU
NUC_003 from Southern Australia to EU
NUC_004 from Niger to EU (mainly France)
NUC_005 from Namibia to EU

The reason for the presence of two “sub-corridors” from Canada mines is due to the fact that, in the recent past and maybe in the future, two different commodities have been transported using the same corridor; yellowcake (U_3O_8) of uranium hexafluoride (UF_6), depending of the activity choices at Blind River/Port Hope Cameco facilities.

In the scenario analyses that will be developed after the TIMES Models adaptations, new corridors could be taken into consideration starting from several new large uranium deposits that have been discovered and will be operating in next decades.

Data upon the uranium resources and ore grade for these deposits have been collected, but the assessment of their reliability, due to the lack of available official information from the Mining Companies, will require some additional work, that will be developed during the Model Adaptation phase of the REACCESS project.

NUC_006 from Kazakhstan to EU
NUC_007 from Uzbekistan to EU
NUC_008 from South Africa to EU
NUC_009 from Gabon to EU

The main uranium “open sea” routes are reproduced in the world map of Figure 3.14.

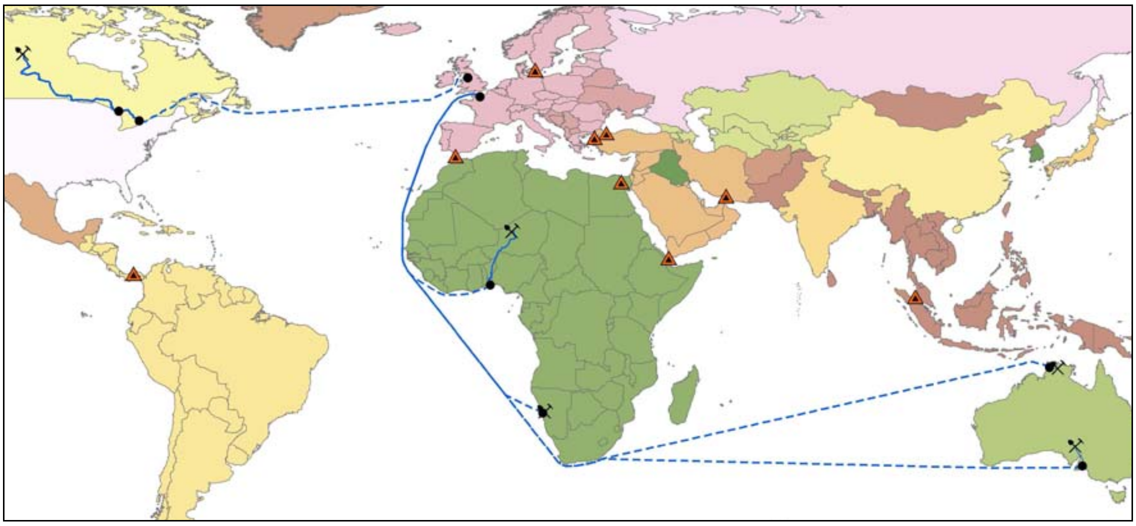


Figure 3.14: Main uranium "open sea" routes.

3.5.2 Main data of the uranium corridors

Corridors NUC_001_A and NUC_001_B

Source site/field name and location:
Surface mines in Athabasca Basin, Saskatchewan, Canada:
Key Lake (since 1975), McArthur Lake (since 1988), McClean Lake (since 1979) and Rabbit Lake (since 1968)

Origin: Athabasca Basin, Saskatchewan, Canada (proven 208,427 tU, probable 125,280 tU and possible reserves 143,610 tU);
Path: truck transportation (inside Canada) from mines to mills and refineries, then ship route from Canada to UK
Destinations: Preston, Lancashire, UK

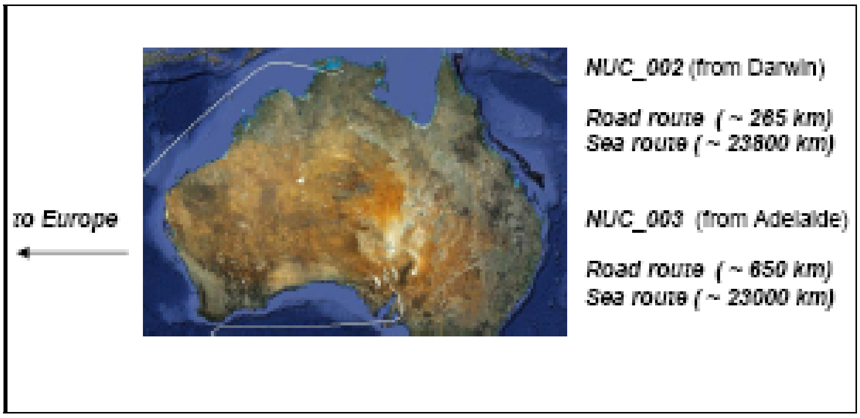
Corridor NUC_001_A
Sector 1 (inside Canada): transportation of U_3O_8 (yellowcake) by truck from the mines to Blind River refinery, then transportation by truck to Port Hope facility (Ontario) were the yellowcake is converted to UF_6
Sector 2 (open sea): transportation by ship from Port Hope (Canada) to Preston (Lancashire, UK). In UK the UF_6 is then transported by truck to Springfield facility (Lancashire) for next processes (enrichment and fuel element fabrication).

Corridor NUC_001_B
Sector 1 (inside Canada): transportation of U_3O_8 (yellowcake) by truck from the mines to Blind River refinery, then transportation by truck to Port Hope facility (Ontario)
Sector 2 (open sea): transportation of the yellowcake by ship from Port Hope (Canada) to Preston (Lancashire, UK)
In UK the yellowcake is then transported by truck to Springfield facility (Lancashire) for conversion to UF_6 and next processes (enrichment and fuel element fabrication).

Corridors NUC_002_ and NUC_003

Source sites/field names and locations:
Three operating uranium mines in Australia, **Ranger** in Northern Territory (NT), **Olympic Dam** and **Beverley** in South Australia (SA).
Ranger activities (since 1981) are connected to the Darwin port. **Olympic Dam** (since 1988) and **Beverley** (since 2000) are connected to the Adelaide port terminal.
Jabiluka is an extension of the Ranger operation, but awaits Aboriginal approval for development.

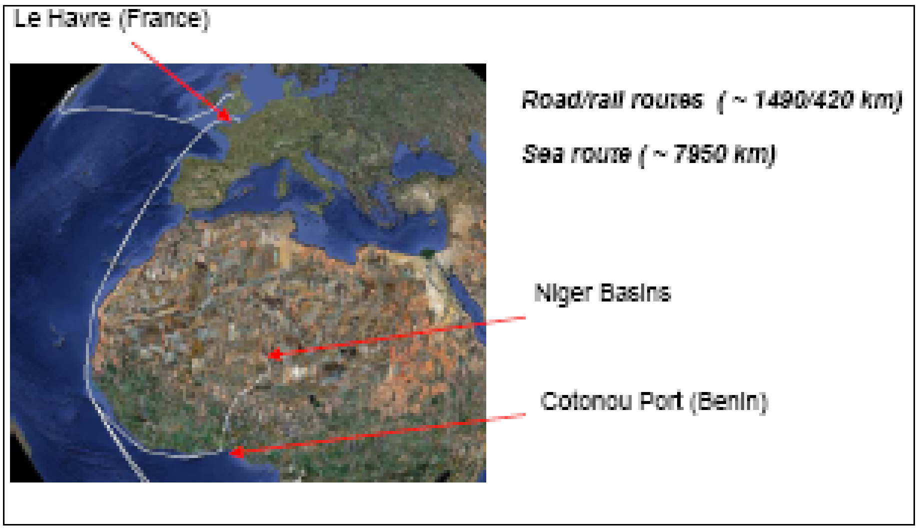
Corridor NUC_002
Origin: Ranger, Northern Territory, Australia (proven 42,121 tU, probable 26,974 tU and possible reserves 15,908 tU)
Path: truck transportation (inside Australia) from mines to the port and then ship route from Australia to EU
Destinations: Europe (main port: Le Havre)
Sector 1 (inside Australia): transportation of U_3O_8 (yellowcake) by truck from the mines to the port of Darwin (NT).
Sector 2 (open sea): transportation by ship from Darwin (NT) to EU.
Corridor NUC_003
Origin: Olympic Dam and Beverley, South Australia, Australia (proven 128,387 tU, probable 130,846 tU and possible reserves 1,973,126 tU);
Path: truck transportation (inside Australia) from mines to the port and then ship route from Australia to EU
Destinations: Europe (main port : Le Havre)
Sector 1 (inside Australia): transportation of U_3O_8 (yellowcake) by truck from the mines to the port of Adelaide (SA).
Sector 2 (open sea): transportation by ship from Adelaide (SA) to EU



Corridor NUC_004

Source site/field name and location:
The operating mines in Niger are: **Arlit** open-pit mine (since 1975), **Akouta** (since 1974), **Imouraren** (since 1966)
The drums from Somair, which weigh up to 20 tons each, are taken by road in a convoy of lorries to Parakou in Benin. There, they are loaded on trains and taken 250 miles to Cotonou, from where they are shipped to France.
The production at the Akouta deposit (close to Akokan) started in 1974; it is an underground operation at a depth of about 250 metres.

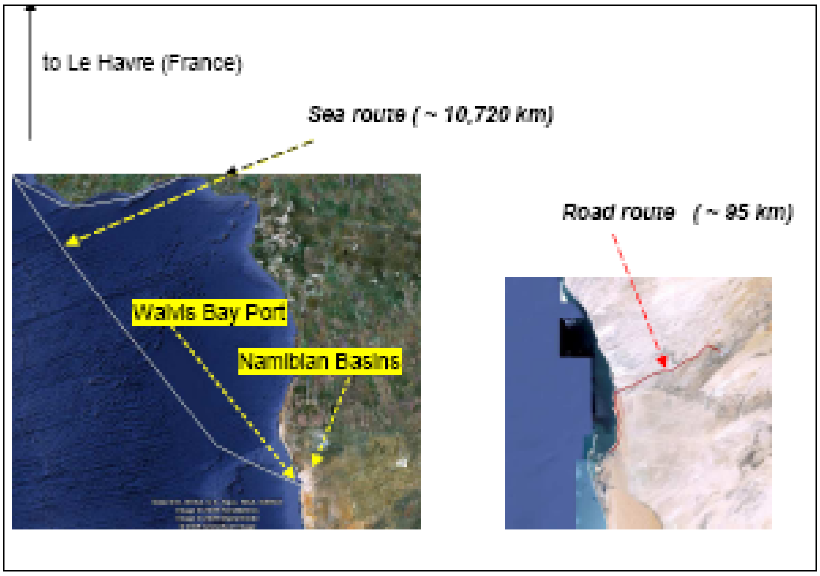
Origin: Arlit Region, Niger (proven reserves 24,625 tU, probable 28,737 tU and possible reserves 189,499 tU);
Path: transportation by trucks and railcars (inside Niger and Benin) from mines to shipping port (Cotonou), then by ship to France (Le Havre)
Sector 1 (inside Niger and Benin): transportation of U_3O_8 (yellowcake) by truck and rail from the mines to Cotonou (Benin)
Sector 2 (open sea): transportation by ship from Cotonou (Benin) to Le Havre (France). In France the yellowcake is then transported by truck to Malvési and Pierrelatte for conversion and enrichment, then to Romans for fuel element fabrication.



Corridor NUC_005

Source site/field name and location:
The operating mines in Namibia are located close to Walvis Bay port.
Langer Heinrich (discovered in 1973 and opened in 2007)), **Rössing** (discovered in 1928 and operating since 1976), **Trekkopje** (operating since 2008)

Origin: Namibia (proven reserves 282,000 tU, probable 24,389 tU and possible reserves 127,182 tU);
Path: truck transportation from mines to mills and refineries – then ship route from Walvis Bay (Namibia) to Europe
Destinations: Preston (Lancashire, UK), Le Havre (France)
Sector 1 (inside Namibia): transportation of U_3O_8 (yellowcake) by truck from the mines to Walvis Bay (Namibia).
Sector 2 (open sea): transportation by ship from Walvis Bay (Namibia) to Europe.



3.5.3 Uranium transport technologies.

Nuclear materials' transports refer to all the segments of the Nuclear Fuel Cycle. These transports are frequently international and very often over large distances. They occur between the different stages of the cycle, even if sometimes two stages can be directly linked and no transport is required (as for mining and milling); generally, materials are in solid form.

Only few countries have all (or, at least, the largest numbers of) the steps of a full nuclear fuel cycle. France (like UK, the USA and Russia) is a good example for showing the complex sequence of material transports involved in the complete nuclear cycle (front and back ends), even if all the yellowcake is imported. The main French sites are reported in the following Figure:

Le Havre
(U_3O_8 concentrate import terminal),

Malvési
(1- U_3O_8 to UF_6 conversion),
Pierrelatte
(2-4 - UF_6 enrichment),
Romans and Marcoule
(4 - fuel element fabrication),
La Hague
(5 - reprocessing) and the
Soulaines
(6) site for the Low and Medium Activity Nuclear Waste repository.

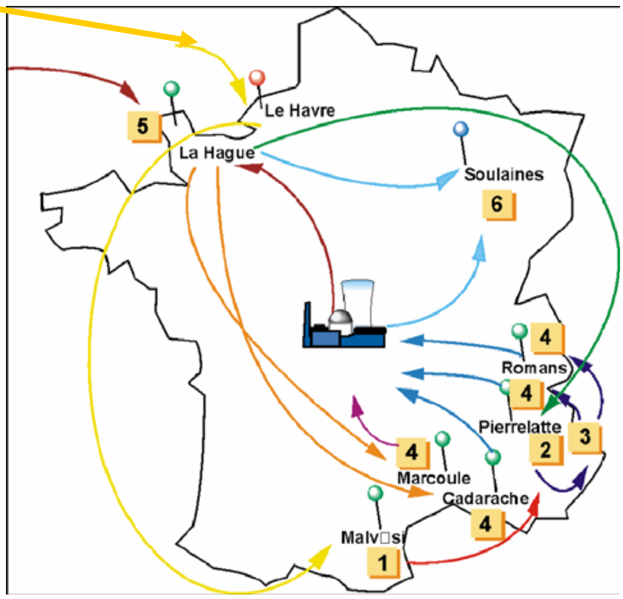


Figure 3.15: Main French sites of the nuclear fuel cycle.

In the front end section of the nuclear cycle, the uranium materials (mainly yellowcake - U_3O_8 concentrate - but also in particular cases UF_6) are transported in special containers, first on land by trucks and railway vehicles and then overseas by ships, from the mines (in Canada, Africa and Australia) to European ports.

The International Maritime Organization (IMO) is the specialised agency of the United Nations Organization providing the mechanism for Member States to develop regulations and codes of practice to preserve safety of life at sea, ensure maritime security, and protect the marine environment from pollution by shipping. The IMO provisions for radioactive material are based on the IAEA Regulations and are incorporated into the IMO International Dangerous Goods Code.

Uranium oxide concentrate is transported from the mines to conversion plants in 200-litre drums packed into normal shipping containers. No radiation protection is required beyond having the steel drums clean and within the steel container.

From the conversion plant, the uranium is in the form of uranium hexafluoride, which again is barely radioactive but has significant chemical toxicity. It is in special containers, which also function for storage.

Typical characteristics of a purpose-built ship are: length 100 m, deadweight 3800 t, displacement 7700 t, maximum cargo capacity 24 casks.

The infrastructures in the EU importing countries are essentially the port terminals where the purpose-built ships unload the casks of yellowcake.

At the present state of the art of the research, Le Havre in France and Preston have been identified as major import terminals. No particular port facilities are needed for the unloading operations of the containers or barrels and their loading on railcars or trucks.

Even if no official news are provided by the companies involved, also other European ports can be used for yellowcake import.

In general, for open sea corridors the quantity of commodities that can be shipped is limited only by the unloading and unloading capacity of the terminals, while the transport itself can be easily increased through the use of a larger number of carriers.

In the case of the uranium fuels, the volume of the materials involved is so little (with reference to the other commodities) that practically no limits exist to the capacity of the corridors.

3.6 Hydrogen

3.6.1 The identification of the corridors

The choice for final destinations in Europe of relevant quantities of hydrogen was based on some preliminary assumptions. At present, the main consumer of hydrogen is the oil and petrochemical sector. Refineries use hydrogen for hydro cracking and in hydrotreaters. It seems reasonable to foresee that in the next decades the hydrogen demand will continue to remain high from the petrochemical sector, also considering that the shortening of the reserves will force to upgrade more low level oil products derived from low quality oil crudes. As the first choice for the importing destinations, thus, some of the main petrochemical poles were selected, in Eastern and Western Europe. It was chosen, as far as possible, to consider import of hydrogen in the liquefied form to happen using ports where regasification plants for LNG were already in place and were oil jetties could ease the docking of LH_2 ships.

Some ports, like the one in Fos-sur-Mer, are to be considered as a gateway to the interior of Europe. From there, a hydrogen pipeline could be able to supply many of the heavy industries of a selected area. For example, in the Rhône valley, there is a concentration of concrete fabrication plants which require huge amounts of energy. In these basins, hydrogen could be used as an energy vector and a real energy source, not only a chemical additive. France and Germany could also be supplied with hydrogen imported through the gateway of Fos-sur-Mer. The consumption of hydrogen in these industrial basins is to be decided on the basis of the competition with other energy sources (electricity, oil products, natural gas).

Finally, hydrogen can be used to fulfil a demand of mobility, electricity and heat in the residential sector. To take into account for this possible evolution of the hydrogen demand, it has been supposed that also some big cities might be supplied with hydrogen through a pipeline network and a proper dedicated infrastructure. Athens, Bratislava, Warszawa, Marseille are among the cities which might be equipped with fleets of hydrogen buses (100 buses for an average 40,000 km/year each) and hydrogen cars (1000 cars, 2000 km/year). The corridors shown in Table 3.11 have been defined as links between hydrogen-supplying regions and hydrogen-demanding regions, such as sites with oil refineries, large energy demand centres and strategic ports as gateways to large industries in Europe. The geographical representation of these corridors is shown in Figure 3.16. A more detailed description of the hydrogen corridors can be found in Annex II.

Table 3.11: Definition of identified hydrogen corridors.

Corridor code	Type	Corridor name	Start	End
HYD_PIP_001	captive	Ukraine-Czech Rep.	Donetsk Basin	Litvìnov
HYD_PIP_002	captive	Ukraine-Poland	Donetsk Basin	Płock
HYD_PIP_003	captive	Ukraine-Slovakia	Donetsk Basin	Bratislava
HYD_PIP_004	captive	Ukraine-Hungary	Donetsk Basin	Százhalombatta
HYD_PIP_005	captive	Turkey-Bulgaria	Tupras Izmit	Burgas
HYD_SHP_001	open sea	Turkey-Italy	Ceyhan	Priolo
HYD_SHP_002	open sea	Turkey-Greece	Ceyhan	Aspropyrgos
HYD_SHP_003	mixed	Algeria-Italy		
	captive		Chott ech Chergui	Skikda
	open sea		Skikda	Gela
HYD_SHP_004	mixed	Algeria-France		
	captive		Chott ech Chergui	Skikda
	open sea		Skikda	Fos-sur-Mer
HYD_SHP_005	mixed	Algeria-Spain		
	captive		Chott ech Chergui	Skikda
	open sea		Skikda	Cartagena
HYD_SHP_006	mixed	Morocco-Spain South		
	captive		Off shore wind PP	Mohammedia
	open sea		Mohammedia	La Rabìda
HYD_SHP_007	mixed	Morocco-Spain North		
	captive		Off shore wind PP	Mohammedia
	open sea		Mohammedia	Gijon - Bilbao

Hydrogen can be transported in a variety of ways but all of them are marked by one of the most important features of hydrogen gas: its low density. To transport hydrogen with an acceptable efficiency, high compression or even liquefaction must be applied, and this costs energy. For the REACCESS project purposes, the following transport technologies were considered as the designed corridors are long enough to exclude the economical convenience of transportation by truck:

- compression + pipelines
- liquefaction + cryogenic ships

3.6.2 Pipelines

Transportation of compressed hydrogen via pipeline is one of the options that are presently investigated for the use of hydrogen as an energy vector. At present, the pipeline network for hydrogen transportation is very limited and derived from the natural gas technology. The operating pressures vary according to the networks and, in general, are comprised between 3.4 and 100 atm (Amos, 1998). The pipeline diameter may vary between 10 and 300 mm. More frequently, the operating pressure is about 10 to 30 bar and diameters are about 25 to 30 cm. For the REACCESS project, the corridors envisaged start from areas with quite high energy potentials and the supply region, being outside the EU is quite far from the final user. In this case, the pipeline could be dimensioned to deliver hydrogen even at a higher pressure (up to 75 bar) in order to be able to compensate for frictional losses in pipelines without too many booster compressors along the pipeline system. Compressors are generally set at a distance comprised between 200 and 300 km each other. Table 3.12 reports the summary of assumptions related to the cost and efficiency parameters for pipeline transportation.

Table 3.12: Parameters for the pipeline transportation of hydrogen (data from Toro et al., 2006, Hysociety, 2005 and Amos, 1998).

Parameter	Unit	Value
Pipe diameter	mm	200-2000
Investment cost	€/km	500,000 - 600,000
Lifetime	years	22
O&M pipeline	% investment	1
Pressure	bar	25-70
Compressor distance	km	200-300
Compressor consumption	kWh_{el}/kWh_{H2}	0.018-0.04
Compressor cost	€/kW	2500
O&M pipeline	% investment	1
Annual operating hours	h/yr	8400

3.6.3 Cryogenic ships

Transportation of hydrogen across the sea is of some interest only if liquid hydrogen is considered. Liquid hydrogen has some negative characteristics: it has a relatively low energy density (even if the situation is much better that with gaseous hydrogen) and it has an ultra low liquefaction temperature which leads to a very high storage cost. Nevertheless, in some circumstances, hydrogen transportation across the seas can be competitive and this justifies the continued research in long range transport of hydrogen using barges or ships. According to thermodynamics, about 14.2 MJ/kg_{LH2} should be removed to cool hydrogen from 298 K (25°C) to 20.3 K (liquefaction temperature) and to condense the gas at 20.3 K and atmospheric pressure. Existing liquefaction plants, though, have higher energy consumption to liquefy hydrogen because they have additional electrical, mechanical and thermal losses.

In the past years the design of cryogenic ships for transporting liquid hydrogen was further developed. One of the first countries interested in the topic was Canada, involved in the EQHHPP project (the Euro-Québec Hydro-Hydrogen Pilot Project 1991-1997). The amount of LH_2 produced in Canada was to be transported in one barge container ship carrying 5 vacuum insulated barge vessels with a content of 3000 m^3 LH_2 to Europe in 17 round trips per year. The overall system efficiency (hydro-electricity to LH_2 delivered in port) was above 50%.

Table 3.13 resumes the parameters assumed for the description in REACCESS of the transportation of liquid hydrogen via ship and of the liquefaction plant. It should be noted that a 720 t of LH_2 ship was selected, so that it is large enough to be able, in a reasonably dimensioned fleet, to distribute the hydrogen potential of some corridors.

Table 3.13: Parameters for the ship transportation of liquid hydrogen (data from Toro et al., 2006 and Hysociety, 2005).

Parameter	Unit	Value
Liquefaction plant capacity	kW_{H2}	284,000
Investment cost	€/kW	750
O&M plant	% investment	2
Annual operating hours	h/yr	8000
Lifetime	years	30
Electricity consumption	kWh_{el}/kWh_{H2}	0,25
Ship capacity	m^3 LH_2	10,000
Ship investment	€	34,400,000
O&M ship	€/year	5,160,000
Wages costs	€/year	2,160,000
Average speed	km/h	33
Lifetime ship	years	25
Fuel consumption (diesel)	liters/100km	5000

Figure 3.16: Identified hydrogen corridors in a map.

4 ASSESSMENT OF FRAMEWORK CONDITIONS

Financial and political framework conditions are important to open up new resources and technological potentials. In the following, important aspects regarding the import of commodities are discussed based on information collected in WP2 and WP3.

4.1 Oil and natural gas

There are several reasons for the recent increased focus on energy security to EU. An important catalyst was the natural gas dispute between the Russian Gazprom and Ukraine in 2006 where about 100 million m^3 gas expected in countries west of Ukraine was not delivered (Whist, 2008). Approximately 80% of the Russian gas exports are currently flowing through the Ukraine (Fakhri, 2009). The Nord Stream pipeline, from Russia to Germany through the Baltic Sea, is a project that will increase the diversification of natural gas routes from Russia to EU. Although the pipeline is not yet realised, it has been a subject for criticism by a number of states that are affected by the pipeline. Official documents from Finland, Estonia, Lithuania, Poland and Sweden have questioned why an onshore solution, that seems to be a cheaper option, has not been chosen. There are mainly two suggested alternatives; the Yamal 2 pipeline and the Amber pipeline. The Yamal 1 pipeline is currently bringing Russian gas to Germany through Belarus and Poland and the proposed Yamal 2 pipeline could be an additional pipeline along the same route. The suggested Amber pipeline would bring Russian gas through Latvia and Lithuania to Poland where it would join the Yamal pipeline to Germany (Whist, 2008).

The public concern of Sweden has been focused on military strategic issues. The pipeline will increase the presence of Russian military in the Swedish Exclusive Economic Zone. The Finnish concern is mainly focused on environmental issues. One can not compare the Baltic Sea to the North Sea; it is more sensitive to environmental impacts because it does not have the same degree of open access to the world oceans (Whist, 2008). The Baltic States and Poland have interpreted the pipeline as a Russian strategy to increase the Russian leverage on these countries (Whist, 2008). With the new pipeline Russia could cut the supply to the states of Eastern Europe without affecting the gas export to Germany.

Another project that may increase the diversity of gas corridors to EU in the future is the Nabucco natural gas pipeline. The pipeline would bring natural gas from Central Asia and the Middle East to Austria through Turkey, Bulgaria, Romania and Hungary bypassing Russia completely. One of the main critics of the project is that it is not clear where the natural gas will come from (Fakhri, 2009). Iran, with the world's second largest reserves, has voluntarily suggested feeding the pipeline but the offer was declined because of western sanctions (Pogany, 2009). Azerbaijan is the only country that has committed supply to the pipeline. In 2013 Azerbaijan is expected to produce between 18 to 19 bm^3/yr. Out of this Turkey is to receive 6 bm^3 and Georgia 0.3 to 0.8 bm^3/yr. Azerbaijan is left with maximum 12 bm^3/yr that is a minimum the country needs itself. It seems that Azerbaijan is not capable to deliver gas to the Nabucco pipeline before the Stage 2 of the Shakh-Deniz field is implemented. The field development has an expected maximum production rate of 8 bm^3/yr with start-up in 2016 (Mishin, 2008).

Algeria is the third largest supplier of gas to Europe after Russia and Norway. The Algerian export accounts for 20% of the European import and the export to Europe has doubled since 1994 to 60 bm^3/yr (Ghiles, 2009). Some concern was expressed on the reliability of the Algerian gas supply to Europe when the country was overwhelmed with violence in the mid 1990's. There was only one incident where an explosion cut of the gas supply to Italy for a few days in 1997 but no terrorist group got close to the export facilities in Arzew and Skikda (Ghiles, 2009). As a result of the current tensions of the Russian gas supply to Europe the focus on the Algerian policy has increased.

The Trans-Saharan pipeline from Nigeria via Niger to Algeria will bring Nigerian gas available on the European market. The 3rd of June 2009 Algeria, Niger and Nigeria signed a contract to build the more than 4000 km pipeline. Nigeria's militant Movement for the Emancipation of the Niger Delta has however threatened to attack the Trans-Saharan pipeline as a result of their demand that the international oil companies shall leave the Niger Delta (Watkins, 2009).

There are several challenges with a new captive oil and gas corridor to EU. The reasons may be political, economical or environmental related. It is difficult to predict how the future corridor situation will be because of all the uncertainties related to the accomplishment of a project.

4.2 Solar electricity

The EU Commission has decided to tackle climate change as one of the biggest challenges that have to be faced. In March 2007 the European Council agreed to set legally binding targets to show Europe's determination. One target is to reach a 20% share of renewables in overall EU energy consumption including a 10% renewable energy in transport fuel as set out in the new Renewables Directive 2009/28/EC (EC, 2009). Starting from a share of 9% renewable energies in the EU final energy consumption in 2005, an increase of 11% is needed until 2020 which has been turned into binding national targets for each member state. Long term targets beyond 2020 of member states comprise a further significant increase of renewable energy use, especially for electricity generation. For instance the German Lead Scenario for the 'Strategy to increase the use of renewable energies' follows the long term target of producing more than 80% of electricity by renewables up to 2050 (Nitsch, 2008).

To reach these set goals the countries of the European Union are free to decide on the promotion schemes they want to adopt. There are mainly three approaches chosen. Feed-in tariff systems provide investors with low risks due to fixed remunerations over a given length of time and have proven to be not only most effective but also most efficient. Therefore the majority of states have adopted this tool so far. The second approach that is chosen by a number of states is the quota system which is often referred to as the more market based promotion scheme. The third approach is a promotion due to tax incentives and/or investment grants used as the major promotion instrument in two countries but additionally provided by some other countries with feed-in tariff or quota systems (Klein et al., 2008). Most national promotion schemes only cover the expansion of capacities inside their own borders. However, the Renewables Directive 2009/28/EC allows member states to import electricity from outside the EU. An additional feed-in tariff for solar electricity imported from North Africa could be a promising promotion scheme for EU member states in order to implement this renewable supply option.

The Union for the Mediterranean founded in 2008 and the Mediterranean Solar Plan as one of its key initiatives are important political processes recently developed. The Mediterranean Solar Plan will comprise a Master Plan Study that will elaborate in detail the strategy and measures necessary until 2020 to implement a total of 20 GW of renewable power capacity in MENA, save 20% of energy compared to business as usual and to start with first projects for the export of solar electricity from MENA to Europe. Another recent initiative is the DESERTEC Industrial Initiative of more than 20 industrial leaders from Europe and the Mediterranean area with the explicit target to realise the DESERTEC plan (see www.desertec.org) of importing about 15% of the EU27 electricity demand in the long term future and to invest more than 400 billion € to achieve this target (founding meeting on July 13, 2009). The ideal framework for the implementation of solar power imports is a multinational private-public initiative under favourable conditions providing incentives and investment guarantees.

Most transmission system operators (TSO) are state owned within the EU27+. State ownership is also the standard for TSO in South Mediterranean countries, except the kingdom of Saudi Arabia. In some EU countries few companies are used to not only hold the transmission grid but also most of the electricity generation of the same area. With the liberalisation of the energy sector in Europe and the formation of international European markets non-discriminatory access to the grid became a requirement. In order to ensure the independence of TSO and real competition between electricity producers it became important to prevent situations with a conflict of interest. Therefore strategic unbundling becomes the requirement for companies within the EU, Norway and Switzerland. Since then there have been discussions whether this change was enough to open the market to new protagonists or if ownership unbundling would be the necessary step. Instead most countries have decided to improve the situation by setting up regulators.

Historically the electricity markets in the South Mediterranean region are state owned monopolies. Due to the expected increase of electricity consumption in this region large investments are necessary to occur. In order to facilitate the needed investment in the power generation sector Morocco, Turkey, Tunisia and Egypt started to allow private participation in the production of electricity in the mid 1990ies. As a result 16% of the current installed capacity in these countries is in the hand of independent power producers. Power Purchase Agreements (PPA) were set up with the new producers as suppliers still remained to be monopolies. Experience has shown that the measures taken were not enough to attract the amount of investment needed. Foreign investors still regard the South Mediterranean region as risk intense and therefore relative unattractive for investment. Therefore many countries in the region have started to adopt further steps towards liberalized electricity markets providing private foreign investors with more guarantees (OME, 2008).

Generally new as well as established power producing companies can commission CSP plants. However, this depends on the market access as well as the cost-benefit-ratio this technology can provide for each entity. So far conventional energy sources in the South Mediterranean region are subject to high subsidies. As a result solar electricity production by CSP plants can not yet compete against conventional sources even though it can be produced much cheaper in this area compared to Europe due to higher insolation. Therefore a promotion system like Power Purchase Agreements might be in order for the integration of renewable energy sources in the South Mediterranean electricity system. Regarding potential exports to the EU27+ electricity from CSP installations have to compete with the European market where prices for conventional energy carriers follow the world market. One option discussed is to enhance national regulations for feed-in tariffs as important incentive and financial guarantee.

4.3 Coal

To get an impression of possible extensions for coal transport by barges, historical time series help to estimate further growth rates. The Rhine is the most important inland water axis for coal transportation with 18 million t in 2000. On the Danube the same number for solid mineral fuels (including in addition to coal, also coke and lignite) was 4 million t in 2000 and 6.8 million t in 2005. In addition, the NEA estimates for the growth of imports in the Rhine corridor is around 7% on average for the entire period from 2000 to 2020. Transport growth for the Danube corridor is 20% for Bulgaria, but almost constant for Austria and Romania. In the same way, coal import is assumed to increase only slightly in the North-South corridor by 7% in

France and Belgium for the period 2000 to 2020. Growth in coal transport, however, is predicted in the East-West-corridor.

Coal import through the East-West corridor is anticipated to increase by 120% in Germany, 102% in Poland and 90% in Czech Republic. The prognosis of the German Federal Ministry for Transport in 1997 predicts cargo transport on German waterways to increase for coal from 27 million t in 2000 to 37 million t in 2015 (BMV, 1997).

In accordance with the substitution of domestic coal production by imported coal, inland water transportation will be subject to structural change on a few inland waterways. Coal pusher barges with 4 and more units from the ARA-ports will increase. Table 4.1 gives an overview of inland navigation relations where coal transport is expected to increase. In comparison to the NEA transport study, the numbers of (PLANCO, 2003) imply a much stronger growth in coal transport in the Rhine and the East-West corridor.

Table 4.1: Expected development of inland transport of coal by ship in Germany – prognosis for 2015 in 1,000 t.

Origin	Destination	2000	2015	absolute change
Poland	Frankfurt/Oder	37	3486	3449
Rotterdam	Wesel	828	2854	2026
Rotterdam	Dortmund	1962	2764	803
Rotterdam	Duisburg	2150	2793	643
Rotterdam	Essen	765	1373	608
Poland	Berlin	818	1302	484
Rotterdam	Stuttgart	345	761	416

Because of the lack of reliable data, an estimate of investments into coal handling capacities is difficult. Cost estimates for coal infrastructure in Australian coal ports indicate an average specific investment cost of US$ 13 per annual ton, though they tend to be lower than in Europe because of economies of scale. To estimate the cost of port expansion in European ports we use therefore the following approach:

Starting from a 2 €/t handling charge (Segerer & Heinecker, 2001), a lifetime of 30 years for a coal terminal and an internal rate of return of 10%, we assume 20.7 € per annual ton handling capacity as specific investment cost.

Since the inventory of dry cargo transporting indicates that there is no shortage of inland water vessels and both self-propelled and push vessels can be used for different kinds of dry cargo transport, it is possible to assume that the vessel infrastructure does not represent a bottleneck in the coal transport chain. Furthermore, investments for vessels are taken into account through depreciation and interests in the fixed costs calculation.

4.4 Biomass

The factors that may define the future development of the biomass market are price competitiveness of bioenergy, the availability of resources (itself depending on several factors, amongst them, the sustainability characteristics of the biomass), the technological development, especially regarding the second generation conversion technologies, as well as the policies related to:

- Supply (to stimulate the production - effect on the availability of resources): Especially countries of Latin America are enacting legislation/policies to promote the production of biofuels, following the examples of the leading biofuels producers Brazil, EU and the USA. There appear to be less regulatory framework in place for bioenergy in Asia, and even less in Africa.
- Demand: The current European Renewable Directive 2009/28/EC promotes the use of biofuels. However, EU27+ might face competing biomass importers such as the USA, Japan and China.
- The trade in biofuels: EU and the USA preferential trade promotion initiatives and agreements offer opportunities for developing countries to benefit from the increasing global demand for bioenergy. But they also apply import tariffs limiting the imports of biofuels or biomass.

In fact, the future demand and supply of biomass and biofuels, resulting from all the factors above, appear to be the most important risk and uncertainty related to the availability of biomass biofuels for Europe, more than the path of the corridors themselves as it is the case for fossil fuels.

In Europe, the primary policy tool behind the development of biofuels is the Directive on the promotion of biofuels for transport (EC, 2003). Most member states national targets followed the reference value of 5.75% by 2010. The new Renewable Energy Directive of April 2009 sets a 10% binding target for energy from renewable sources penetration in all form of transport in 2020 (EC, 2009).

In order to reach the biofuel targets, biofuels are supported on an EU and Member State level with a wide variety of measures such as command and control instruments, economic instruments, procurement instruments, collaborative instruments, communication and diffusion instruments. These measures can be pointed at various stages of the fuel chain.

In other countries outside the EU, there are a number of different policy measures being implemented to support the development and use of biofuel industries. countries of Latin America are enacting legislation/policies to promote the production of biofuels, following the examples of the leading biofuels producers (Brazil, EU and the USA). With the exception of a few countries like Philippines and Indonesia, there appear to be fewer regulatory frameworks in place for bioenergy in Asia, while Africa appears to have the least regulation and policies for bioenergy (Jull et al., 2007). China is a net exporter of bioethanol with Japan, Korea and other Asian countries being the predominant export destinations for Chinese ethanol. However, China has an ambitious biofuel penetration target of 15% in 2020. Furthermore, Chinese ethanol exports in 2007 dropped by 88 percent from the previous year, as a result of export rebate removal and this policy is expected to continue in the next years. These two facts could lead to a lower amount of bioethanol available for exports. Japan is also incentivising the production and use of biofuels. Since Japan has a limited potential for agricultural production of biofuels feedstock, its strategy would include the use of agricultural and forest residues to produce biofuels with second generation technologies, the import of biofuels from outside (mainly bioethanol from Brazil) or the investment in joint ventures with companies from producer countries, mainly Brazil. Some important biodiesel exporter countries such as Argentina (5% in 2010) and Indonesia (10% in 2010, 20% in 2025) are also setting ambitious targets for biofuels use. As result, these countries could reduce the amount of biodiesel available for exports to supply the European demand.

The sustainability debate related to the use of energy crops to produce biofuels is considered as the greatest barrier to biofuel trade in the future years (Kojima et al., 2007). For example, the cultivation of soybeans in Latin America and palm in Indonesia and Malaysia is associated to the additional pressure on land and on valuable ecosystems such as rain forests (burning and clearing) and the violation of land property rights of small farmers. The water issue appears also crucial, especially in the context of higher climate variability. The contribution of large-scale plantation to the local economy, the quality of employment, the potential use of child labour is also considered. The link between the biofuel and food markets is another crucial part of the debate, more particularly regarding the impacts on food prices (increase, volatility) and poverty alleviation. The biotechnology issue might be another limiting factor. Genetic modification of energy crops could increase the yield for example. However, many countries are highly opposed to import genetically modified products.

However, dedicated woody energy crop plantations are considered as more sustainable. If designed and managed wisely, they can contribute to soil carbon accumulation, soil fertility, reduced nutrient leaching, shelter belts for the prevention of soil erosion, plantations for the removal of cadmium from contaminated arable land (phytoextraction), and vegetation filters for the treatment of nutrient-rich, polluted water (Junginger et al., 2006). They also require very few inputs of herbicides and pesticides. Finally, the international classification and certification of biomass, including minimum social and ecological standards and tracing biomass from production to end-use, might ensure the sustainability of biomass. However, such a system is complex and raises many questions (criteria, control process, additional cost, risk of leakage, compatibility with international treaties and WTO rules, distinction with the different uses of biomass, etc.).

4.5 Nuclear fuels

A relevant contribution to the knowledge of the EU nuclear supply situation has been given by the study on the "Analysis of the Nuclear Fuel Availability at EU Level from a Security of Supply Perspective, developed by the Task Force on Security of Supply of the Advisory Committee of the Euratom Supply Agency developed before the EU enlargement on May 1st, 2004".

The study puts in evidence that the nuclear fuel supply is important, since nuclear reactors are a key element in the EU electricity supply, and a stable system of electricity supply is essential for the European citizens and for the economy.

Even if nuclear fuel used in the EU is largely locally processed (conversion, enrichment and fuel fabrication), natural uranium is almost totally imported. However, due to geopolitical conditions, uranium imports are less vulnerable than imports of oil and gas.

The primary production of natural uranium covers only some 60% of world demand, while the remaining part comes from historical production (inventories and weapons dismantling) and from the re-enrichment of tails of depleted uranium resulting from the enrichment process.

Until the mid 1980's, primary production was above consumption, but after the scaling back of new nuclear power programmes, investments in mining were also curtailed and a steady reduction of inventories followed.

The ESA study verifies that the production has been progressively concentrated in a limited number of facilities, while the opening of new mines or processing facilities is being involving years of environmental and safety assessments, which mean that new supply lines cannot quickly respond to an increase in demand.

Finally, the study stated the "transport is an essential part of the nuclear fuel supply chain, in particular for conversion and enrichment, due to the geographical imbalances of their production between Europe and North America.

New transport regulations and the reluctance of many ports and carriers to accept nuclear materials as cargo put a threat on these necessary movements of nuclear materials."

It is important make a distinction between delivery disturbances occurring in the short term and long term, because only for this last situation the market and industry have time to react.

The proved reserves (=reasonably assured below 40 $/kgU extraction cost) and stocks will be exhausted within the next 30 years at current annual demand. Likewise, possible resources – which include all estimated discovered resources with extraction costs of up to 130 $/kg – will be exhausted within 70 years.

At present, of the current uranium demand of 67 ktU/yr only 42 ktU/yr is supplied by new production, the rest (about 25 ktU/yr) is drawn from stockpiles which were accumulated before 1980. Since these stocks will be exhausted within the next 10 years, uranium production capacity must increase by at least some 50% in order to match the future demand at current capacity.

Recent problems and delays with important new mining projects (e.g. Cigar Lake in Canada) give rise to doubts as to whether this expansion will be completed in time or can be realised at all.

If only the proven reserves below 40 $/kgU can be converted into production volumes, then supply problems are likely even before 2020. If all estimated known resources up to 130 $/kgU extraction cost can be converted into production volumes, a shortage can at best be delayed until about 2050.

The competition with non-EU importers in the world energy market involves several large countries, either in the developed world as well in the developing one.

In comparison to the estimated amount of uranium resources required in 2009 by EU27+ countries (~22,600 tU), the main competitors – the USA, Japan, Russia, South Korea, Canada, India, Brazil, South Africa, Argentina – account for ~39,500 tU of the global figure of ~42,000 tU of the rest of the world.

4.6 Hydrogen

The possibility for hydrogen to become a real option for future energy systems is assured by the effort that all of the international organisations such as IEA and the European Commission are putting in developing frameworks, political tools and economic support. Many of the IEA member states participate in the Hydrogen Implementing Agreement (HIA); some of them plus non OECD counties such as Brazil, China, India and Russia participate in the International Partnership for the Hydrogen Economy (IPHE), established in 2003, which aim is to foster the transition to the hydrogen economy by supporting R&D and policy evolution.

The EU Energy Policy issued on the 10th of January, 2007 gave strength to the research targets that many institutions all over Europe had established in the previous years to develop a hydrogen economy. To depict a framework for these actions to be coordinated, it created the Hydrogen and Fuel Cell Technology Platform (HFP), which has the first purpose of "defining the technological and market developments needed by 2020 to create a hydrogen-oriented energy system by 2050". It should not be forgotten that the EU financially supports research on the hydrogen and fuel cells topic with specific measures in its Framework Programmes.

It is a shared objective of all the organisations to develop a strategy where hydrogen is first of all a fuel for clean transportation. The target of the EU is to have about 1.8 million hydrogen fuelled vehicles operating by year 2020 while for hydrogen to be exploited in the energy sector under various forms (distributed CHP generation, for example) it foresees a reasonable target in year 2040.

As our exercise in REACCESS has to explore the evolution of the supply corridors from year 2005 on, it seems reasonable to create the path from outside EU towards EU before the final high level end use technology is fully developed (hydrogen cars, buses, fuel cells for CHP), envisaging the first mass users of hydrogen as the petrochemical poles and then drifting the already settled supply network towards the urban user agglomerates when the technology is ready to penetrate.

5 SPATIAL INDICATORS AND SPATIAL ANALYSIS

Energy resources and corridors are especially subject to availability and security issues. Since these issues are highly dependent on the geographical setup of the energy supply system, a spatial analysis based on suitable indicators has been carried out to support the quantitative evaluation of risk and availability of corridors and their individual sections.

A distinction between captive and open sea corridors has been made: while captive corridors refer to spatially fixed systems, the open sea ones must be identified only within a certain spatial range. Therefore, their spatial identification is the result of a series of evaluations that will be presented in Section 5.2.

Since different transport technologies are involved, individual analyses have been carried out for the single commodities and the respective transport technologies, as shown in Table 5.1.

Table 5.1: Commodities and associated transport technologies.

Commodity	captive			open sea
	pipeline	power line	rail /road system	
natural gas [1]	X			X
oil [2]	X		X	X
electricity		X		
coal			X	X
biomass			X	X
nuclear fuels			X	X
hydrogen	X		X [3]	X

[1] compressed and liquefied [2] crude oil and refined products [3] for the upstream segments

Also the resource fields connected to the corridors have been geo-referenced as performed for the captive corridors.

The REACCESS project aims at considering existing as well as planned and proposed transport infrastructures for the different energy carriers: therefore, also these last infrastructures with their geographical setup have been considered.

HVDC power lines and hydrogen routes are neither existing nor yet planned as energy supply corridors for EU27+. Suitable assumptions on possible future HVDC systems and hydrogen routes were made by using a geographical model framework.

5.1 Spatial identification of captive corridors

The spatial identification and characterisation of captive oil and gas corridors and their energy resource fields have been mainly based on the information available in data sources listed in Table 5.2 and on the results of studies developed in the framework of EU and other organisation energy programmes (e.g. Encouraged).

Table 5.2: Data sources for captive corridor infrastructures.

CEFIC Petrochemistry Programme, 2002	EUROSTAT, 2008c
Cohen, 2007	GASUNIE, 2008
CYGAM Energy Inc., 2006	GTAI, 2006
De La Flor, 2005	Google, 2007
EEGAS, 2008	Google Earth Community, 2005
ENI, 2002	King & Spalding, 2006
EIA, 2003a	NCEAS, 2004
EIA, 2008b	Nigeria LNG Limited, 2008
EIR/HILL/G & F Int., 2003a	OAO Gazprom, 2006
EIR/HILL/G & F Int., 2003b	Petroleum Economist, 2006 (World Energy Atlas 2007)
EON Ruhrgas, 2007	Petroleum Economist, 2008 (World Energy Atlas 2009)
EON Ruhrgas, 2008	USGS, 2000b (Geological Provinces of the World)
ESRI, 2005	Waterborne Energy Inc., 2008
EUROSTAT, 2008b	

However, these datasets include a very large number of elementary infrastructures, even if belonging to the same energy “route” and can not be directly used for corridor identification and further detailed spatial analysis, without the help of additional information taken from other sources: mainly satellite images and results of ad hoc studies (see Figure 5.1).

As a consequence, a manual digitalization of pipeline infrastructures was considered necessary and was performed based on the information obtained from the generalised spatial setup. The improvement of spatial representation of the pipeline infrastructure was done via Google Earth satellite images and place names.

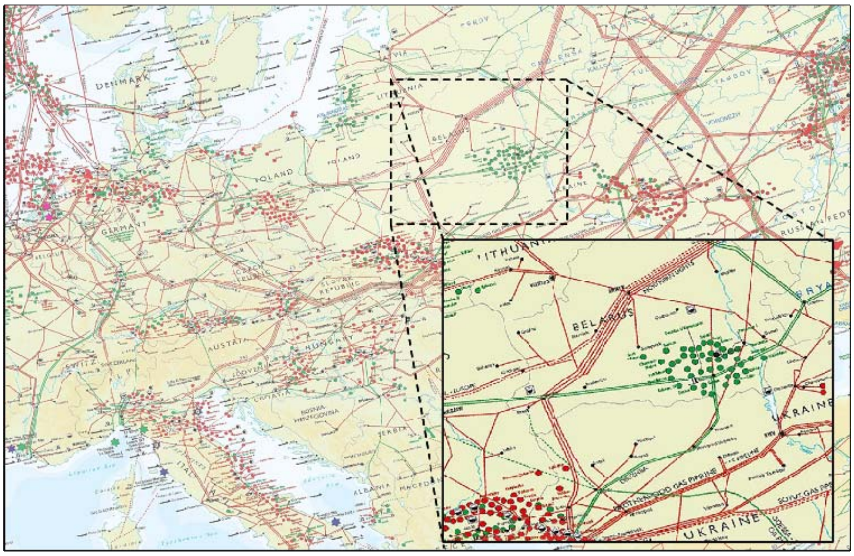


Figure 5.1: Screenshot from the World Energy Atlas 2007 outlining oil (green) and gas (red) pipeline infrastructure.

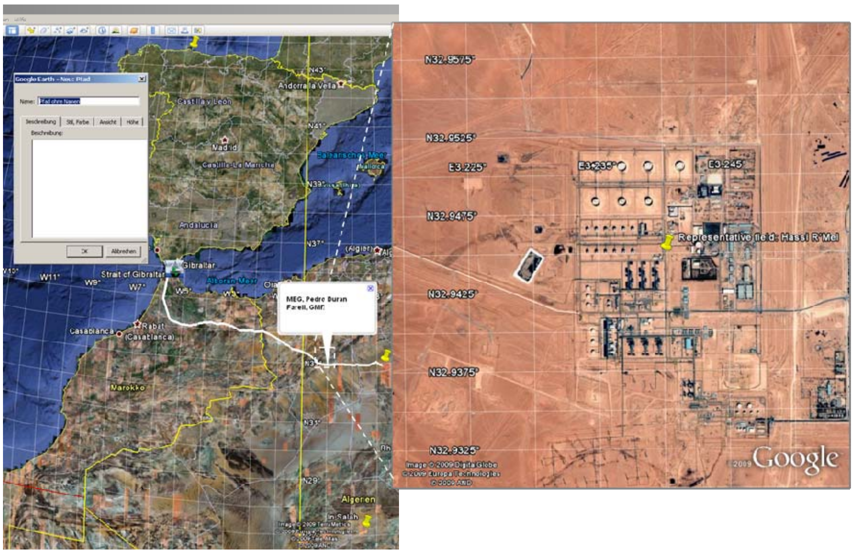


Figure 5.2: Manual digitalization of infrastructures (pipelines) with the help of satellite images.

Depending on the satellite image quality, the digitalization of pipelines (with a deviation from the actual infrastructure limited to a span from a couple of meters up to a few hundred meters) has been performed. This infrastructure dataset is appropriate for the use within a detailed spatial analysis, to produce quantitative evaluations about site dependent risk and availability aspects for each single corridor and for individual corridor sections. The next Chapter will describe the approach.

A corridor is defined by a **starting point** (e.g. energy resource field, port/terminal) in an exporting country and an **end point** (a port/terminal or a transfer facility) within EU27+ and often consist of **subsequent segments**, in the upstream and in the downstream ends, which are usually identified by natural or country boundaries.

The opportunity to consider these segments/sections separately arises from the need to give risk analysts suitable spatial details for their analyses.

The geographical setup of the captive oil and gas corridors and their source fields considered in the REACCESS project is outlined in Figure 5.3 and Figure 5.4, where only the external (from EU countries) parts of the corridors are represented.

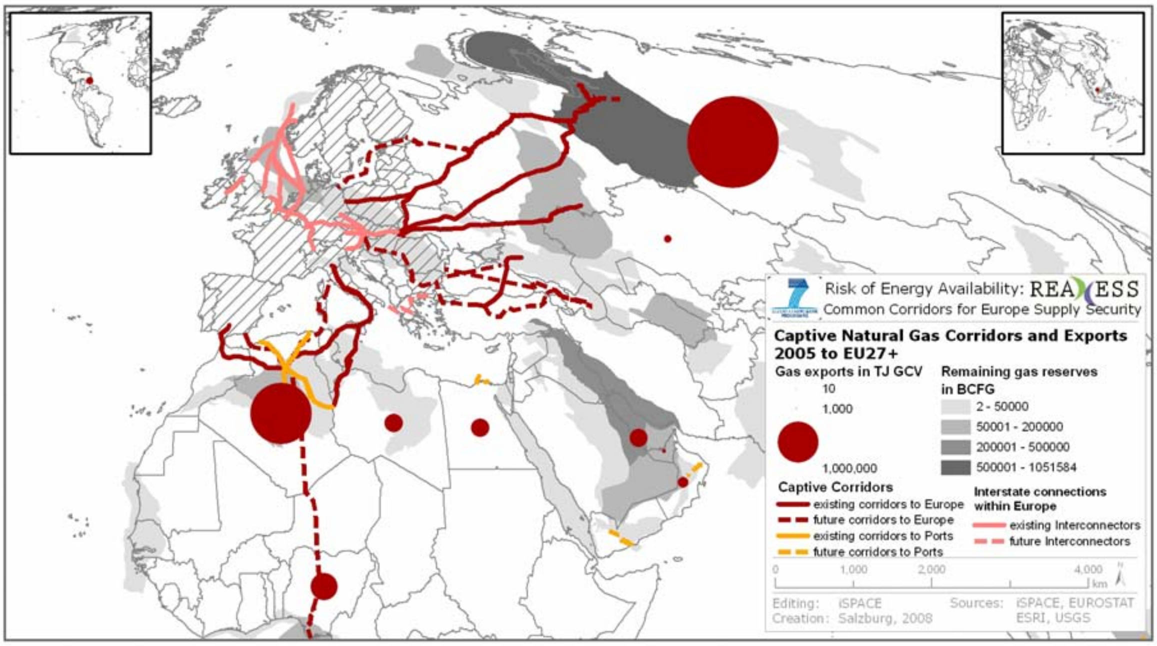


Figure 5.3: Examples of spatial setup of captive gas (red and orange lines) corridors to EU27+.

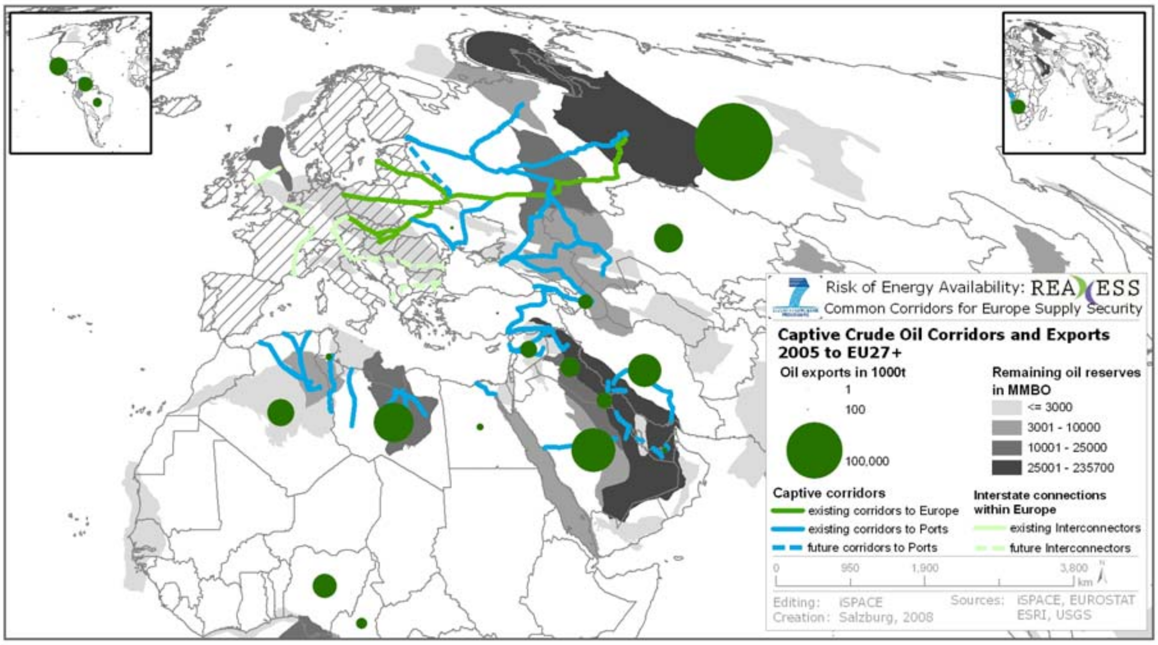


Figure 5.4: Examples of spatial setup of captive oil (blue and green lines) corridors to EU27+.

5.2 Spatial identification and characterisation of open sea corridors

Due to the relevant quantities of energy commodities exchanged by sea, their importance in the world economy and, in particular, the global distribution of the energy carriers, marine energy trade, with all its characteristics, must receive particular attention in the framework of a worldwide energy analysis. Table 5.3 shows the list of data sources used for open sea corridors analysis.

The work performed for open sea corridors linked quantitative considerations on the world maritime trade, collected by each commodity task team into the data base template, with the GIS representation of routes and infrastructures and the results of the analysis of their spatial characteristics. This work allowed to evaluate, from one side, the environmental impacts and, on the other side, the risk and security indexes of the whole European energy supply system.

It should be pointed out that the maritime routes are characterized by some degree of approximation because ships move along certain “sea lanes” that are not geographically fixed (as pipelines are): as a consequence, for the corridor’s spatial identification, a global GIS dataset outlining the global density of all shipping routes for all commodities, provided by the National Center for Ecological Analysis Synthesis (2004) was used as a background (see Figure 5.5).

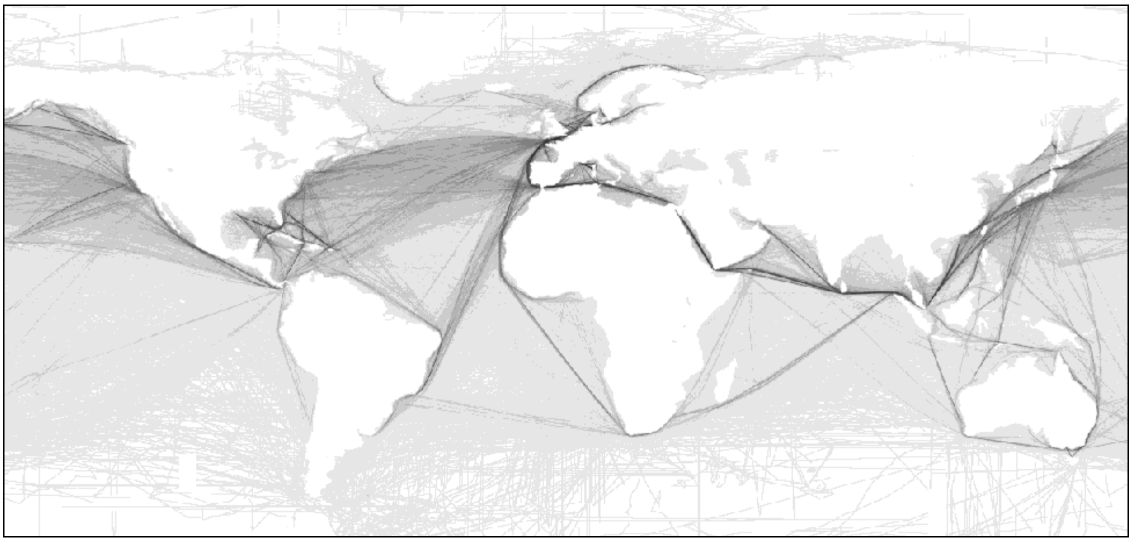


Figure 5.5: Global shipping routes. Source: National Center for Ecological Analysis and Synthesis (NCEAS, 2004).

Once the starting and destination ports of a corridor had been identified, the route with the highest shipping density between these two points was assumed. Very often, alternative paths (and therefore corridors) related to the same pair of ports were identified. For each commodity specific auxiliary shapefiles (with information upon routes, ports, fields and infrastructures) were created. The main results of digitalising the open sea corridors are presented in Figure 5.6 for oil, Figure 5.7 for LNG, Figure

5.8 for coal, Figure 5.9 for uranium fuels, and Figure 5.10 for hydrogen. Similar results were obtained for coal and biomass shipping trade.

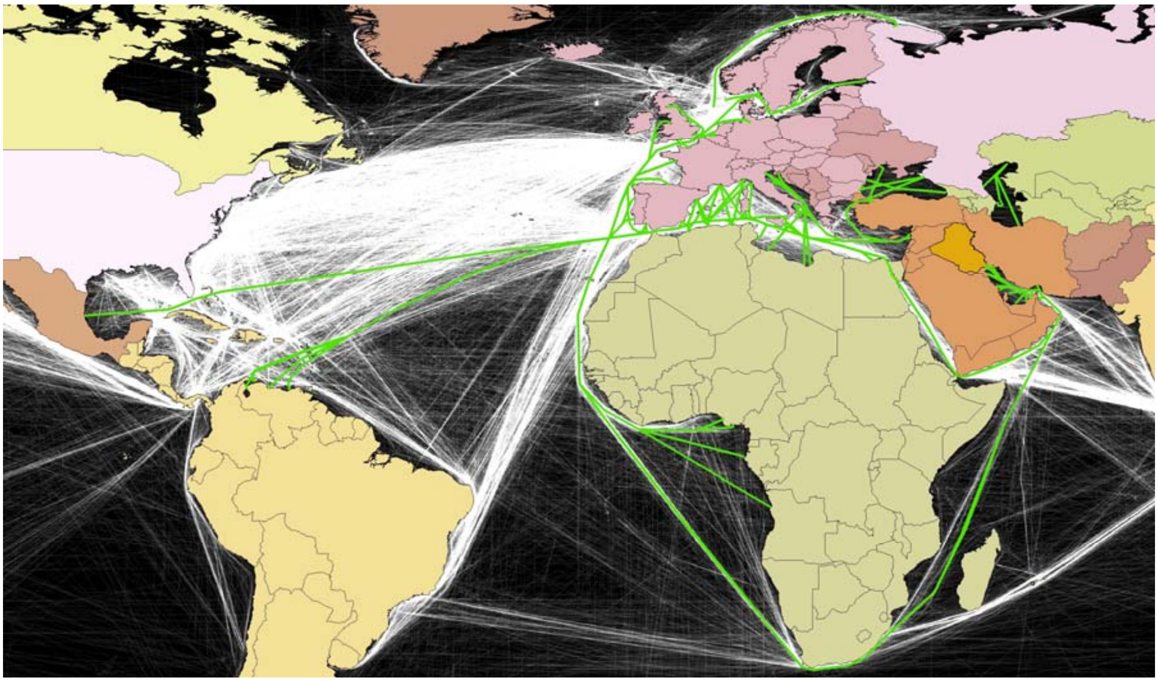


Figure 5.6: Main oil shipping routes to EU27+.

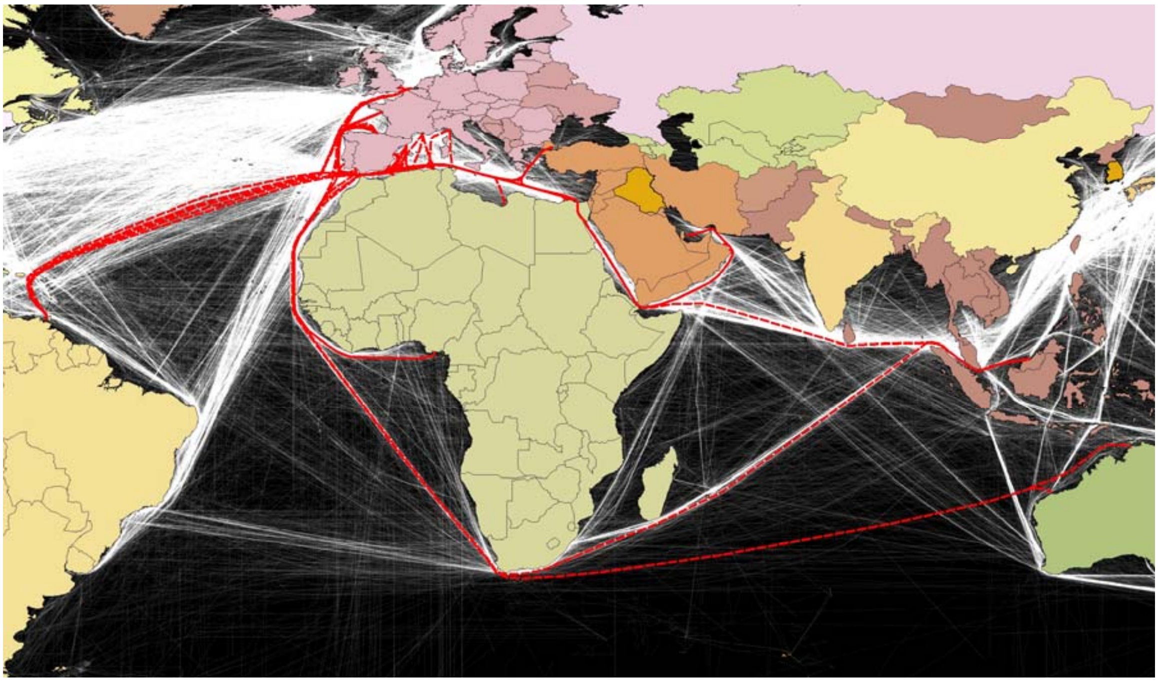


Figure 5.7: Main LNG shipping routes to EU27+.

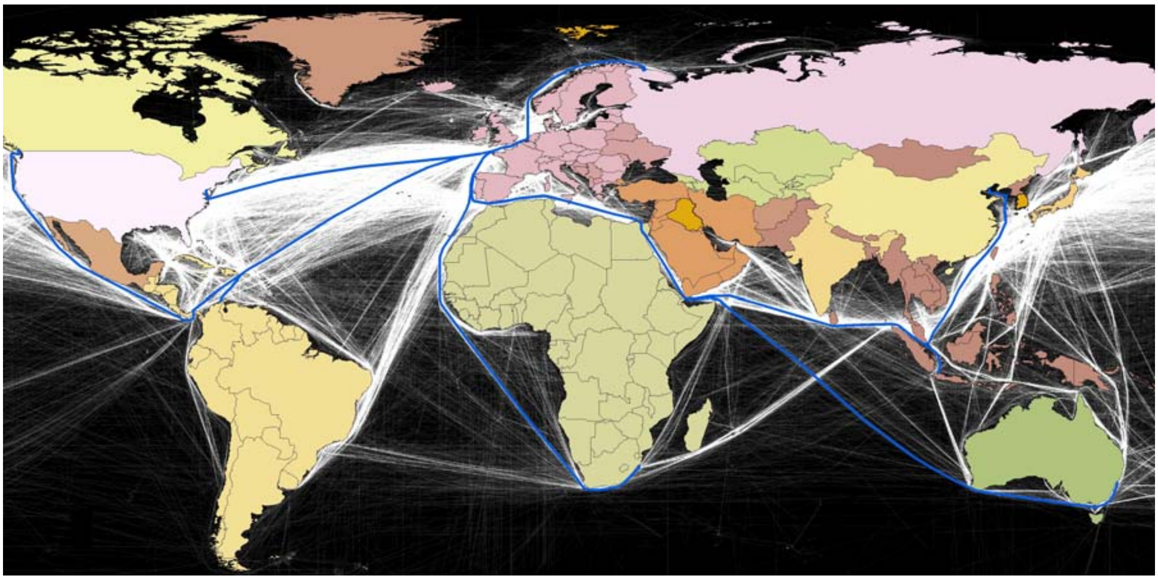


Figure 5.8: Main routes for coal supply to EU27+.

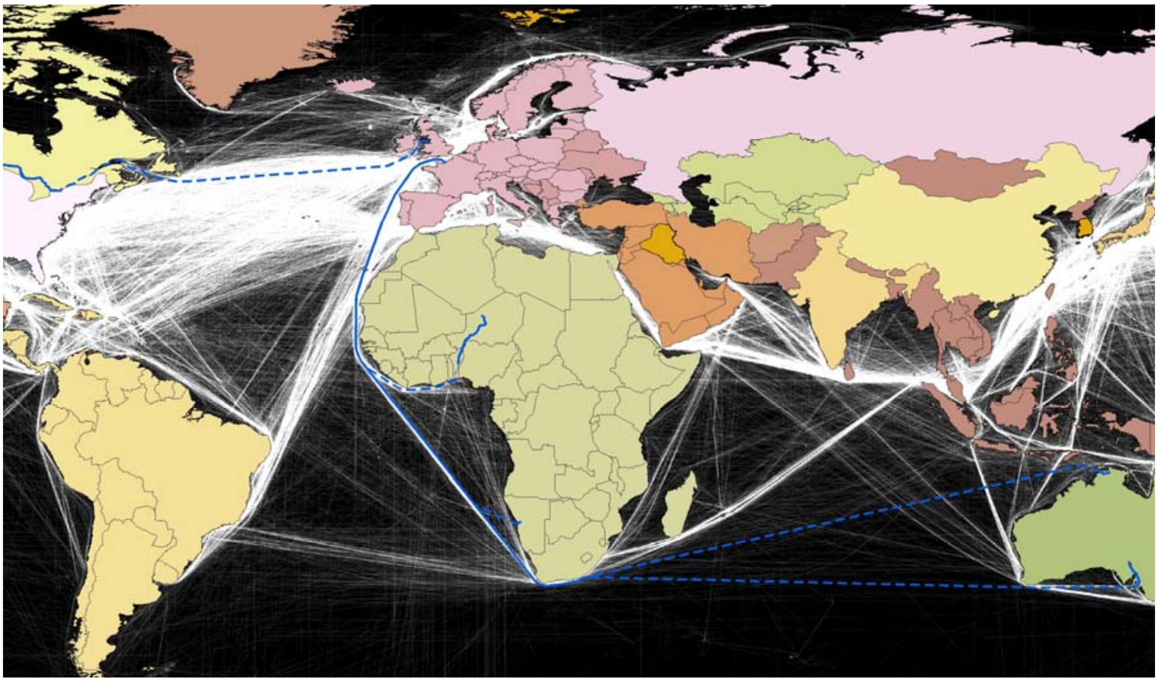


Figure 5.9: Main uranium shipping routes to EU27+ (with upstream corridor sections).

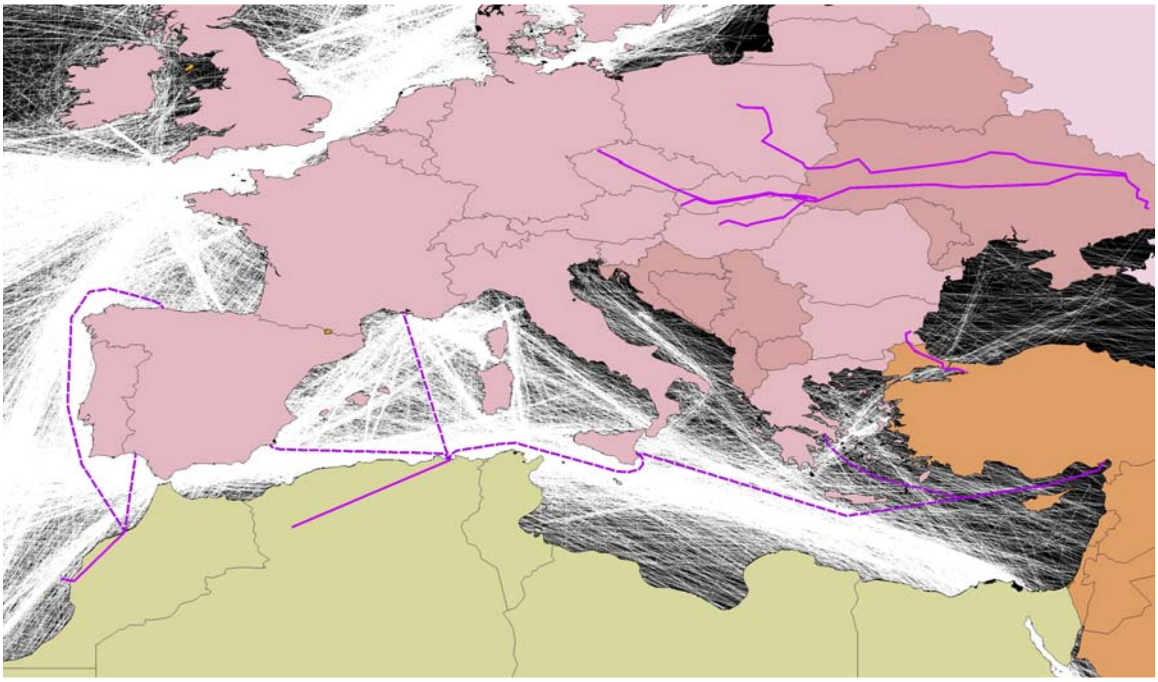


Figure 5.10: Main hydrogen routes to EU27+ (open sea and captive corridors).

Table 5.3: Data sources for open sea corridors analysis.

Petroleum Economist, 2008 (World Energy Atlas 2009)
Steminorder, 2009 (Global Shipping Platform)
EIA, 2009a (Annual Energy Outlook 2009)
ESRI, 2008 (Data & Maps world dataset)
Google, 2007
EUROSTAT, 2008d
ENI, 2006 (World Oil and Gas Review)
NCEAS, 2004
EIA, 2009b
WDPA, 2009 (World Database on Protected Areas)
IMO, 2009
GSIS, 2009 (Global Integrated Shipping Information System)
ABS, 2009
RINA, 2009
World Shipping Register, 2009
World Port Sources, 2009
GTI, 2009 (Global Trade Atlas)
ICS & ISF, 2009
Google Maps, 2009
ITOPF, 2009

5.3 Detailed spatial analysis of captive and open sea corridors

5.3.1 Captive corridors

The following parameters were taken into account for the characterisation of and spatial analysis for *captive corridors*:

- length and average slope of each corridor section,
- protected areas within a defined radius around each corridor section,
- population density within a defined buffer (5 km to 50 km) around each corridor section,
- human influence index for each corridor section,
- land use within a defined buffer (50 km to 10 km) along the corridor,
- risks of natural hazards for each corridor section.

Like in every GIS tool, the information associated to the corridor can be represented graphically in order to put into evidence particular data or characteristics.

Table 5.4 outlines spatial indicator datasets that have been utilized to carry out the spatial analysis for the captive energy corridors.

For each single corridor section a spatial buffer has been made for the evaluation of the underlying indicator sets. The buffer size has been defined with reference to the potential influence a single indicator dataset could have on the corridor (Figure 5.11).

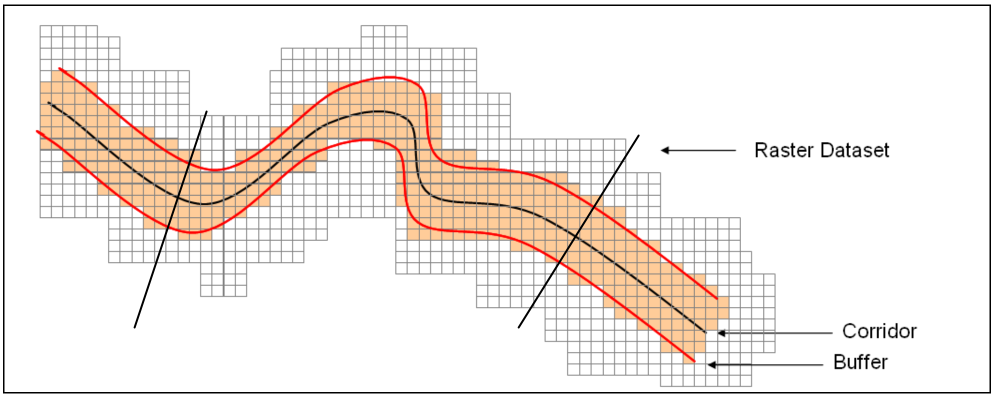
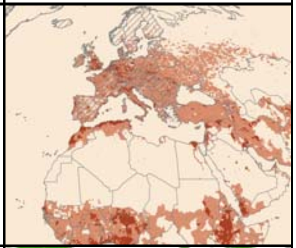
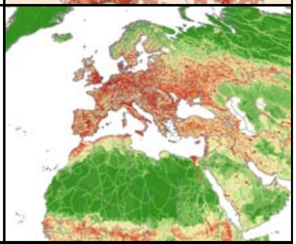
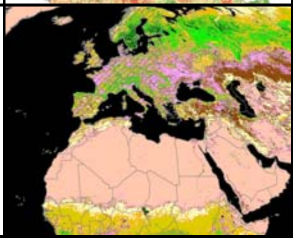
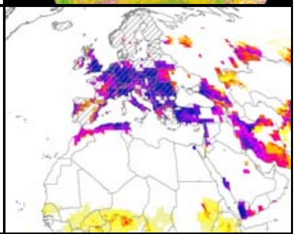
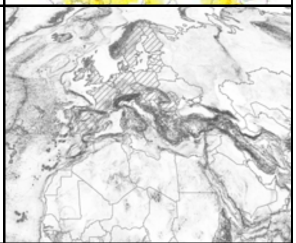
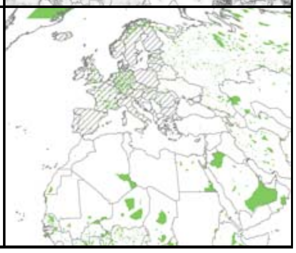


Figure 5.11: Buffer analysis on corridor section.

Table 5.4: Spatial Indicators considered for the spatial analysis.

Index	Unit	Source	Resolution	Map
Population	Specific population per area (Persons / sqkm)	CIESIN, IPFRI, World Bank; and CIAT, 2004	1 km	
Human Influence Index	Categorised human influence (0..64, 0 means no influence, 64 means total control)	WCS and CIESIN, 2005	1 km	
Landcover	Categorised Land cover Classes (14 Classes; reduced to 4 classes)	Hansen, M., R. DeFries, J.R.G. Townshend, and R. Sohlberg (2000),	1 km	
Hazards *(Volcano, Cyclone, Flood, Landslide, Earthquake)*	Categorised economic loss risk (1..10; 10 means maximum risk)	CIESIN, 2005	5 km	
Slope	Categorised slop classes in % (3 classes) derived from SRTM30 DEM	NASA and NIMA, 2000	1 km	
Protected areas	International and national sites from the World Database on Protected Areas	UNEP-WCMC and IUCN, 2007	Different scales – vector data	

Suitable aggregations of the spatial indicator data underlaid by the buffer were performed using the following rules:

- Spatial indicators are represented by two different classes. Class 1 includes indicators that can be interpreted as threats to the corridor in terms of risks and/or availability. Class 2 includes indicators that present economic influences to the corridor.

- The indicator set outlining hazards (Class 1) can be interpreted as risk of breakdown of the corridor. Different categories of economic loss are distinguished. From the categories falling under the defined buffer the median and the maximum value are considered as most interesting for an interpretation of risk – and therefore also an economic loss – related to this corridor section.
- The economic indicators (Class 2) are classified into 3 categories for each indicator (outlined in Table 5.5). For each buffer, the share of area which is characterised by one of the categories is calculated.

Table 5.5: Categorisation within spatial indicators with economic relevance.

Indicator	Category 1	Category 2	Category 3
Terrain slope	plain (0% - 2%)	normal (2% - 15%)	mountain (> 15%)
Population density	low (< 5 Pers./km²)	medium (5 - 50 Pers./km²)	high (> 50 Pers./km²)
Human influence index	low (< 5)	medium (5 - 40)	high (> 40)
Land use	open land	forest	urban build-up

The above described spatial analysis has been performed for all corridors identified within the project. Each individual buffer is associated to a calculation of the attributes listed in Table 5.6.

Table 5.6: Calculated attributes within spatial analysis for each single spatial buffer.

<table>
<tr><td colspan="4">Length of corridor section</td></tr>
<tr><td colspan="4">List of crossed country IDs by corridor section</td></tr>
<tr><td rowspan="12">Percentage area share
(Class 2)</td><td rowspan="3">Terrain slope</td><td>category 1</td><td></td></tr>
<tr><td>category 2</td><td></td></tr>
<tr><td>category 3</td><td></td></tr>
<tr><td rowspan="3">Population density</td><td>category 1</td><td></td></tr>
<tr><td>category 2</td><td></td></tr>
<tr><td>category 3</td><td></td></tr>
<tr><td rowspan="3">Human influence index</td><td>category 1</td><td></td></tr>
<tr><td>category 2</td><td></td></tr>
<tr><td>category 3</td><td></td></tr>
<tr><td rowspan="3">Land use</td><td>category 1</td><td></td></tr>
<tr><td>category 2</td><td></td></tr>
<tr><td>category 3</td><td></td></tr>
<tr><td rowspan="10">Categorised Economic loss risk of Hazards
(Class 1)</td><td rowspan="2">Volcano</td><td>median</td><td></td></tr>
<tr><td>maximum</td><td></td></tr>
<tr><td rowspan="2">Earthquake</td><td>median</td><td></td></tr>
<tr><td>maximum</td><td></td></tr>
<tr><td rowspan="2">Floods</td><td>median</td><td></td></tr>
<tr><td>maximum</td><td></td></tr>
<tr><td rowspan="2">Cyclone</td><td>median</td><td></td></tr>
<tr><td>maximum</td><td></td></tr>
<tr><td rowspan="2">Landslide</td><td>median</td><td></td></tr>
<tr><td>maximum</td><td></td></tr>
</table>

The approach of the spatial analysis combines the geographical aspect which has to be considered in terms of evaluation of single corridors with the summarizing approach over single *model regions* in the REACCESS model.

5.3.2 Open sea corridors

For *open sea* corridors, in addition to the route lengths, other data were collected and geo- referenced:

- the presence and nature of chokepoints and bottlenecks along the sea route (which represent particular situations and must be considered as burden for the ship traffic);
- the characteristics (depth, max allowable cargo admitted,...) of main ports/terminals involved in the energy commodity trade;

In order to take into account (also for alternative option choice) the sea/river/lake characteristics and conditions, the following data (if available) were collected and geo-referenced:

- protected marine/fluvial areas,
- inland water characteristics,
- sea and inland water depths,
- presence of islands, streams, rapids, waterfalls,
- ice distribution (icebergs and ice fields),
- pack and ice shelves.

Particular attention was devoted to the distribution of population density and the land cover (split among desert, agricultural, urbanized and protected areas) around ports and terminals. If several EU destinations are to be considered for the same commodity route, the most relevant destination/port was chosen in order to simplify the modelling approach. The selection was also done using economic and trade data.

As far as the full characterisation of the energy ship carriers is concerned, several parameters were linked to each corridor in order to perform the requested economic (delivery costs) and environmental (polluting impact) evaluations:

- ship type, dimension and capacity,
- ship speed,
- loading and unloading time,
- chokepoint delay time or transit limits,
- investment, operation and maintenance costs,
- type and quantity of fuel consumed,
- pollutant emission coefficients.

The values of the distances between exporting and European ports are necessary for the evaluation of the transport costs and have been calculated (see oil port distance matrix in Table 5.8).

Summarising, for all the open sea corridors has been possible:

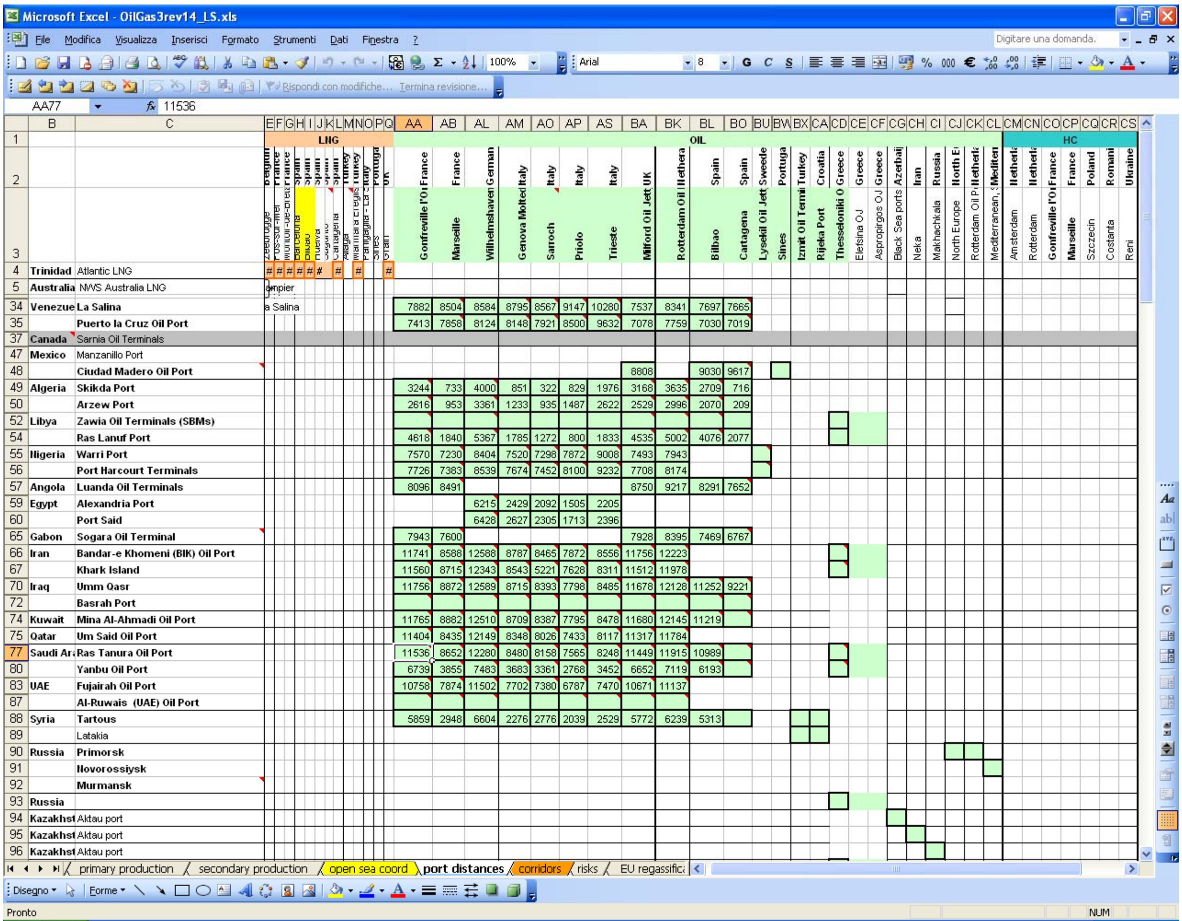
- to spatially represent the routes themselves
- to calculate their lengths
- to identify the number and the type of chokepoints and bottlenecks crossed by the routes
- to represent into the maps the most congested areas of ship transit (these data have been also used to evaluate and calculate alternative paths).

The approach of the spatial analysis combines the geographical aspect which has to be considered in terms of an evaluation of single corridors with the summarizing approach over single *model regions* in the REACCESS model.

Table 5.7: Categorisation within spatial indicators with economic relevance.

Indicator	Category 1	Category 2	Category 3
Terrain slope	plain (0% - 2%)	normal (2% - 15%)	mountain (> 15%)
Population density	low (< 5 Pers./km²)	medium (5 - 50 Pers./km²)	high (> 50 Pers./km²)
Human influence index	low (< 5)	medium (5 - 40)	high (> 40)
Land use	open land	forest	urban build-up

Table 5.8: Oil terminal/port distance matrix.



			Gonfreville l'Ol France	Marseille France	Wilhelmshaven German	Genova Molted Italy	Sarroch Italy	Priolo Italy	Trieste Italy	Milford Oil Jett UK	Rotterdam Oil I Nethera	Bilbao Spain	Cartagena Spain
4	Trinidad	Atlantic LNG											
5	Australia	NWS Australia LNG											
34	Venezue	La Salina	7882	8504	8584	8795	8567	9147	10280	7537	8341	7697	7665
35		Puerto la Cruz Oil Port	7413	7858	8124	8148	7921	8500	9632	7078	7759	7030	7019
37	Canada	Sarnia Oil Terminals											
47	Mexico	Manzanillo Port											
48		Ciudad Madero Oil Port								8808		9030	9617
49	Algeria	Skikda Port	3244	733	4000	851	322	829	1976	3168	3635	2709	716
50		Arzew Port	2616	953	3361	1233	935	1487	2622	2529	2996	2070	209
52	Libya	Zawia Oil Terminals (SBMs)											
54		Ras Lanuf Port	4618	1840	5367	1785	1272	800	1833	4535	5002	4076	2077
55	Nigeria	Warri Port	7570	7230	8404	7520	7298	7872	9008	7493	7943		
56		Port Harcourt Terminals	7726	7383	8539	7674	7452	8100	9232	7708	8174		
57	Angola	Luanda Oil Terminals	8096	8491						8750	9217	8291	7652
59	Egypt	Alexandria Port			6215	2429	2092	1505	2205				
60		Port Said			6428	2627	2305	1713	2396				
65	Gabon	Sogara Oil Terminal	7943	7600						7928	8395	7469	6767
66	Iran	Bandar-e Khomeni (BIK) Oil Port	11741	8588	12588	8787	8465	7872	8556	11756	12223		
67		Khark Island	11560	8715	12343	8543	5221	7628	8311	11512	11978		
70	Iraq	Umm Qasr	11756	8872	12589	8715	8393	7798	8485	11678	12128	11252	9221
72		Basrah Port											
74	Kuwait	Mina Al-Ahmadi Oil Port	11765	8882	12510	8709	8387	7795	8478	11680	12145	11219	
75	Qatar	Um Said Oil Port	11404	8435	12149	8348	8026	7433	8117	11317	11784		
77	Saudi Ara	Ras Tanura Oil Port	11536	8652	12280	8480	8158	7565	8248	11449	11915	10989	
80		Yanbu Oil Port	6739	3855	7483	3683	3361	2768	3452	6652	7119	6193	
83	UAE	Fujairah Oil Port	10758	7874	11502	7702	7380	6787	7470	10671	11137		
87		Al-Ruwais (UAE) Oil Port											
88	Syria	Tartous	5859	2948	6604	2276	2776	2039	2529	5772	6239	5313	
89		Latakia											
90	Russia	Primorsk											
91		Novorossiysk											
92		Murmansk											
93	Russia												
94	Kazakhst	Aktau port											
95	Kazakhst	Aktau port											
96	Kazakhst	Aktau port											

6 CONCLUSIONS

With regard to the EU27+ energy import situation and security of supply, expected developments and perspectives for each relevant commodity the following conclusions can be summarised as a result of the activities performed in WP2 and WP3.

6.1 Oil and natural gas

Conventional oil and natural gas resources are geographically uneven distributed. Saudi Arabia, Iran and Iraq are the countries with largest proven oil reserves where Saudi Arabia has 22% of the worldwide reserves. Russia, Iran and Qatar are the countries with largest proven natural gas reserves, where Russia has 27% of the worldwide reserves. Because of the uneven distribution of the reserves, oil and natural gas has being traded and transported all over the world since long time. Import corridors can be divided into captive and open sea corridors. The main direct captive oil corridor from Norway to EU is the Norpipe oil pipeline. There are other direct oil pipelines from Russia and Africa to EU. There are several captive gas corridors to EU: pipelines from Africa, Russia, Central Asia and Norway. The open sea imports of oil and gas to EU are carried out by crude oil and refined products tankers and by the LNG fleets. The import of LNG to EU has increased significantly during the past years with 88% from 1997 to 2007.

There are several pipeline projects that will increase the diversity of the corridors to EU if they are implemented. The **GALSI** pipeline will export gas from Algeria to Italy via Sardinia and the **MEDGAZ** pipeline will export gas from Algeria to Spain. The planned **Nord Stream** pipeline will transport gas from Russia and from Central Asia to Germany through the Baltic Sea the **Nabucco** pipeline will transport gas from the Turkey-Iran and the Turkey-Georgia border to Austria. Several project are aiming to constitute alternative transit routes from the Caspian and Central Asia giant fields.

6.2 Solar electricity

A well balanced mix of renewable energy sources backed by gas fired peaking plants can provide sustainable, competitive and secure electricity for Europe. An efficient grid infrastructure is required for the distribution of renewable electricity from the best centres of production to the main centres of demand. In addition to the domestic renewable energy sources in Europe, the huge potential of solar energy in North African and Middle East countries are a promising option for the import of renewable electricity to the European markets.

Solar electricity generated by concentrating solar thermal power stations in MENA and transferred to Europe via high-voltage direct current transmission can provide firm capacity for base-load, intermediate and peaking power, effectively complementing European electricity sources. Starting between 2020 and 2025, solar electricity imports could subsequently be extended to around 700 TWh/yr by 2050. High solar irradiance in MENA and low transmission losses of 10-15% may reduce solar electricity import costs to around 0.05 $€_{2000}$/kWh. Total technical power generation potentials in the seven MENA countries considered are calculated to amount to about 538.000 TWh/yr. A small share of less than 0.2% of the suitable land for CSP plants would be enough to supply about 15% of the electricity demand expected in EU27+ in 2050. The GIS analysis of possible HVDC corridors from MENA to Europe led to the description and characterisation of 37 possible import routes to 14 European demand centres. Systems of feed-in tariffs like those implemented in the German or Spanish Renewable Energy Acts are very effective instruments for the market introduction of renewables and may be also used for the promotion of solar power imports.

6.3 Coal

Europe imported about 200 million tonnes of hard coal in 2005 corresponding to more than 80% of coal consumption. Import dependency increased since the end of the 70s with a decreasing domestic coal production. Identified proven coal reserves of the world add up to about 21.3 million PJ of energy. The large potential and the relative low costs compared to oil and gas caused an increasing use of coal on the global scale in the past. Expansion of coal combustion is still promising for some countries although this will strongly increase CO_2 emissions and expected global climate effects. The implementation of a European or ideally global emission trading system could significantly increase costs for and reduce the amount of coal consumption.

Coal import to EU27+ is described through a number of open sea corridors, originating in supplying countries with destination Rotterdam and Marseille (the main coal hubs that distribute coal also to neighbouring countries) and also other coal ports in Europe. Some large waterways (mainly the Rhine and Danube Rivers) play a significant role in distributing coal to inland EU countries. This inland transport corridors are responsible for additional costs that are relevant for the assessment of coal import costs to EU27+.

6.4 Biomass

Bioenergy is a source of storable and widely usable non-fossil energy and therefore interesting for EU27+ energy policy in terms of energy security (through diversification) as well as GHG policy. The issue of the amount of bioenergy available for EU27+ (and thus, the competition for biomass with other potential countries and regions) is more important than the path/localisation of the corridors themselves (mainly open sea), contrary to oil and gas corridors.

The potentials for biomass are very uncertain and the use of at least two scenarios may be required. Bioenergy markets are very dynamic (many recent investments), and the calibration of the models to the year 2005 only may hide many changes in production and trade which occurred between 2005 and today. Sustainability issues related to the production of energy crops and biofuels is considered as the greatest barrier to biofuel trade in the future.

6.5 Nuclear fuels

Even if nuclear fuel used in the EU is largely locally processed, natural uranium is almost totally imported. Primary production of natural uranium covers only ~60% of world demand, while the rest comes from historical production (inventories and weapons dismantling) and from re-enrichment. Proved reserves (=reasonably assured below 40 $/kgU extraction cost) and stocks will be exhausted within the next 30 years at current annual demand. Likewise, possible resources – which contain all estimated discovered resources with extraction costs of up to 130 $/kgU – will be exhausted within 70 years. If only the proven reserves below 40 $/kgU can be converted into production volumes, then supply problems are likely before 2020.

Transport is an essential part of the nuclear fuel supply chain. In addition to the existing routes (from Canada, Australia, Niger and Namibia) for supplying uranium raw materials to the EU27+ countries where nuclear cycle are operating, new corridors will be established from Kazakhstan, Uzbekistan, South Africa and Gabon, where large deposits will start to be exploited by the decade 2010-2020.

6.6 Hydrogen

Hydrogen corridors from extra EU countries to EU27+ do not exist at present and have to be designed if in the future a significant hydrogen demand develops. As a starting point, some of the main petrochemical areas were chosen as final destination of hydrogen produced outside the EU as up to now refineries are the most important customers for hydrogen. In the future, when corresponding EU energy policy recommendations were effective and a hydrogen economy is established, new destinations will develop in big urban areas, where hydrogen will be used as fuel for clean transportation and as a clean energy vector to produce electricity and heat.

Liquid hydrogen corridors will have the same risk associated to transportation via ship as other fuels (e.g. LNG) as LH_2 will be shipped from North Africa and Turkey using known maritime routes. Pipelines will preferably stay in the path of other natural gas or oil pipelines thus risk indexes originated from socio political issues will be the same as for the other fuels. A specific assessment should be performed for the technological risk associated with hydrogen as its chemical and physical characteristics are different from those of natural gas.

7 REFERENCES

Abanades S., Charvin P., Flamant G., Neveu P. (2006). Screening of water-splitting thermochemical cycles potentially attractive for hydrogen production by concentrated solar energy - Energy 31 (2006), pp. 2805-2822.

ABS (2009). American Bureau of Shipping, Houston, USA (http://www.eagle.org).

Ahlbrandt T.S. (2000). The USGS world oil assessment, Published at Search and Discovery, June 2000, http://www.searchanddiscovery.net/documents/ahlbrandt/images/usgs.pdf (accessed 16th November 2009).

Amos W. (1998). The Costs of Storing and Transporting Hydrogen - National Renewable Energy Laboratory, US DoE, November 1998. Report no. NREL/TP-570-25106.

BCI (2008). Buck Consultants International, ProgTrans, VBD European Development Centre for Inland and Coastal Navigation, via Donau. PINE Prospects of Inland navigation within the enlarged Europe. Nijmegen. (http://ec.europa.eu/transport/iw/doc/ pine_report_report_full_en.pdf accessed on October 27th 2008).

BP (2008a). Statistical Review of World Energy 2008, (1998), (2006), British Petroleum (BP) (see http://www.bp.com/) (downloaded 2008).

BP (2008b). South Caucasus Pipeline - Supplying gas to meet the needs of regional consumers. BP p.l.c. website, About BP Caspian (downloaded 2008) (http://www.bp.com/sectiongenericarticle.do?categoryId=9006670&contentId=7015095).

BMV (1997). Bundesverkehrswegeplan 1997, Bonn (in German).

Campbell, C.J. (2000), “Peak Oil”, available at: http://www.hubbertpeak.com/de/lecture.html (accessed 16 November 2009).

CEFIC Petrochemistry Programme (2002). Locations of CIS Crackers. Online, downloaded 29th Sept. 2008 (http://www.petrochemistry.net/ftp/pressroom/cis.pdf).

CIEMAT, 2009 : Labriet M., Cabal H., Lechón Y.: REACCESS Technical Note 3.4.1 “Biomass: Present and future potentials for European and non-European countries” and Technical Note 3.4.2 “Biomass: Characterisation of Infrastructure and Corridors & Analysis of Policy Conditions”, CIEMAT Spain, May 2009

CIESIN et. al. (2005). Natural Disaster Hotspots – A Global Risk Analysis. Global Multihazard Total Economic Loss Risk Deciles. Downloaded 1st April 2009 (http://www.ldeo.columbia.edu/chrr/research/hotspots/coredata.html).

CIESIN, IPFRI, World Bank; and CIAT (2004). Global Rural-Urban Mapping Project (GRUMP): Urban/Rural Population grids. Downloaded 1st April 2009 (http://sedac.ciesin.columbia.edu/gpw/).

Cohen A. (2007). Europe’s Strategic Dependence on Russian Energy. Online, (http://www.heritage.org/Research/Europe/upload/bg_2083.pdf) downloaded 29th Sept. 2008.

CYGAM Energy Inc. (2006). Tunisia. Downloaded 29th Sept. 2008 (http://www.cygamenergyinc.com/operations-tunisia.html).

De Jonge R.J., Heijn D.V., Penn G. (eds.) (2004). Inland Water Transport. A Dutch Approach: Centuries of Experience. NEDECO Inland Waterway Transport Cluster, Agency for International Business and Cooperation of the Dutch Ministry of Economic Affairs. The Hague. (http://www.hollandtrade.com/vko/landenwater/PDF/Nedeco_bidbook.pdf accessed on 28th October 2008).

De La Flor F.P. (2005). LNG plants in Spain: Something more than projects. Presentation at the IEA/GLE Joint Workshop. Downloaded 29th Sept. 2008 (http://www.iea.org/textbase/ work/2005/LNGGasMarkets/session_7/3_Francisco_de_la_Flor.pdf).

Deffeyes K. (2008). Hubbert’s Peak: The Impending World Oil Shortage, Princeton University Press 2008, Princeton, New Jersey. EIA-Energy Information Administration.

Donaukommission (2007). Statistisches Jahrbuch der Donaukommission für das Jahr 2005. Budapest. (http://www.danubecomintern.org/ADOBE%20ACROBAT/Stat-ejeg-2005/Stat%20JB%202005.pdf accessed on October 28th 2008).

EC (2003). Promotion of the use of biofuels and other renewable fuels for transport. Directive 2003/320/ec. OJEU L123, 17 May 2003. Brussels, Belgium.

EC (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

ECE (2008). HVDC Projects Listing. University of Idaho, College of Engineering Department of Electrical and Computer Engineering (http://www.ece.uidaho.edu/hvdcfacts/Projects/HVDCProjectsListingMay2008-existing.pdf).

Ecorys (2007). Ecorys Transport, Mettle: Charging and pricing in the area of inland waterways – Practical guideline for realistic transport pricing. Client: European Commission – DG Tren. Rotterdam.

EEGAS (2008). East European Gas Analysis (EEGAS). Selected Maps and Schemes of Gas Pipelines of Russia and the FSU. Downloaded 29th Sept. 2008 (http://www.eegas.com/maps.htm).

EIA (2003a). Energy Information Administration (EIA): Selected Oil and Gas Pipeline Infrastructure in the Former Soviet Union. Downloaded 23rd Sept. 2008 (http://www.eia.doe.gov/cabs/Russia/images/fsu_energymap.pdf).

EIA (2003b). Energy Information Administration (EIA): The Global Liquefied Natural Gas Market: Status and Outlook (http://www.eia.doe.gov/oiaf/analysispaper/global/).

EIA (2007). Energy Information Administration (EIA): Performance Profiles of Major Energy Producers 2006. DOE/ EIA- 0206 (06), December 2007.

EIA (2008a). Energy Information Administration (EIA): Country Analysis Briefs. Central Asia (http://www.eia.doe.gov/emeu/cabs/).

EIA (2008b). Energy Information Administration (EIA): Langdon D. Clough (Editor) Energy profile of Russia. In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). Downloaded 23rd Sept. 2008 (https://www.eoearth.org/article/Energy_profile_of_Russia).

EIA (2009a). Energy Information Administration (EIA): Annual Energy Outlook 2009 (http://www.eia.doe.gov/oiaf/aeo/).

EIA (2009b). Energy Information Administration (EIA): Country Analysis Briefs (http://www.eia.doe.gov/emeu/international/contents.html).

EIR/HILL/G & F Int. (2003a). Inogate. Projects of Pan-European Interest. Proposed Priority Axes for Crude Oil Pipelines. Downloaded 23rd Sept. 2008 (http://www.inogate.org/en/images/maps/oil_map_big.gif).

EIR/HILL/G & F Int. (2003b). Inogate. Projects of Pan-European Interest. Proposed Priority Axes for Natural Gas Pipelines. Downloaded 23rd Sept. 2008 (http://www.inogate.org/en/images/maps/gas_map_big.gif).

ENI (2002). International Pipelines across the Mediterranean. Presentation in Paris 23rd March 2002. Downloaded 29th Sept. 2008 (http://www.cygamenergyinc.com/operations-tunisia.html).

ENI (2006). World Oil and Gas Review, 2006 Eni, Italy (http://www.eni.it/wogr_2006/index.html).

ENI (2008). Western Libyan Gas Project. Eni company (http://www.eni.it/en_IT/innovation-technology/projects/western-libyan-gas-project/western-libyan-gas-project.shtml) (downloaded 2008).

EON Ruhrgas (2007). Europäischer Erdgasverbund 2007. Downloaded 29th Sept. 2008 (http://www.eon-ruhrgas.com/cps/rde/xbcr/SID-3F57EEF5-2C742F24/er-corporate/ER-607_d.pdf).

EON Ruhrgas (2008). Erdgaswirtschaft im Überblick. Markt. Leistungen. Perspektiven. Downloaded 23rd Sept. 2008 (http://bookletsorder.eon-ruhrgas.com/ DownloadPdf.aspx?Datei=ErdgasImUeberblick_2007.pdf).

ESRI (2005). Data & Maps world dataset. Redlands, CA USA.

ESRI (2008). Data & Maps world dataset. Redlands, CA USA (http://www.esri.com/).

Eurostat (2008a). EXTRA EU27 Trade Since 2000 By Mode of Transport (HS2-HS4). Product 2701. Eurostat Luxembourg (http://epp.eurostat.ec.europa.eu/newxtweb/ accessed on October 23th 2008).

EUROSTAT (2008b). Eurostat Database. Table NRG 124A. Imports (by country of origin) - gas - annual data. Downloaded 23rd Sept. 2008 (http://epp.eurostat.ec.europa.eu/extraction/ evalight/EVAlight.jsp?A=1&language=en&root=/theme8/nrg/nrg_124a).

EUROSTAT (2008c). Eurostat Database. Table NRG 123A. Imports (by country of origin) - oil - annual data. Downloaded 23rd Sept. 2008 (http://epp.eurostat.ec.europa.eu/ extraction/evalight/EVAlight.jsp?A=1&language=en&root=/theme8/nrg/nrg_123a).

EUROSTAT (2008d). Eurostat Database. Tables MAR_GO_QM (+ Country Extension). Maritime transport - Goods (gross weight) - Quarterly data - Main ports - One detailed table per each reporting country - by direction, partner entity and type of cargo (detailed classification). Downloaded 1st Dec. 2008 (http://epp.eurostat.ec.europa.eu/portal/page/ portal/transport/data/database).

Fakhri V. (2009). BBC News, Europe's pipeline politics, BBC Azeri Service, June 7 2009 (http://news.bbc.co.uk/2/hi/europe/8083511.stm).

FAPRI (2008). FAPRI 2008 U.S. and World Agricultural Outlook, Food and Agricultural Policy Research Institute, Iowa State University. University of Missouri-Columbia. January 2008 (http://www.fapri.iastate.edu/outlook/2008/).

GASUNIE (2008). Press release: Gate LNG terminal signs agreement with E.ON Ruhrgas. (http://www.nvnederlandsegasunie.nl/en/news.htm#20071218_1) (downloaded 29th Sept. 2008).

Gazprom (2008). Distribution / Europe. Gazprom, Moscow (http://www.gazprom.com/eng/ articles/article20160.shtml).

Ghiles F. (2009). Algeria: A strategic Gas Partner for Europe. Journal of Energy Security, February 19 2009.

Google (2007). Google Earth 4.2. Mountain View.

Google Earth Community (2005). CrudeOilRefineries.kmz. (http://bbs.keyhole.com/ubb/ ubbthreads.php?ubb=download&Number=63884&filename=142111-CrudeOilRefineries.kmz).

Google Maps (2009). (http://maps.google.it/).

GSIS (2009). Global Integrated Shipping Information System. International Maritime Organization (IMO) (http://gisis.imo.org/Public/).

GTAI (2006). Germany Trade and Invest (GTAI): Swinemünde erhält Terminal für Flüssiggas. (http://www.gtai.de/DE/Content/__SharedDocs/Links-Einzeldokumente-Datenbanken/ fachdokument.html?fIdent=MKT20061221102838) (downloaded 29th Sept. 2008).

GTI (2009). Global Trade Atlas. Global Trade Information Services Inc. (http://www.gtis.com/gta/).

Hamelinck C.N., Suurs R.A.A., Faaij A.P.C. (2008). International bioenergy transport costs and energy balance. Biomass and Bioenergy, Volume 29, Issue 2, pp. 114-134.

Hansen M., DeFries R., Townshend J.R.G., Sohlberg R. (2000). Global land cover classification at 1km resolution using a decision tree classifier. Int. J. of Remote Sensing. Vol. 21: pp 1331-1365. (http://www.landcover.org/data/landcover/, download 1st April 2009).

Hayes M.H. (2004). Algerian gas to Europe: The Transmed pipeline and early Spanish gas import projects. Working paper # 27, May 2004, Geopolitics of Natural Gas Study, Stanford University and James A. Baker III Institute.

Hoogwijk (2004). On the global and regional potential of renewable energy sources. PhD thesis, Utrecht University, 256 p.

Hysociety (2005). HySociety Database for Hydrogen. (http://www.eu.fhg.de/h2database/) (last visit 10/03/2009).

ICS & ISF (2009). International Chamber of shipping and international Shipping Federation (http://www.marisec.org/).

IEA (2005a). International Energy Agency (IEA), Paris: Resources to Reserves - Oil and Gas Technologies for the Energy Markets of the Future. ISBN: 2-64-10947-1, 2005 (http://www.iea.org/textbase/nppdf/free/2005/oil_gas.pdf)

IEA (2005b). International Energy Agency (IEA), Paris: Prospects for Hydrogen and Fuel Cells. OECD/IEA, 2005. (http://www.iea.org/textbase/nppdf/free/2005/hydrogen2005.pdf).

IEA (2007a). International Energy Agency: Energy Balance. Paris.

IEA (2007b). International Energy Agency (IEA), Paris: World Energy Outlook 2006. OECD/IEA, 2007 (http://www.iea.org/weo/2006.asp).

IMO (2009). International Maritime Organization website (http://www.imo.org).

ITOPF (2009). International Tanker Owners Pollution Federation Limited, London UK (http://www.itopf.com/).

JRC (2000). Joint Research Center (JRC): Global Landcover Map 2000. Downloaded 2nd March 2009 (http://www-tem.jrc.it/glc2000/ProductGLC2000.htm).

Junginger M., Faaij A., Schouwenberg P.P., Arthers C., Bradley D., Best G., Heinimö J., Hektor B., Horstink P., Grassi A., Kwant K., Leistad Ø., Ling E., Peksa M., Ranta T., Rosillo-Calle F., Ryckmans Y., Wagener M., Walter A., Woods J. (2006). Opportunities and barriers for sustainable international bioenergy trade and strategies to overcome them. Report IEA Bioenergy Task 40. 17 p. (http://www.bioenergytrade.org/downloads/ t40opportunitiesandbarriersforbioenergytradefi.pdf).

King & Spalding (2006). LNG in Europe. An Overview of European Import Terminals. Houston & London. (http://www.kslaw.com/library/pdf/LNG_in_Europe.pdf) (download 29th Sep. 2008).

Kingston (2004). North Africa - An Energy Source for Europe? Kingston Energy Consulting & Prospex Research, December 2004 (http://www.kingstonenergy.com/papers.asp).

Klein A., Pfluger B., Held A., Ragwitz M., Resch G., Faber T. (2008). (EEG): Evaluation of different feed-in tariff design options – Best practice paper for the International Feed-In Cooperation, October 2008.

Kojima M. and Johnson T. (2005). Potential for biofuels for transport in developing countries. World Bank, Energy Sector Management Assistance Program, 182 p. (http://esmap.org/filez/pubs/31205BiofuelsforWeb.pdf).

Konstantin P. (2007). Praxisbuch Energiewirtschaft – Energieumwandlung, -transport und -beschaffung im liberalisierten Markt. Springer-Verlag, Berlin (in German).

Laherrère, J. (2000). Is the USGS assessment reliable. Paper presented at the WEC cyber conference, May 19, available at: http://www.oilcrisis.com/laherrere/usgs2000/ (accessed 16 November 2009.

Lehtila, A. (2009). Private communication. Data based on Pahkala, K., Hakala, K., Kontturi, M., & Niemeläinen, O. 2009. Peltobiomassat globaalina energianlähteenä. Maa- ja elintarviketalous (2009):137, 53 pages (in Finnish).

Mbendi (2005). Crude Petroleum and Natural Gas Extraction in Algeria - Overview. MBendi, modified: 23 May 2005 (downloaded 2008).

Mishin V. (2008). Azerbaijan Wants Its Gas to Flow to Nabucco. Nezavisimaya, March 11 2008 (http://en.ng.ru/energy/2008-03-11/6_nabucco.html).

Nabucco (2008). Nabucco Gas Pipeline Project, website (http://www.nabucco-pipeline.com/).

NASA and NIMA (2000). Global SRTM 30 arcsec Seamless data. (http://www.dgadv.com/srtm30/) (downloaded 2nd March 2009).

NCEAS (2004). National Center for Ecological Analysis and Synthesis (NCEAS) (http://www.nceas.ucsb.edu/ecology/economics).

NGA (2005). National Geospatial Intelligence Agency (NGA): World Port Index. (http://pollux.nss.nima.mil/NAV_PUBS/WPI/PUB150.ZIP) (downloaded 29th Sept. 2008).

Nigeria LNG Limited (2008). Marketing. Downloaded 29th Sept. 2008 (http://www.nlng.com/NLNGnew/marketing/Delivery.htm).

Nitsch J. (2008). Lead Study 2008: Further development of the 'Strategy to increase the use of renewable energies' within the context of the current climate protection goals of Germany and Europe. Study commiss. by the German Federal Ministry for the Environment, Nature Conservation & Nuclear Safety (BMU) (http://www.erneuerbare-energien.de/inhalt/42726).

Nord Stream (2008). The new gas supply route to Europe. FACTS Issue 0/2008 (http://www.nord-stream.com/en/press0/library0.html) (downloaded 01/2009).

NPD (2005). Norwegian Petroleum Directorate (NPD): Fakta norsk petroleumsverksemd 2005. (http://www.npd.no/).

OAO Gazprom (2006). Gazprom in Figures 2002-2006. Downloaded 23rd Sept. 2008 (http://www.gazprom.com/documents/Stat_Report_Eng.pdf).

OGP (2007). International Association for Oil and Gas Producers (OGP): Environmental performance in the E&P industry 2006 data, Report number 399, October 2007.

Oil & Gas UK (2008). Oil & Gas UK: Industry Issues, Environment, Decommissioning (http://www.ukooa.co.uk/issues/decommissioning/index.cfm).

OME (2008). Mediterranean Energy Perspectives 2008, Observatoire Méditerranéen de l'Energie, report 2008.

OPEC (2008). Annual Statistical Bulletin. Organisation of Petroleum-Exporting Countries (OPEC), latest issues available online 2002 - 2007 (www.opec.org/library) (downloaded 2008).

Ozturk H., Bascetincelik A. (2006). Energy Exploitation of Agricultural Biomass Potential in Turkey - Energy exploration & exploitation. Volume 24, Number 4+5, 2006 pp. 313-330.

Petroleum Economist (2006). World Energy Atlas 2007. The Petroleum Economist Ltd, Ed. Schlumberger, London (http://www.worldenergyatlas.com/).

PLANCO (2003). Consulting GmbH: Potenziale und Zukunft der deutschen Binnenschifffahrt Projekt 30.0324/2002 Schlussfolgerungen und Empfehlungen für das Bundesministerium für Verkehr, Bau- und Wohnungswesen. Essen (in German).

Pogany P. (2009). Nabucco pipeline in the cobweb of Byzantine energy politics. Energy Bulletin, Apr 7 2009 (http://www.energybulletin.net/node/48560).

Pyrdol J. & Baron B. (2006). What Is More Profitable to Build? GTL Production Facilities or LNG Liquefaction Plants. World Natural Gas Markets and Trade (EMF-23), Berlin Meeting, June 2006.

Railion (2007). Preise und Konditionen der Railion Deutschland AG, Allgemeine Bestimmungen für Gütertransportleistungen ab 1.Januar 2007 (in German).

Remme U., Blesl M., Fahl U. (2007). Global resources and energy trade: An overview for coal, natural gas, oil and uranium. Band 101. IER university of Stuttgart.

RINA (2009). Registro Italiano Navale (RINA S.p.A), Genova, Italy (http://www.rina.org/).

Schillings C., Mannstein H., Meyer R. (2004). Operational method for deriving high resolution direct normal irradiance from satellite data. Solar Energy, 76 (4), pp 475-484.

Segerer H., Heinecker M. (2001). Studie Donau-Logistik. Technische und logistische Maßnahmen zur weiteren Entwicklung der Verkehre über die deutschen und österreichischen Donauhäfen. Im Auftrag des Freistaats Bayern und der EHG Ennshafen Ges.m.b.H., ed. W. Günther, Lehrstuhl für Fördertechnik Materialfluß Logistik, Munich (in German) (http://www.binnenhafen.info/info_index.php?aid=5025 accessed on October 27th 2008).

Smeets E. and Faaij A. (2007). Bioenergy production potentials from forestry to 2050. Climatic Change, Volume 81, Numbers 3-4, pp 353-390.

Smeets E., Faaij A. and Lewandowski I. (2004). A Quickscan of global bio-energy potentials to 2050. An analysis of the regional availability of biomass resources for export in relation to the underlying factors. Report NWS-E-2004-109.

Smeets E., Faaij A., Lewandowski I. and Turkenburg W. (2007). A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combustion Science, Volume 33, pp 56-106.

Sonatrach (2006). Sonatrach Annual Report 2006 (http://www.sonatrach-dz.com/rapanu-2006uk.pdf).

SSB (2008). Exports of stabilized crude oil shipped from Norwegian territory. Revised figures. Statistics Norway (http://www.ssb.no/muh_en/mu2007/tab23.html) (downloaded 2008).

Statoil (2001). Exploration and Production, Norway. September 2001. Presentation available on Statoil website (http://www.statoil.ru/FIN/NR303094.nsf/Attachments/aEPnorway.pdf/$FILE/aEPnorway.pdf).

Steminorder, 2009. Global Shipping Platform (http://www.steminorder.com/).

Suurs R. (2002). Long distance bioenergy logistics. An assessment of costs and energy consumption for various biomass energy transport chains. Utrecht University, Copernicus Institute.

Toro F., Hasenauer U., Wietschel M., Schade W. (2006). Technology trajectories for transport and its energy supply. Deliverable 2 of TRIAS (Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Toufaux News (2007). Algérie-Nigeria: examen du projet de gazoduc transsaharien. Downloaded 23rd Sept. 2008 (http://www.toufaux.com/08/Algerie-Nigeria-examen-projet-gazoduc-transharien400.html).

Trieb F., O'Sullivan M., Pregger T., Schillings Ch., Krewitt W. (2009). Characterisation of Solar Electricity Import Corridors – Export Potentials, Infrastructures and Costs. DLR report July 2009 and Technical Note TN2.3 for REACCESS project, funded by European Commission 7th Framework Programme.

Trieb F., Schillings C., Kronshage S., Viebahn P., May N., Paul C., Klann U., Kabariti M., Bennouna A., Nokraschy H., Hassan S., Georgy Yussef L., Hasni T., Bassam N., Satoguina H. (2005). Concentrating Solar Power for the Mediterranean Region (MED-CSP). Final Report DLR-ITT Stuttgart, commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Germany (www.dlr.de/tt/med-csp).

Trieb F., Schillings C., Kronshage S., Viebahn P., May N., Paul C., Kabariti M., Bennouna A., Nokraschy H., Hassan S., Georgy Yussef L., Hasni T., Bassam N., Satoguina H. (2006). Trans-Mediterranean Interconnection for Concentrating Solar Power (TRANS CSP). Final Report DLR-ITT Stuttgart, commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Germany (www.dlr.de/tt/trans-csp).

UN (2007). United Nations Conference on Trade and Development, Review on maritime transport 2007, United Nations, New York and Geneva, 2007.

UN Comtrade (2008). United Nations Commodity Trade Statistics Database, International Merchandise Trade Statistics (IMTS) (http://comtrade.un.org/) (downloaded at the end of 2008).

UNEP-WCMC and IUCN (2007). World Database on Protected Areas (WDPA). Downloaded 23rd Sept. 2008 (http://www.wdpa.org).

USDA (2008). United States Department of Agriculture (USDA), Foreign Agricultural Service: GAIN Reports. (http://www.fas.USDa.gov/scriptsw/AttacheRep/default.asp) (download end of 2008).

USGS (2000a). U.S Geological Survey (USGS): USGS World Petroleum Assessment 2000. USGS World Energy Assessment Team 2000, Denver, CO.

USGS (2000b). Geological Provinces of the World – WEP_PRVG. Downloaded 23rd Aug. 2008 (http://certmapper.cr.usgs.gov/data/wep/dds60/wep_prvg.zip).

USGS (2007). U.S Geological Survey (USGS): An evaluation of the USGS World Petroleum Assessment - Supporting Data, Open-file-report 2007-1021, US Department of Interior, 15.02.2007.

VDKI (2008). Verein der Kohleimporteure: Jahresbericht 2008 – Fakten und Trends 2007/08. Hamburg (http://www.kohlenimporteure.de/wDeutsch/download/VDKIGeschaeftsbericht-2008.pdf?navid=14 accessed on November 3rd 2008) (in German).

Viebahn P., Kronshage S., Trieb F., Lechon Y. (2008). Final report on technical data, costs, and life cycle inventories of solar thermal power plants – NEEDS Deliverable n° 12.2 - RS 1a.

Voies navigables de France (2007). Délibération relative à la détermination des tarifs de péages de navigation de marchandises et du service spécial d'éclusage applicables à compter du 1er juillet 2007. Béthune (in French).

Waterborne Energy Inc. (2008). The European Waterborne LNG Report. Vol. 3, No. 10. Houston. (http://www.waterbornelng.com/eurolngsample.pdf) (downloaded 29th Sept. 2008).

Watkins E. (2009). Nigerian militants threatened proposed Trans-Sahara gas line. Oil & Gas Journal, July 7 2009.

WCS and CIESIN (2005). The Global Human Influence Index (HII) Dataset of the Last of the Wild Project, Version 2. Downloaded 1st April 2008 (http://sedac.ciesin.columbia.edu/wildareas/downloads.jsp#infl).

WDPA (2009). World Database on Protected Areas, 2009 WDPA Release. United Nations Environment Programme, World Conservation Monitoring Centre, Cambridge, UK (http://www.wdpa.org/).

WEC (2007). 2007 Survey of Energy Resources - World Energy Council, London, UK. ISBN: 0 946121 26 5, pp. 9-22.

Whaley, J. (2007). Do OPEC Reserve Figures Matter? Available at: http://www.geoexpro.com/news/do_opec_re/ (accessed 16 November 2009).

Whist B.S. (2008). Nord Stream: not Just a Pipeline. FNI Report 15/2008, November 2008.

Wietschel M. et al. (2006). Report on feasibility of optimized hydrogen corridors and timing – Report from the ENCOURAGED project. Available at http://www.ecn.nl/fileadmin/ecn/units/bs/ENCOURAGED/WP/ENCOURAGED-report-WP3.pdf (last visit 11/03/2009).

World Bank (2008). World Bank: Global Gas Flaring Reduction Partnership. (http://go.worldbank.org/NEBP6PEHS0) (downloaded 2008).

World Port Sources (2009). WaterWare Internet Services, Inc., San Jose, CA, USA (http://www.worldportsource.com).

World Shipping Register (2009). (http://82.146.41.123/).

Yenikeyeff S.M. (2006). The G8 and Russia: Security of Supply vs. Security of Demand?", working paper, Oxford Institute for Energy Studies, Oxford Energy Comment, available at: http://www.oxfordenergy.org/pdfs/comment_0806-1.pdf (accessed 16 November 2009).

Yenikeyeff S.M. (2008). Kazakhstan's Gas: Export Markets and Export Routes. Oxford Institute for Energy studies, ISBN 978-1-901795-79-0, November 2008.

Yenikeyeff S.M. (2009). Caspian Natural Gas?1: Kazakh export plans affect regional producers, buyers. Oil & Gas Journal January 05, 2009, volume 107, issue 1.

ZKR (2003). Zentralkommission für die Rheinschifffahrt (ZKR): Wirtschaftliche Entwicklung der Rheinschifffahrt – Statistiken 2002 – Rhein- und Binnenschifffahrtsstatistiken. Strasbourg (in German).

ANNEX I– RESOURCES AND PRODUCTION

Table A1.1: Crude oil resources (reserves, field growths and undiscovered fields) in supply regions (reserves data from 2005) (*figures in billion barrels).*

Region/country	Reserves	Undiscovered fields	Field growth	Total
Africa	**113.8**	**118.7**	**84.5**	**317.1**
Algeria	11.8	10.3	8.8	30.9
Angola	9.0	18.6	6.6	34.3
Egypt	3.6	4.4	2.7	10.7
Gabon	2.2	8.6	1.6	12.5
Libya	39.1	9.6	29.3	77.9
Nigeria	35.9	37.9	26.5	100.3
Sudan	6.4	1.8	4.7	12.8
Others	5.8	27.6	4.4	37.8
Middle East	**738.3**	**298.3**	**479.5**	**1516.1**
Iran	132.7	70.0	86.2	288.9
Iraq	115.0	53.6	74.7	243.3
Kuwait	101.5	4.2	65.9	171.6
Oman	5.6	5.4	3.6	14.7
Qatar	15.2	5.7	9.9	30.7
Saudi Arabia	264.3	141.9	171.7	577.8
Syrian Arab. Republic	3.2	1.7	2.1	7.0
United Arab. Emirates	97.8	10.5	63.5	171.8
Others	3.0	5.3	1.9	10.3
Asia Pacific	**39.7**	**56.2**	**23.5**	**119.4**
Australia	4.0	12.5	2.4	18.9
Brunei	1.1	2.8	0.7	4.6
China	16.0	19.2	9.5	44.7
India	5.6	3.4	3.3	12.3
Indonesia	4.3	11.8	2.5	18.7
Malaysia	4.3	5.1	2.5	11.9
Others	4.4	1.5	2.6	8.5
North America	**33.7**	**115.2**	**96.2**	**245.1**
United States	29.3	86.0	76	166.40
Canada	4.4	3.7	20.2	53.24
Greenland	0	25.5	0	25.50
Latin America	**117.8**	**140.7**	**96.5**	**355.0**
Argentina	2.3	4.5	2.0	8.8
Brazil	11.2	60.2	9.6	81.0
Colombia	1.5	6.2	1.3	8.9
Ecuador	5.1	1.1	4.4	10.6
Mexico	14.8	23.5	8.1	46.4
Venezuela	79.7	26.6	68.4	174.7
Others	3.2	18.7	2.7	24.7
Russia	**72.4**	**123.7**	**50.9**	**247.0**
CAC	**47.8**	**13.7**	**46.2**	**107.7**
Azerbaijan	7.0	2.9	4.9	14.9
Kazakhstan	39.6	3.6	27.9	71.1
Turkmenistan	0.5	6.8	11.6	18.9
Uzbekistan	0.6	0.4	1.8	2.9
Rest of the world	**30.6**	**204.4**	**24.0**	**169.3**
Norway	7.7	14.5	6.5	17.9
Total world	**1.194**	**981.3**	**901.3**	**3076.7**

Table A1.2: Natural gas resources (reserves, field growths and undiscovered fields) in supply regions ***(figures in $Tm^3 = 10^{12}\ m^3$).***

Region/country	Reserves	Undiscovered fields	Field growth	Total
Africa	**14.3**	**10.5**	**12.0**	**36.8**
Algeria	4.6	1.5	3.8	9.8
Egypt	1.9	0.6	1.6	4.1
Libya	1.5	0.6	1.3	3.4
Nigeria	5.2	4.0	4.4	13.6
Others	1.2	3.8	1.0	6.0
Middle East	**72.1**	**37.7**	**67.2**	**177.0**
Iran	26.7	9.3	24.9	61.0
Iraq	3.2	3.6	3.0	9.7
Kuwait	1.6	0.2	1.5	3.2
Oman	1.0	1.0	0.9	2.9
Qatar	25.8	1.2	24.0	51.0
Saudi Arabia	6.8	20.2	6.4	33.4
United Arab. Emirates	6.1	1.3	5.7	13.0
Others	0.9	0.9	0.9	2.7
Asia Pacific	**14.4**	**19.2**	**8.8**	**42.3**
Australia	2.5	4.4	1.5	8.5
Bangladesh	0.4	1.1	0.3	1.8
China	2.2	3.5	1.3	7.0
India	0.9	1.0	0.6	2.4
Indonesia	2.8	4.4	1.7	8.8
Malaysia	2.5	2.0	1.5	6.0
Myanmar	0.5	0.9	0.3	1.7
Pakistan	0.8	0.9	0.5	2.2
Others	1.7	1.1	1.1	3.9
North America	**7.0**	**16.5**	**11.2**	**34.7**
United States	5.5	11.9	10.1	27.4
Canada	1.6	0.7	1.1	3.4
Greenland	0	3.9	0	3.9
Latin America	**7.5**	**17.4**	**5.0**	**29.9**
Argentina	0.6	1.2	0.4	2.2
Brazil	0.3	6.4	0.2	NA
Bolivia	0.8	0.8	0.6	2.1
Mexico	0.4	1.4	0.3	2.1
Trinidad & Tobago	0.5	1.0	0.3	1.9
Venezuela	4.3	3.3	2.7	10.4
Others	0.6	3.2	0.4	4.2
Russia	**47.8**	**34.3**	**32.5**	**114.6**
CAC	**9.1**	**12.2**	**7.1**	**28.4**
Azerbaijan	1.4	2.0	1.1	4.5
Kazakhstan	3.0	2.1	2.0	7.2
Turkmenistan	2.9	6.1	2.8	11.8
Uzbekistan	1.9	0.4	1.1	3.4
Rest of the world	**6.8**	**11.0**	**8.0**	**25.8**
Norway	2.4	5.9	1.5	9.8
Total world	**179.0**	**158.8**	**151.7**	**489.5**

Table A1.3: Refinery capacities for 1995, 2000 and 2005 by country (BP, 2008a).
(figures in kb/d = 1000 barrels per day)

Region/country	**1995**	**2000**	**2005**
Africa	**2910**	**3034**	**3311**
Middle East	**5826**	**6362**	**7179**
Iran	1332	1574	1684
Iraq	634	639	644
Kuwait	795	690	915
Saudi Arabia	1692	1846	2061
United Arab. Emirates	220	440	620
Other Middle East	1153	1173	1255
Asia Pacific	**17295**	**21435**	**22694**
Australia	818	924	813
China	4014	5407	6587
India	1133	2219	2558
Indonesia	990	1126	1056
Japan	**5006**	**5010**	**4531**
Singapore	1273	1255	1255
South Korea	1727	2598	2598
Taiwan	732	732	1159
Thailand	529	872	876
Other Asia Pacific	1073	1292	1261
North America	**17125**	**18456**	**19262**
USA	**15333**	**16595**	**17335**
Canada	1792	1861	1927
Latin America	**6054**	**6544**	**6763**
Argentina	648	626	611
Brazil	1481	1863	1940
Mexico	1444	1481	1463
Venezuela	1192	1280	1357
Other Latin America	2733	2775	2855
Russia	**6123**	**5351**	**5412**
Total world	**75978**	**81955**	**85702**

Table A1.4: LNG plants capacities (BP, 2008a) *(figures in 10^6 tons LNG).*

Region/country	Plant name	Start-up	Design capacity	Production 1998	Production 2005	Production 2007
Africa				**18.8**	**33.2**	**45.0**
Algeria	Skikda I	1972	2.8			
	Skikda II	1981	3			
	Arzew I	1964	1.1			
	Arzew II	1978	7.8			
	Arzew III	1981	7.8			
	Gassi Touil	2009	4			
Egypt	Damietta	2005	4.5			
	Idku I	2005	4.5			
	Idku II	2005	4.5			
Libya	Marsa El Brega	1970	0.9			
Nigeria	Bonny Island 1/2	1999	5.9			
	Bonny Island 3	2002	2.8			
	Bonny Island 4/5	2006	7.6			
	Bonny Island 6	2007	4			
Equatorial Guinea	EG LNG	2007	3.7			
Angola	Soyo	2012	5.2			
Middle East				**0.0**	**0.0**	**0.0**
Oman	Qalhat 1	2000	6.6			
	Qalhat 2	2005	3.3			
Qatar	RasGas 1 & 2	1999	6.4			
	RasGas 3	2004	4.7			
	RasGas 4	2005	4.7			
	RasGas 5	2007	4.7			
	RasGas 6	2008	7.8			
	RasGas 7	2009	7.8			
	Qatargas 1-3	1996	9.6			
	Qatargas 4 -5	2008	15.6			
	Qatargas III	2009	7.8			
	Qatargas III	2010	7.8			
UAE	Das Island 1	1977	2.3			
	Das Island 2	1977	2.5			
Yemen	Yemen LNG	2009	6.7			
Asia Pacific				**53.7**	**61.3**	**63.6**
Indonesia	Arun I	1978	4.5			
	Arun II	1984	3			
	Arun III	1986	1.5			
	Bontang A/B	1977	4.3			
	Bontang C/D	1983	4.3			
	Bontang E	1983	2.3			
	Bontang F	1983	2.3			
	Bontang G	1997	2.6			
	Bontang H	1999	2.7			
	Tangguh	2008/2009	4.2 - 8.4			
Australia	Darwin	2002/2006	3.5			
	Burrup I-III (Dampier)	1989/92	7.5			
	Burrup IV (Dampier)	2004	4.2			
Malaysia	Bintulu MLNG 1	1983	7.5			
	Bintulu MLNG 2	1995	7.5			
	Bintulu MLNG 3	2003	7.6			
Brunei	Lumut	1972	7.2			
North America				**1.3**	**1.3**	**0.9**
United Sates	Kenai	1969	1.4			
Latin America				**0.0**	**10.2**	**13.2**
Trinidad & Tobago	Point Fortin 1	1999	3.0			
	Point Fortin 2	2002	3.3			
	Point Fortin 3	2003	3.3			
	Point Fortin 4	2006	5.2			
Rest of the world				**0.0**	**0.0**	**0.1**
Norway	Snøhvit	2007	4.2			
Total world				**73.8**	**106.1**	**122.8**

Table A1.5: Solar electricity: list of identified resources (technical potential) and production capacities in energy supply regions.

		Resources		Production	
COM_CODE	Country	Suitable land for CSP [km²]	Solar radiation [kWh/(m² · yr)]	Load factor [h/yr]	Potential CSP production capacity [MW]
CSP_001_01	Morocco	6083	2100	5813	98903
CSP_001_02	Morocco	5650	2200	6125	91323
CSP_001_03	Morocco	10875	2300	6438	174842
CSP_001_04	Morocco	17194	2400	6750	275105
CSP_001_05	Morocco	34348	2500	7063	547134
CSP_001_06	Morocco	30569	2600	7375	484967
CSP_001_07	Morocco	18930	2700	7688	299187
CSP_001_08	Morocco	48074	2800	8000	757171
CSP_002_01	Algeria	6237	2100	5813	101401
CSP_002_02	Algeria	34142	2200	6125	551839
CSP_002_03	Algeria	29006	2300	6438	466351
CSP_002_04	Algeria	39462	2400	6750	631392
CSP_002_05	Algeria	222860	2500	7063	3549979
CSP_002_06	Algeria	384570	2600	7375	6100970
CSP_002_07	Algeria	428487	2700	7688	6772190
CSP_002_08	Algeria	277580	2800	8000	4371890
CSP_003_01	Tunisia	9288	2100	5813	151006
CSP_003_02	Tunisia	6445	2200	6125	104176
CSP_003_03	Tunisia	9864	2300	6438	158584
CSP_003_04	Tunisia	19464	2400	6750	311428
CSP_003_05	Tunisia	22823	2500	7063	363550
CSP_003_06	Tunisia	11637	2600	7375	184614
CSP_003_07	Tunisia	240	2700	7688	3794
CSP_004_01	Libya	7773	2100	5813	126382
CSP_004_02	Libya	25331	2200	6125	409425
CSP_004_03	Libya	109712	2300	6438	1763915
CSP_004_04	Libya	176659	2400	6750	2826546
CSP_004_05	Libya	152875	2500	7063	2435172
CSP_004_06	Libya	183342	2600	7375	2908605
CSP_004_07	Libya	155513	2700	7688	2457870
CSP_004_08	Libya	373665	2800	8000	5885218
CSP_005_01	Saudi Arabia	32807	2100	5813	533386
CSP_005_02	Saudi Arabia	135285	2200	6125	2186654
CSP_005_03	Saudi Arabia	336109	2300	6438	5403857
CSP_005_04	Saudi Arabia	334997	2400	6750	5359947
CSP_005_05	Saudi Arabia	187726	2500	7063	2990333
CSP_005_06	Saudi Arabia	65508	2600	7375	1039246
CSP_005_07	Saudi Arabia	42773	2700	7688	676026
CSP_005_08	Saudi Arabia	14720	2800	8000	231836

		Resources		Production	
COM_CODE	**Country**	**Suitable land for CSP [km²]**	**Solar radiation [kWh/(m² · yr)]**	**Load factor [h/yr]**	**Potential CSP production capacity [MW]**
CSP_006_01	Jordan	2097	2100	5813	34097
CSP_006_02	Jordan	5902	2200	6125	95391
CSP_006_03	Jordan	19197	2300	6438	308651
CSP_006_04	Jordan	10985	2400	6750	175753
CSP_006_05	Jordan	10742	2500	7063	171116
CSP_006_06	Jordan	7239	2600	7375	114845
CSP_006_07	Jordan	3152	2700	7688	49819
CSP_007_01	Egypt	206	2100	5813	3355
CSP_007_02	Egypt	1481	2200	6125	23939
CSP_007_03	Egypt	16846	2300	6438	270840
CSP_007_04	Egypt	40969	2400	6750	655503
CSP_007_05	Egypt	41347	2500	7063	658627
CSP_007_06	Egypt	44613	2600	7375	707766
CSP_007_07	Egypt	98004	2700	7688	1548941
CSP_007_08	Egypt	354972	2800	8000	5590815

Table A1.6: Coal: list of identified resources and proven reserves in energy supply regions.

World region	Country/region	Field location	Proven reserves [GJ]
AFR_P	Nigeria, Nassarawa	Lafia-Obi area	4.56E+09
AFR_N	South Africa, Mpumalanga province	Karoo basin	1.24E+12
AUS	Australia, New South Wales	Singleton	1.61E+12
AUS	Australia, Queensland	Moranbah	1.61E+12
CAN	Canada	British Columbia Vancouver	9.03E+10
CHI	China, Shanxi	Shenhua	2.52E+12
CSA_P	Venezuela	Guasare	1.26E+10
CSA_N	Colombia	La Guajira - El Cerrejón	3.58E+11
EUR	Czech Republic	Ostrava-Karvina Basin	3.17E+11
EEU	Poland	Upper Silesian Basin	3.17E+11
EUR	Germany, North Rhine-Westphalia	Ruhr Basin	9.99E+09
JPN	Japan, Kyûshû	Karatsu	2.20E+12
IND	India, West Bengal	Raniganj	8.85E+09
MEA_P	Iran, Alborz	Tazreh	1.02E+10
MEA_N	Turkey	North-West Anatolia Zonguldak	2.52E+10
MEX	Mexico, Coahuila	Sabinas-Saltillito-Monclova basin	2.16E+10
ODA_P	Indonesia, Kalimantan	Barito basin	6.51E+10
ODA_N	North Korea	Pyongyang Province	1.05E+11
RUS	Siberian Federal District Novosibirsk	Kemerovo, Kuznetsk Basin	3.54E+12
SFS	Kazakhstan, Pavlodar	Karaganda Basin	7.10E+11
UBM	Ukraine, Donets Basin	Donets Basin	4.03E+11
USA	USA, Pennsylvan., Appalachian region	Lackawanna county	6.13E+12

Table A1.7: Biomass: list of identified resources and production potentials in energy supply regions.

COM_CODE	Region	Resource type	Resource proven 2005	Resource proven 2050	unit
Surplus agriculture land - cost 1					
BIOL_101	AFR	Land	79.4	79.4	Mha
BIOL_102	AUS	Land	126.4	126.4	Mha
BIOL_103	CAC	Land	43.5	43.5	Mha
BIOL_104	CAN	Land	4.5	4.5	Mha
BIOL_105	CHI	Land	13.6	13.6	Mha
BIOL_106	CSA	Land	93.3	93.3	Mha
BIOL_107	IND	Land	29.0	29.0	Mha
BIOL_108	JPN	Land	0.0	0.0	Mha
BIOL_109	MEA	Land	22.9	22.9	Mha
BIOL_110	MEX	Land	21.8	21.8	Mha
BIOL_111	ODA	Land	6.7	6.7	Mha
BIOL_112	OEE	Land	10.5	10.5	Mha
BIOL_113	RUS	Land	28.1	28.1	Mha
BIOL_114	SKO	Land	0.0	0.0	Mha
BIOL_115	USA	Land	35.2	35.2	Mha
BIOL_116	EUR	Land	17.1	17.1	Mha
Surplus agriculture land - cost 2					
BIOL_201	AFR	Land	24.6	24.6	Mha
BIOL_202	AUS	Land	89.6	89.6	Mha
BIOL_203	CAC	Land	14.9	14.9	Mha
BIOL_204	CAN	Land	3.1	3.1	Mha
BIOL_205	CHI	Land	1.3	1.3	Mha
BIOL_206	CSA	Land	36.0	36.0	Mha
BIOL_207	IND	Land	0.0	0.0	Mha
BIOL_208	JPN	Land	0.0	0.0	Mha
BIOL_209	MEA	Land	0.1	0.1	Mha
BIOL_210	MEX	Land	0.9	0.9	Mha
BIOL_211	ODA	Land	0.3	0.3	Mha
BIOL_212	OEE	Land	0.0	0.0	Mha
BIOL_213	RUS	Land	14.9	14.9	Mha
BIOL_214	SKO	Land	0.0	0.0	Mha
BIOL_215	USA	Land	11.2	11.2	Mha
BIOL_216	EUR	Land	0.0	0.0	Mha
Equivalent energy crop - cost 1					
BIO_101	AFR	Energy	9.0	23.7	EJ
BIO_102	AUS	Energy	18.8	22.2	EJ
BIO_103	CAC	Energy	9.4	17.3	EJ
BIO_104	CAN	Energy	1.9	1.7	EJ
BIO_105	CHI	Energy	5.6	10.0	EJ
BIO_106	CSA	Energy	17.7	28.9	EJ
BIO_107	IND	Energy	4.5	12.1	EJ
BIO_108	JPN	Energy	0.0	0.0	EJ
BIO_109	MEA	Energy	1.5	2.0	EJ
BIO_110	MEX	Energy	3.1	6.7	EJ
BIO_111	ODA	Energy	1.5	2.9	EJ
BIO_112	OEE	Energy	1.7	4.2	EJ
BIO_113	RUS	Energy	6.9	11.2	EJ
BIO_114	SKO	Energy	0.0	0.0	EJ
BIO_115	USA	Energy	11.6	13.0	EJ
BIO_116	EUR	Energy	6.7	8.4	EJ

COM_CODE	Region	Resource type	Resource proven 2005	Resource proven 2050	unit
Equivalent energy crop - cost 2					
BIO_201	AFR	Energy	2.8	7.3	EJ
BIO_202	AUS	Energy	13.3	15.8	EJ
BIO_203	CAC	Energy	3.2	6.0	EJ
BIO_204	CAN	Energy	1.3	1.1	EJ
BIO_205	CHI	Energy	0.5	0.9	EJ
BIO_206	CSA	Energy	6.8	11.1	EJ
BIO_207	IND	Energy	0.0	0.0	EJ
BIO_208	JPN	Energy	0.0	0.0	EJ
BIO_209	MEA	Energy	0.0	0.0	EJ
BIO_210	MEX	Energy	0.1	0.3	EJ
BIO_211	ODA	Energy	0.1	0.1	EJ
BIO_212	OEE	Energy	0.0	0.0	EJ
BIO_213	RUS	Energy	3.7	5.9	EJ
BIO_214	SKO	Energy	0.0	0.0	EJ
BIO_215	USA	Energy	3.7	4.2	EJ
BIO_216	EUR	Energy	0.0	0.0	EJ
Agriculture and forestry					
BIO_401	AFR	Energy	4.7	15.0	EJ
BIO_402	AUS	Energy	0.2	2.0	EJ
BIO_403	CAC	Energy	0.1	0.7	EJ
BIO_404	CAN	Energy	0.4	2.4	EJ
BIO_405	CHI	Energy	2.6	3.8	EJ
BIO_406	CSA	Energy	2.6	9.9	EJ
BIO_407	IND	Energy	3.3	5.7	EJ
BIO_408	JPN	Energy	0.0	0.0	EJ
BIO_409	MEA	Energy	0.0	0.0	EJ
BIO_410	MEX	Energy	0.2	1.1	EJ
BIO_411	ODA	Energy	1.1	1.4	EJ
BIO_412	OEE	Energy	0.0	0.1	EJ
BIO_413	RUS	Energy	0.2	2.2	EJ
BIO_414	SKO	Energy	0.0	0.1	EJ
BIO_415	USA	Energy	0.9	4.6	EJ
BIO_416	EUR	Energy	2.0	4.0	EJ
Wood for energy (residues excluded)					
BIO_501	AFR	Energy	4.3	4.3	EJ
BIO_502	AUS	Energy	0.1	0.1	EJ
BIO_503	CAC	Energy	0.0	0.0	EJ
BIO_504	CAN	Energy	0.6	0.6	EJ
BIO_505	CHI	Energy	7.3	7.3	EJ
BIO_506	CSA	Energy	7.9	7.9	EJ
BIO_507	IND	Energy	3.8	3.8	EJ
BIO_508	JPN	Energy	0.0	0.0	EJ
BIO_509	MEA	Energy	0.3	0.3	EJ
BIO_510	MEX	Energy	0.6	0.6	EJ
BIO_511	ODA	Energy	0.688	0.688	EJ
BIO_512	OEE	Energy	0.0	0.0	EJ
BIO_513	RUS	Energy	0.1	0.1	EJ
BIO_514	SKO	Energy	0.0201	0.0201	EJ
BIO_515	USA	Energy	0.6	0.6	EJ
BIO_516	EUR	Energy	1.6	1.6	EJ

Table A1.8: Nuclear fuels: list of identified resources and production capacities in energy supply regions.

Source fields	**Reserves (tU)**			**Capacities**
	Proven	Probable	Possible	tU/yr
Athabasca Basin, Saskatchewan, Canada	151,160 7,950 2,950			7,200 (McArthur River) 2,316 (Rabbit Lake) 2,121 (McClean Lake)
Northern Territory, Australia	43,966	714,000	1,530,000	5,006 (Ranger)
South Australia, Australia	284,700			3,688 (Olympic Dam) 825 (Beverley)
Arlit , Akouta, Imouraren, Niger	16,716 [1] 7.909 [2]	15,737 [2]	45,000 [1] 146,000 [3]	1,315 (Arlit) 1,778 (Akouta)
Namibian Basin	37,900			3,147 (Rössing)

[1] ore grade 0.3%

[2] ore grade 0.46%

[3] ore grade 0.11%

Table A1.9: Hydrogen: list of identified resources and production capacities in energy supply regions.

		Resources		**Production capacity**	
COM_CODE	**Country**	**Proven**	**unit**	**Primary energy [GWh/yr]**	**Hydrogen gaseous [GWh H_2/yr]**
LIG_001	Ukraine	1,940,000	kt lignite	4,722	800
BIO_001	Turkey	174,308	GWh biomass energy content	87,154	40,000
LAN_001	Algeria	195	km² suitable land for CSP	40,950	18,690
WIN_001	Morocco	20,000	km² suitable land for wind PP	36,000	26,250

ANNEX II – IDENTIFIED CORRIDORS

A2.1 Oil and Natural Gas

The following Tables list the identified captive and open sea corridors for oil (crude and refined) and gas import. Several routes are made by more than one segment, often crossing more than one country.

Table A2.1: Identified captive and open sea corridors for oil and natural gas.

Natural Gas (by pipelines)

16 routes	Corridor Code:	
5 from AFR	NG_PIP_xxx	
		014 from Algeria to Italy
		015 from Algeria to Spain
		018 from Libya to Italy
		019 from Algeria to Spain
		020 from Algeria to Italy
11 from RUS and FSU		033 from Turkmenistan to Greece
		034 from Azerbaijan to Romania
		044 from Azerbaijan to EU (Nabucco)
		045 from Russia to (Yamal Europe)
		046 from Russia to Dolina (Brotherhood)
		047 from Russia to EU27+ (Northern Lights)
		048 from Russia to EU27+ (Blue Stream)
		050 from Russia to EU27+ (North Stream)
		051 from Russia to EU27+ (Soyuz)
		052 from Russia to EU27+ (South Stream)
		053 from Russia to EU27+ (Dolina - EU)

Crude Oil (by pipelines)

2 routes	Corridor Code	
	OIL_PIP_xxx	
		014 from Russia to EU27+ (Baltic Pipeline System)
		017 from Russia to EU27+ (Druzhba)
6 Upstream pipes		002 from Iraq to Ceyhan
		008 from Azerbaijan to Ceyhan
		009 from Azerbaijan to Novorossiysk
		010 from Russia to Novorossiysk
		011 from Kazakhstan to Novorossiysk
		025 from Kazakhstan to Primorsk (for Germany)

Refined Oil Products (by tankers)

14 routes	Corridor Code:	
	REF_SHP_xxx	
Origins		from 011 to 013 from Venezuela;
		from 029 to 034 from Algeria;
		from 051 to 054 from Kuwait;
		063 from Saudi Arabia

Destinations	Italy	4 terminals (Genoa, Priolo, Sarroch, Trieste)
	United Kingdom	1 terminal (Milford Oil Jetty)
	France	2 terminals (Marseille, Gonfreville)
	Netherlands	1 terminal (Rotterdam)
	Spain	2 terminals (Bilbao, Cartagena)

Crude Oil (by tankers)

95 routes — Corridor Code: OIL_SHP_xxx

Origins
005 from Venezuela (2 Terminals) to France (2 terminals)
006 from Venezuela (2 Terminals) to Germany (1 terminal)
007 from Venezuela (2 Terminals) to Italy (4 terminals)
008 from Venezuela (2 Terminals) to NL (1 terminal)
009 from Venezuela (2 Terminals) to Spain (2 terminals)
010 from Venezuela (2 Terminals) to UK (1 terminal)
011 from Venezuela to Rest of Western EU
018 from Canada to Italy
023 from Mexico to Spain (2 Terminals)
028 from Mexico to Portugal (1 Terminals)
042 from Algeria (2 Terminals) to Belgium (1 terminal)
043 from Algeria (2 Terminals) to France (2 terminals)
044 from Algeria (2 Terminals) to Germany (1 terminal)
045 from Algeria a (2 Terminals) to Italy (4 terminals)
046 from Algeria (2 Terminals) to NL (1 terminal)
047 from Algeria (2 Terminals) to Spain (2 terminals)
048 from Algeria (2 Terminals) to UK (1 terminal)
049 from Algeria to Rest of Western EU
065 from Libya (2 Terminals) to Belgium (1 terminal)
066 from Libya (2 Terminals) to France (2 terminals)
067 from Libya (2 Terminals) to Germany (1 terminal)
068 from Libya (2 Terminals) to Italy (4 terminals)
069 from Libya (2 Terminals) to NL (1 terminal)
070 from Libya (2 Terminals) to Spain (2 terminals)
071 from Libya (2 Terminals) to Greece (1 terminal)
072 from Libya (2 Terminals) to UK (1 terminal)
073 from Libya to Rest of Western EU
080 from Libya (2 Terminals) to France (2 terminals)
081 from Libya (2 Terminals) to Germany (1 terminal)
082 from Libya (2 Terminals) to Italy (4 terminals)
083 from Libya (2 Terminals) to NL (1 terminal)
084 from Libya (2 Terminals) to Sweden (1 terminal)
085 from Libya (2 Terminals) to UK (1 terminal)
086 from Libya to Rest of Western EU
099 from Angola (1 Terminal) to Belgium (1 terminal)
100 from Angola (1 Terminal) to France (2 terminals)
101 from Angola (1 Terminal) to NL (1 terminal)
102 from Angola (1 Terminal) to Spain (2 terminals)
103 from Angola (1 Terminal) to UK (1 terminal)
104 from Angola to Rest of Western EU
114 from Egypt (2 terminals) to Italy (4 terminals)
121 from Gabon (1 terminal) to France (2 terminals)
123 from Gabon (1 terminal) to Spain (2 terminals)
128 from Gabon (1 terminal) to NL (1 terminal)
130 from Gabon (1 terminal) to UK (1 terminal)
135 from Iran (2 Terminals) to France (2 terminals)
136 from Iran (2 Terminals) to Germany (1 terminal)
137 from Iran (2 Terminals) to Italy (4 terminals)
138 from Iran (2 Terminals) to NL (1 terminal)

225 from Iran (2 Terminals) to Greece (1 terminal) 139 from Iran (2 Terminals) to UK (1 terminal) 140 from Iran to Rest of Western EU 153 from Iraq (2 Terminals) to France (2 terminals) 154 from Iraq (2 Terminals) to Germany (1 terminal) 155 from Iraq (2 Terminals) to Italy (4 terminals) 156 from Iraq (2 Terminals) to NL (1 terminal) 158 from Iraq (2 Terminals) to Spain (2 terminals) 157 from Iraq (2 Terminals) to UK (1 terminal) 159 from Iraq to Rest of Western EU 242 from Syria (1 Terminal) to France (2 terminals) 247 from Syria (1 Terminal) to Germany (1 terminal) 241 from Syria (1 Terminal) to Italy (4 terminals) 245 from Syria (1 Terminal) to NL (1 terminal) 243 from Syria (1 Terminal) to Spain (2 terminals) 244 from Syria (1 Terminal) to UK (1 terminal) 169 from Kuwait (1 Terminal) to France (2 terminals) 170 from Kuwait (1 Terminal) to Germany (1 terminal) 171 from Kuwait (1 Terminal) to Italy (4 terminals) 172 from Kuwait (1 Terminal) to NL (1 terminal) 173 from Kuwait (1 Terminal) to Spain (2 terminals) 174 from Kuwait (1 Terminal) to UK (1 terminal) 175 from Kuwait to Rest of Western EU 186 from Qatar (1 Terminal) to France (2 terminals) 187 from Qatar (1 Terminal) to Germany (1 terminal) 188 from Qatar (1 Terminal) to Italy (4 terminals) 189 from Qatar (1 Terminal) to NL (1 terminal) 190 from Qatar (1 Terminal) to UK (1 terminal) 191 from Qatar to Rest of Western EU 202 from Saudi Arabia (2 Terminals) to France (2 terminals) 203 from Saudi Arabia (2 Terminals) to Germany (1 terminal) 204 from Saudi Arabia (2 Terminals) to Italy (4 terminals) 205 from Saudi Arabia (2 Terminals) to NL (1 terminal) 206 from Saudi Arabia (2 Terminals) to Spain (2 terminals) 207 from Saudi Arabia (2 Terminals) to UK (1 terminal) 256 from Saudi Arabia (2 Terminals) to Greece (1 terminal 208 from Saudi Arabia to Rest of Western EU 219 from UAE (1 terminal) to France (2 terminals) 220 from UAE (1 terminal) to Germany (1 terminal) 221 from UAE (1 terminal) to Italy (4 terminals) 222 from UAE (1 terminal) to NL (1 terminal) 222 from UAE (1 terminal) to UK (1 terminal) 223 from UAE (1 terminal) to Greece (1 terminal 224 from UAE to Rest of Western EU 257 from Russia to Greece

A2.2 Solar Electricity

Identified corridors for import of solar electricity to the EU27+ border are listed in Table A2.2. Total length of the HVDC corridors is indicated as well as the length of the submarine cables included as separate corridor sectors. Corridors of the same origin country are competing options with different paths (countries crossed) but also partly different destinations. Defined internal paths to EU member states and selected agglomerations are indicated in (Trieb et al., 2009).

Table A2.2: Identified corridors for import of solar electricity to the EU27+ border.

Corr. code	Corridor name	Start	End (EU 27+ border)	Length (sea) [km]
ELE_LIN_01	Morocco-Spain 1	West of Marrakech	Paloma Baja	623 (32)
ELE_LIN_02	Morocco-Spain 2	Boulemane Province	Casas de Porro	421 (27)
ELE_LIN_03	Morocco-Spain 3	Boulemane Province	Algeciras	418 (16)
ELE_LIN_04	Morocco-Spain 4	Boulemane Province	San Agustin/El Ejido	452 (149)
ELE_LIN_05	Algeria-Spain 1	Benoud	Casas de Porro	881 (27)
ELE_LIN_06	Algeria-Spain 2	Benoud	San José	632 (201)
ELE_LIN_07	Algeria-Spain 3	Dzioua	Casas de Porro	1310 (27)
ELE_LIN_08	Algeria-Spain 4	Dzioua	San José	993 (201)
ELE_LIN_09	Algeria-Italy 1	Dzioua	Setti Ballas (Sardegna)	782 (271)
ELE_LIN_10	Tunisia-Spain 1	Bordj-Bouguiba	Roquetas de Mar	1485 (199)
ELE_LIN_11	Tunisia-Spain 2	Bordj-Bouguiba	San José	1486 (201)
ELE_LIN_12	Tunisia-Italy 1	Bordj-Bouguiba	Setti Ballas (Sardegna)	803 (196)
ELE_LIN_13	Tunisia-Italy 2	Bordj-Bouguiba	Mazara del Vallo (Sicilia)	702 (272)
ELE_LIN_14	Lybia-Spain 1	Sinawin	Roquetas de Mar	1664 (199)
ELE_LIN_15	Lybia-Spain 2	Sinawin	San José	1665 (201)
ELE_LIN_16	Lybia-Italy 1	Sinawin	Setti Ballas (Sardegna)	969 (196)
ELE_LIN_17	Lybia-Italy 2	Sinawin	Mazara del Vallo (Sicilia)	873 (272)
ELE_LIN_18	Lybia-Spain 3	Jaghbub	Roquetas de Mar	3032 (363)
ELE_LIN_19	Lybia-Spain 4	Jaghbub	San José	3033 (365)
ELE_LIN_20	Lybia-Italy 3	Jaghbub	Setti Ballas (Sardegna)	2337 (360)
ELE_LIN_21	Lybia-Italy 4	Jaghbub	Maucini (Sicilia)	1564 (164)
ELE_LIN_22	Saudi Arabia-Spain 1	Halit Ammar	San José or Roquetas de Mar	4377 (424)
ELE_LIN_23	Saudi Arabia-Italy 1	Halit Ammar	Setti Ballas (Sardegna)	3679 (418)
ELE_LIN_24	Saudi Arabia-Greece 1	Halit Ammar	Aghios Merkourios	2449 (227)
ELE_LIN_25	Saudi Arabia-Bulgaria 1	Halit Ammar	Strandzha	2292 (108)
ELE_LIN_26	Jordan-Spain 1	El Mudawwara	San José or Roquetas de Mar	4364 (424)
ELE_LIN_27	Jordan-Italy 1	El Mudawwara	Setti Ballas (Sardegna)	3666 (418)
ELE_LIN_28	Jordan-Greece 1	El Mudawwara	Aghios Merkourios	2364 (227)
ELE_LIN_29	Jordan-Bulgaria 1	El Mudawwara	Strandzha	2207 (335)
ELE_LIN_30	Egypt-Spain 1	Al-Bahr al-ahmar	San José or Roquetas de Mar	4002 (424)
ELE_LIN_31	Egypt-Italy 1	Al-Bahr al-ahmar	Setti Ballas (Sardegna)	3304 (418)
ELE_LIN_32	Egypt-Greece 1	Al-Bahr al-ahmar	Potami	2168 (687)
ELE_LIN_33	Egypt-Bulgaria 1	Al-Bahr al-ahmar	Strandzha	2227 (618)
ELE_LIN_34	Egypt-Spain 2	Al-Wadi al-dschadid	San José or Roquetas de Mar	4075 (424)
ELE_LIN_35	Egypt-Italy 2	Al-Wadi al-dschadid	Setti Ballas (Sardegna)	3377 (418)
ELE_LIN_36	Egypt-Greece 2	Al-Wadi al-dschadid	Potami	2481 (663)
ELE_LIN_37	Egypt-Bulgaria 2	Al-Wadi al-dschadid	Strandzha	2540 (594)

A2.3 Coal

The following Table lists identified open sea import corridors for hard coal from main supplying countries to EU27+ countries. Additional corridor segments by rail in both, supply countries and import countries representing transport to/from the sea ports were defined in the frame of work package 5 and are not shown in this report. Chapter 3.3 describes main EU27 corridors for coal transport by inland shipping.

Table A2.3: Identified open sea corridors for coal import to the EU27+ border.

Corr. code	Corridor name	Start	End (EU 27+ border)	Length [km]
HC_SHP_01_01	South Africa-Netherlands	Richards Bay Port	Rotterdam Port	12973
HC_SHP_01_02	South Africa-Belgium	Richards Bay Port	Antwerp Port	12960
HC_SHP_01_03	South Africa-France	Richards Bay Port	Le Havre Port	12789
HC_SHP_01_04	South Africa-France	Richards Bay Port	Marseille Port	11080
HC_SHP_01_04_LONG	South Africa-France	Richards Bay Port	Marseille Port	11652
HC_SHP_01_05	South Africa-Spain	Richards Bay Port	Cartagena Port	11382
HC_SHP_01_05_LONG	South Africa-Spain	Richards Bay Port	Cartagena Port	11876
HC_SHP_01_06	South Africa-Italy	Richards Bay Port	Genova Port	10589
HC_SHP_01_06_LONG	South Africa-Italy	Richards Bay Port	Genova Port	11509
HC_SHP_01_07	South Africa-UK	Richards Bay Port	UK Coal Port	12812
HC_SHP_01_08	South Africa-Ireland	Richards Bay Port	Ireland Coal Port	12626
HC_SHP_01_09	South Africa-Denmark	Richards Bay Port	Denmark Coal Port	13736
HC_SHP_01_10	South Africa-Sweden	Richards Bay Port	Sweden Coal Port	14310
HC_SHP_01_11	South Africa-Norway	Richards Bay Port	Norway Coal Port	14315
HC_SHP_01_12	South Africa-Finland	Richards Bay Port	Finland Coal Port	14710
HC_SHP_01_13	South Africa-Romania	Richards Bay Port	Constanta Port	10482
HC_SHP_01_13_LONG	South Africa-Romania	Richards Bay Port	Constanta Port	14940
HC_SHP_01_14	South Africa-Bulgaria	Richards Bay Port	Bulgaria Coal Port	9939
HC_SHP_01_15	South Africa-Germany	Richards Bay Port	Germany Coal Port	13434
HC_SHP_01_16	South Africa-Greece	Richards Bay Port	Greece Coal Port	9669
HC_SHP_01_17	South Africa-Portugal	Richards Bay Port	Portugal Coal Port	11037
HC_SHP_02_01	Australia-Netherlands	Newcastle Port	Rotterdam Port	21501
HC_SHP_02_01_LONG	Australia-Netherlands	Newcastle Port	Rotterdam Port	23300
HC_SHP_02_02	Australia-Belgium	Newcastle Port	Antwerp Port	13353
HC_SHP_02_02_LONG	Australia-Belgium	Newcastle Port	Antwerp Port	23830
HC_SHP_02_03	Australia-France	Newcastle Port	Le Havre Port	21318
HC_SHP_02_03_LONG	Australia-France	Newcastle Port	Le Havre Port	23000
HC_SHP_02_04	Australia-France	Newcastle Port	Marseille Port	18247
HC_SHP_02_04_LONG	Australia-France	Newcastle Port	Marseille Port	23860
HC_SHP_02_05	Australia-Spain	Newcastle Port	Cartagena Port	18549
HC_SHP_02_05_LONG	Australia-Spain	Newcastle Port	Cartagena Port	21730
HC_SHP_02_06	Australia-Italy	Newcastle Port	Genova Port	18737
HC_SHP_02_06_LONG	Australia-Italy	Newcastle Port	Genova Port	23214
HC_SHP_02_07	Australia-UK	Newcastle Port	UK Coal Port	21340
HC_SHP_02_08	Australia-Ireland	UK Coal Port	Ireland Coal Port	13159
HC_SHP_02_09	Australia-Denmark	UK Coal Port	Denmark Coal Port	22264
HC_SHP_02_10	Australia-Sweden	UK Coal Port	Sweden Coal Port	22838
HC_SHP_02_11	Australia-Norway	Newcastle Port	Norway Coal Port	22844
HC_SHP_02_12	Australia-Finland	Newcastle Port	Finland Coal Port	23238
HC_SHP_02_13	Australia-Romania	Newcastle Port	Constanta Port	17305
HC_SHP_02_13_LONG	Australia-Romania	Newcastle Port	Constanta Port	25353
HC_SHP_02_14	Australia-Bulgaria	Newcastle Port	Bulgaria Coal Port	17105
HC_SHP_02_15	Australia-Germany	Newcastle Port	Germany Coal Port	21962
HC_SHP_02_16	Australia-Greece	Newcastle Port	Greece Coal Port	16834
HC_SHP_02_17	Australia-Portugal	Newcastle Port	Portugal Coal Port	19457
HC_SHP_03_01	Colombia-Netherlands	Puerto Bolivar Port	Rotterdam Port	8458
HC_SHP_03_02	Colombia-Belgium	Puerto Bolivar Port	Antwerp Port	8846
HC_SHP_03_03	Colombia-France	Puerto Bolivar Port	Le Havre Port	8274
HC_SHP_03_04	Colombia-France	Puerto Bolivar Port	Marseille Port	8854
HC_SHP_03_05	Colombia-Spain	Puerto Bolivar Port	Cartagena Port	8291
HC_SHP_03_06	Colombia-Italy	Puerto Bolivar Port	Genova Port	8859

Corr. code	Corridor name	Start	End (EU 27+ border)	Length [km]
HC_SHP_03_07	Colombia-UK	Puerto Bolivar Port	UK Coal Port	8098
HC_SHP_03_08	Colombia-Ireland	Puerto Bolivar Port	Ireland Coal Port	7509
HC_SHP_03_09	Colombia-Denmark	Puerto Bolivar Port	Denmark Coal Port	9130
HC_SHP_03_10	Colombia-Sweden	Puerto Bolivar Port	Sweden Coal Port	9911
HC_SHP_03_11	Colombia-Norway	Puerto Bolivar Port	Norway Coal Port	8850
HC_SHP_03_12	Colombia-Finland	Puerto Bolivar Port	Finland Coal Port	10311
HC_SHP_03_13	Colombia-Romania	Puerto Bolivar Port	Constanta Port	11230
HC_SHP_03_14	Colombia-Bulgaria	Puerto Bolivar Port	Bulgaria Coal Port	11030
HC_SHP_03_15	Colombia-Germany	Puerto Bolivar Port	Germany Coal Port	8911
HC_SHP_03_16	Colombia-Greece	Puerto Bolivar Port	Greece Coal Port	10665
HC_SHP_03_17	Colombia-Portugal	Puerto Bolivar Port	Portugal Coal Port	7285
HC_SHP_04_01	USA-Netherlands	Baltimore Port	Rotterdam Port	6796
HC_SHP_04_02	USA-Belgium	Baltimore Port	Antwerp Port	6806
HC_SHP_04_03	USA-France	Baltimore Port	Le Havre Port	7217
HC_SHP_04_04	USA-France	Baltimore Port	Marseille Port	7732
HC_SHP_04_05	USA-Spain	Baltimore Port	Cartagena Port	7170
HC_SHP_04_06	USA-Italy	Baltimore Port	Genova Port	7780
HC_SHP_04_07	USA-UK	Baltimore Port	UK Coal Port	6287
HC_SHP_04_08	USA-Ireland	Baltimore Port	Ireland Coal Port	5791
HC_SHP_04_09	USA-Denmark	Baltimore Port	Denmark Coal Port	7337
HC_SHP_04_10	USA-Sweden	Baltimore Port	Sweden Coal Port	8119
HC_SHP_04_11	USA-Norway	Baltimore Port	Norway Coal Port	7046
HC_SHP_04_12	USA-Finland	Baltimore Port	Finland Coal Port	8519
HC_SHP_04_13	USA-Romania	Baltimore Port	Constanta Port	10150
HC_SHP_04_14	USA-Bulgaria	Baltimore Port	Bulgaria Coal Port	9950
HC_SHP_04_15	USA-Germany	Baltimore Port	Germany Coal Port	7235
HC_SHP_04_16	USA-Greece	Baltimore Port	Greece Coal Port	9585
HC_SHP_04_17	USA-Portugal	Baltimore Port	Portugal Coal Port	6061
HC_SHP_05_01	Canada-Netherlands	Vancouver Port	Rotterdam Port	16417
HC_SHP_05_02	Canada-Belgium	Vancouver Port	Antwerp Port	16427
HC_SHP_05_03	Canada-France	Vancouver Port	Le Havre Port	16903
HC_SHP_05_04	Canada-France	Vancouver Port	Marseille Port	16814
HC_SHP_05_05	Canada-Spain	Vancouver Port	Cartagena Port	16253
HC_SHP_05_06	Canada-Italy	Vancouver Port	Genova Port	16862
HC_SHP_05_07	Canada-UK	Vancouver Port	UK Coal Port	15934
HC_SHP_05_08	Canada-Ireland	Vancouver Port	Ireland Coal Port	9736
HC_SHP_05_09	Canada-Denmark	Vancouver Port	Denmark Coal Port	17053
HC_SHP_05_10	Canada-Sweden	Vancouver Port	Sweden Coal Port	17834
HC_SHP_05_11	Canada-Norway	Vancouver Port	Norway Coal Port	16871
HC_SHP_05_12	Canada-Finland	Vancouver Port	Finland Coal Port	18234
HC_SHP_05_13	Canada-Romania	Vancouver Port	Constanta Port	19233
HC_SHP_05_14	Canada-Bulgaria	Vancouver Port	Bulgaria Coal Port	19033
HC_SHP_05_15	Canada-Germany	Vancouver Port	Germany Coal Port	16886
HC_SHP_05_16	Canada-Greece	Vancouver Port	Greece Coal Port	18668
HC_SHP_05_17	Canada-Portugal	Vancouver Port	Portugal Coal Port	16101
HC_SHP_06_01	Indonesia-Netherlands	Tanjung Bara Port	Rotterdam Port	11757
HC_SHP_06_01_LONG	Indonesia-Netherlands	Tanjung Bara Port	Rotterdam Port	25320
HC_SHP_06_02	Indonesia-Belgium	Tanjung Bara Port	Antwerp Port	17578
HC_SHP_06_02_LONG	Indonesia-Belgium	Tanjung Bara Port	Antwerp Port	24300
HC_SHP_06_03	Indonesia-France	Tanjung Bara Port	Le Havre Port	17510
HC_SHP_06_03_LONG	Indonesia-France	Tanjung Bara Port	Le Havre Port	25120
HC_SHP_06_04	Indonesia-France	Tanjung Bara Port	Marseille Port	14306
HC_SHP_06_04_LONG	Indonesia-France	Tanjung Bara Port	Marseille Port	24220
HC_SHP_06_05	Indonesia-Spain	Tanjung Bara Port	Cartagena Port	14596
HC_SHP_06_05_LONG	Indonesia-Spain	Tanjung Bara Port	Cartagena Port	22610
HC_SHP_06_06	Indonesia-Italy	Tanjung Bara Port	Genova Port	14790
HC_SHP_06_06_LONG	Indonesia-Italy	Tanjung Bara Port	Genova Port	24595
HC_SHP_06_07	Indonesia-UK	Tanjung Bara Port	UK Coal Port	17393
HC_SHP_06_08	Indonesia-Ireland	Tanjung Bara Port	Ireland Coal Port	17221
HC_SHP_06_09	Indonesia-Denmark	Tanjung Bara Port	Denmark Coal Port	18589
HC_SHP_06_10	Indonesia-Sweden	Tanjung Bara Port	Sweden Coal Port	19371
HC_SHP_06_11	Indonesia-Norway	Tanjung Bara Port	Norway Coal Port	18943
HC_SHP_06_12	Indonesia-Finland	Tanjung Bara Port	Finland Coal Port	19771
HC_SHP_06_13	Indonesia-Romania	Tanjung Bara Port	Constanta Port	13324
HC_SHP_06_13_LONG	Indonesia-Romania	Tanjung Bara Port	Constanta Port	26500

Corr. code	Corridor name	Start	End (EU 27+ border)	Length [km]
HC_SHP_06_14	Indonesia-Bulgaria	Tanjung Bara Port	Bulgaria Coal Port	13124
HC_SHP_06_15	Indonesia-Germany	Tanjung Bara Port	Germany Coal Port	18037
HC_SHP_06_16	Indonesia-Greece	Tanjung Bara Port	Greece Coal Port	12869
HC_SHP_06_17	Indonesia-Portugal	Tanjung Bara Port	Portugal Coal Port	13324
HC_SHP_07_01	China-Netherlands	Quinhuangdao Port	Rotterdam Port	20384
HC_SHP_07_01_LONG	China-Netherlands	Quinhuangdao Port	Rotterdam Port	28520
HC_SHP_07_02	China-Belgium	Quinhuangdao Port	Antwerp Port	20394
HC_SHP_07_02_LONG	China-Belgium	Quinhuangdao Port	Antwerp Port	27530
HC_SHP_07_03	China-France	Quinhuangdao Port	Le Havre Port	20212
HC_SHP_07_03_LONG	China-France	Quinhuangdao Port	Le Havre Port	28220
HC_SHP_07_04	China-France	Quinhuangdao Port	Marseille Port	17121
HC_SHP_07_04_LONG	China-France	Quinhuangdao Port	Marseille Port	28330
HC_SHP_07_05	China-Spain	Quinhuangdao Port	Cartagena Port	17412
HC_SHP_07_05_LONG	China-Spain	Quinhuangdao Port	Cartagena Port	26590
HC_SHP_07_06	China-Italy	Quinhuangdao Port	Genova Port	18014
HC_SHP_07_06_LONG	China-Italy	Quinhuangdao Port	Genova Port	27850
HC_SHP_07_07	China-UK	Quinhuangdao Port	UK Coal Port	20209
HC_SHP_07_08	China-Ireland	Quinhuangdao Port	Ireland Coal Port	20036
HC_SHP_07_09	China-Denmark	Quinhuangdao Port	Denmark Coal Port	21405
HC_SHP_07_10	China-Sweden	Quinhuangdao Port	Sweden Coal Port	22186
HC_SHP_07_11	China-Norway	Quinhuangdao Port	Norway Coal Port	21759
HC_SHP_07_12	China-Finland	Quinhuangdao Port	Finland Coal Port	22586
HC_SHP_07_13	China-Romania	Quinhuangdao Port	Constanta Port	17241
HC_SHP_07_13_LONG	China-Romania	Quinhuangdao Port	Constanta Port	29900
HC_SHP_07_14	China-Bulgaria	Quinhuangdao Port	Bulgaria Coal Port	15940
HC_SHP_07_15	China-Germany	Quinhuangdao Port	Germany Coal Port	20853
HC_SHP_07_16	China-Greece	Quinhuangdao Port	Greece Coal Port	15684
HC_SHP_07_17	China-Portugal	Quinhuangdao Port	Portugal Coal Port	18418
HC_SHP_08_01	Russia-Netherlands	Murmansk Port	Rotterdam Port	2900
HC_SHP_08_02	Russia-Belgium	Murmansk Port	Antwerp Port	3060
HC_SHP_08_03	Russia-France	Murmansk Port	Le Havre Port	3050
HC_SHP_08_04	Russia-UK	Murmansk Port	UK Coal Port	2800
HC_SHP_08_05	Russia-Denmark	Murmansk Port	Denmark Coal Port	2600
HC_SHP_08_06	Russia-Sweden	Murmansk Port	Sweden Coal Port	2700
HC_SHP_08_07	Russia-Norway	Murmansk Port	Norway Coal Port	2000
HC_SHP_08_08	Russia-Italy	Murmansk Port	Genova Port	6500
HC_SHP_08_09	Russia-Spain	Murmansk Port	Cartagena Port	3250
HC_SHP_08_10	Russia-Germany	Murmansk Port	Germany Coal Port	2800
HC_SHP_09_01	Ukraine-Bulgaria	Odessa Port	Bulgaria Coal Port	500
HC_SHP_09_02	Ukraine-Greece	Odessa Port	Greece Coal Port	1200
HC_SHP_09_03	Ukraine-France	Odessa Port	Marseille Port	3500
HC_SHP_09_04	Ukraine-Italy	Odessa Port	Genova Port	2700
HC_SHP_09_05	Ukraine-Spain	Odessa Port	Cartagena Port	3700
HC_SHP_09_06	Ukraine-Portugal	Odessa Port	Portugal Coal Port	4500
HC_SHP_09_07	Ukraine-Cyprus	Odessa Port	Cyprus Coal Port	1900
HC_SHP_10_01	Venezuela-Netherlands	La Salina Port	Rotterdam Port	8458
HC_SHP_10_02	Venezuela-Belgium	La Salina Port	Antwerp Port	8846
HC_SHP_10_03	Venezuela-France	La Salina Port	Le Havre Port	8274
HC_SHP_10_04	Venezuela-France	La Salina Port	Marseille Port	8854
HC_SHP_10_05	Venezuela-Spain	La Salina Port	Cartagena Port	8291
HC_SHP_10_06	Venezuela-Italy	La Salina Port	Genova Port	8859
HC_SHP_10_07	Venezuela-UK	La Salina Port	UK Coal Port	8098
HC_SHP_10_08	Venezuela-Ireland	La Salina Port	Ireland Coal Port	7509
HC_SHP_10_09	Venezuela-Denmark	La Salina Port	Denmark Coal Port	9130
HC_SHP_10_10	Venezuela-Sweden	La Salina Port	Sweden Coal Port	9911
HC_SHP_10_11	Venezuela-Norway	La Salina Port	Norway Coal Port	8850
HC_SHP_10_12	Venezuela-Finland	La Salina Port	Finland Coal Port	10311
HC_SHP_10_13	Venezuela-Romania	La Salina Port	Constanta Port	11230
HC_SHP_10_14	Venezuela-Bulgaria	La Salina Port	Bulgaria Coal Port	11030
HC_SHP_10_15	Venezuela-Germany	La Salina Port	Germany Coal Port	8911
HC_SHP_10_16	Venezuela-Greece	La Salina Port	Greece Coal Port	10665
HC_SHP_10_17	Venezuela-Portugal	La Salina Port	Portugal Coal Port	7285

A2.4 Biomass

Table A2.4 lists name, start and end locations and the length of identified biomass corridors which will be integrated in the TIMES models in REACCESS. With the intention of avoiding long distances for truck transportation, which turns out to have the highest costs, two destination ports have been selected for the imports of biofuels in Europe, one in Northern Europe and the other in Southern Europe. Rotterdam is the biggest port of Europe (378.4 Mt of total handled tonnage) and one of the largest petrochemical logistics hubs. Located on the south east coast of France on the Mediterranean Sea, Marseille is France's largest commercial port. This choice gives the opportunity of reaching Southern European countries.

Table A2.4: Identified biomass corridors.

Corr. code	Corridor name	Start	End	Length [km]
BIO_SHP_01	Bioethanol Africa to Northern Europe	Cape Town	Rotterdam	11414
BIO_SHP_02	Bioethanol Africa to Southern Europe	Cape Town	Marseille	10705
BIO_SHP_03	Pellets Canada to Northern Europe	Montreal	Rotterdam	6093
BIO_SHP_04	Pellets Canada to Southern Europe	Montreal	Marseille	7167
BIO_SHP_05	Bioethanol China to Northern Europe	Shanghai	Rotterdam	19481
BIO_SHP_06	Bioethanol China to Southern Europe	Shanghai	Marseille	16218
BIO_SHP_07	Biodiesel Brazil to Northern Europe	Sao Paolo	Rotterdam	10056
BIO_SHP_08	Biodiesel Brazil to Southern Europe	Sao Paolo	Marseille	9384
BIO_SHP_09	Bioethanol Brazil to Northern Europe	Sao Paolo	Rotterdam	10056
BIO_SHP_10	Bioethanol Brazil to Southern Europe	Sao Paolo	Marseille	9384
BIO_SHP_11	Biodiesel Argentina to Northern Europe	Mar de Plata	Rotterdam	11744
BIO_SHP_12	Biodiesel Argentina to Southern Europe	Mar de Plata	Marseille	11073
BIO_SHP_13	Biodiesel Malaysia to Northern Europe	Penang	Rotterdam	14807
BIO_SHP_14	Biodiesel Malaysia to Southern Europe	Penang	Marseille	11544
BIO_SHP_15	Bioethanol Pakistan to Northern Europe	Karachi	Rotterdam	11355
BIO_SHP_16	Bioethanol Pakistan to Southern Europe	Karachi	Marseille	8091
BIO_SHP_17	Pellets Russia - North to Northern Europe	Primorsk	Rotterdam	2406
BIO_SHP_18	Pellets Russia - South to Southern Europe	Novorossyisk	Marseille	3397
BIO_SHP_19	Biodiesel USA to Northern Europe	New York	Rotterdam	6265
BIO_SHP_20	Biodiesel USA to Southern Europe	New York	Marseille	7215

A2.5 Nuclear Energy

Table A2.5 lists code, start and end locations and the length of identified uranium corridors which will be integrated in the TIMES models in REACCESS.

Table A2.5: Identified existing uranium corridors.

Corridor code	Start	End	Length [km]
NUC_001_A and NUC_001_B	Canada	UK, France	3800 (road) 6900-7650 (sea)
NUC_002	Northern Australia	France	265 (road) 23800 (sea)
NUC_003	Southern Australia	France	650 (road) 23000 (sea)
NUC_004	Niger	France	1490 (road) 7950 (sea)
NUC_005	Namibia	France	95 (road) 10720 (sea)

A2.6 Hydrogen

Corridors from Ukraine

Four alternative corridors with different pipeline length are assumed to start from the Donetsk basin where the most relevant reserves of Ukrainian lignite are concentrated. The final destinations were chosen among the most strategic and productive petrochemical poles in Eastern Europe. The pipelines proposed do not exist at present, so the lengths indicated in Table A2.6-1 are estimated considering the distances on a GIS map between the starting points and the EU border crossing.

Table A2.6-1: Distances in corridors from Ukraine.

Corridor code	Corridor name	Start	End	Length [km]
HYD_PIP_001	Ukraine-Czech Rep.	Donetsk B.	Slovakia border	1160
HYD_PIP_002	Ukraine-Poland	Donetsk B.	Poland border	1035
HYD_PIP_003	Ukraine-Slovakia	Donetsk B.	Slovakia border	1160
HYD_PIP_004	Ukraine-Hungary	Donetsk B.	Hungary border	1150

Once the lignite is extracted it is gasified. The installed capacity of 100 MW_{H2} could produce up to 800 GWh_{H2}. The assumed potential (300 kt/yr) can be fully processed (with efficiency of 56%) in the gasification capacity foreseen. If the lignite production evolves in the years, more gasification units of the same size should be installed. According to the technological choice of pipelines, a 30 bar, 250 mm diameter pipeline is able to deliver the full amount of hydrogen. The cost of the pipeline is assumed as the lowest value in the range due to the small diameter.

Corridors from Turkey

The biomass potential (mainly agricultural residues) in Turkey is quite spread over the territory. Hydrogen produced could be transported towards collection points by tube trailers (trucks), via rail or via pipeline. As the steam reforming plants cannot be located in this phase of the project, neither the network can be defined and so in the corridors plot in Figure 5.10, upstream sections of Turkish corridors are not shown.

It is proposed to split hydrogen export from Turkey into two different corridor starting points. The first corridor starts near Izmit, where a petrochemical plant is installed and the area could host a collection point for 25% of the total hydrogen produced in Turkey. Hydrogen is compressed and transported via pipeline from Izmit towards Bulgaria. The pipeline is designed to be larger than those coming from Ukraine as the amount of hydrogen to be transported is much bigger. For this pipeline a 500 mm diameter was chosen maintaining the internal pressure at the 30 bar value.

A second corridor would start in Turkey from the Ceyhan port, where a liquefaction plant would be installed to liquefy hydrogen collected from the distributed system of biomass steam reformers. Liquefaction plants have been already designed in Japan to liquefy as much as 300 t_{LH2}/d which roughly corresponds to a capacity of 500 MW. Considering the (remaining 75%) quantity of hydrogen to liquefy, a certain number of liquefaction plants would be necessary to process the full amount of gas.

The corridor may end in Sicily, at Priolo, where a large petrochemical facility is installed. From Sicily a further pipeline could be envisaged to distribute hydrogen to the rest of Italy. About 18 ships would be needed to transport the full amount of LH_2 as the trip to Sicily would last three days each route and the capability to liquefy in Ceyhan allows to load three ships per day (each ship can carry ~24 GWh_{H2}).

The third corridor from Turkey starts again from Ceyhan liquefaction plant, but the load would be delivered in Greece at the Aspropyrgos refining centre. The trip to Greece is shorter so that the number of ships needed to transport the full amount of LH_2 is only 12. The two shipping corridors are competing options (see Table A2.6-2).

Table A2.6-2: Distances in corridors from Turkey.

Corridor code	Corridor name	Start	End	Length [km]
HYD_PIP_005	Turkey-Bulgaria	Izmit	Bulgaria border	250
HYD_SHP_001	Turkey-Italy	Ceyhan	Priolo	2000
HYD_SHP_002	Turkey-Greece	Ceyhan	Aspropyrgos	1300

Corridors from Algeria

The corridors from Algeria are constituted by common pipelines with 500 mm diameter and 35 bar internal pressure towards the Skikda terminal combined with open sea routes from Skikda to final destinations in Italy, Spain and France. The onshore pipelines are dimensioned to deliver the whole amount of hydrogen obtained via thermo-chemical water splitting in the Chott ech Chergui area from concentrating solar power plants. The liquefaction plant in Skikda should be large enough to process the input of hydrogen from the desert. Again a cluster of liquefaction plants is necessary for this operation. The LH_2 can then be shipped via cryogenic tanker towards the destinations Gela, Fos-sur-Mer and Cartagena (Table A2.6-3).

Table A2.6-3: Distances in corridors from Algeria.

Corridor code	Corridor name	Start	End	Length [km]
HYD_SHP_003	Algeria-Italy			
		Chott ech Chergui	Skikda	720
		Skikda	Gela	670
HYD_SHP_004	Algeria-France			
		Chott ech Chergui	Skikda	720
		Skikda	Fos-sur-Mer	750
HYD_SHP_005	Algeria-Spain			
		Chott ech Chergui	Skikda	720
		Skikda	Cartagena	720

The distances to be covered are not very long and ships can do the round trip in two days. This allows for reducing the fleet to 4 ships only. The three corridors are, again, in competition among them. It should be noted that the corridor heading to Fos-sur-Mer has the possibility to supply not only the refineries nearby but to continue as a captive branch toward France and Germany. The modulation of the supply might be foreseen to be unbalanced towards this destination.

Corridors from Morocco

The corridors from Morocco towards the EU are thought to supply the wind energy storage in the form of hydrogen to Spain. The first branch is common and captive and only required if the electrolyser plant is not next to the liquefaction plant in Mohammedia. Table A2.6-4 lists the distances for the two corridors.

Table A2.6-4: Distances in corridors from Morocco.

Corridor code	Corridor name	Start	End	Length [km]
HYD_SHP_006	Morocco-Spain South			
		Off shore wind pp	Mohammedia	320
		Mohammedia	La Rabìda	390
HYD_SHP_007	Morocco-Spain North			
		Off shore wind pp	Mohammedia	320
		Mohammedia	Gijon - Bilbao	1550

The captive corridor features two pipelines with a diameter of 750 mm and an internal pressure of 40 bar. The pipeline heads to the liquefaction plant (again a cluster) and then it is ready to be shipped towards Spain. The ships may vary in number dependent on the destination: for the North of Spain up to 12 ships might be necessary, for South of Spain just 3 ships are sufficient as the roundtrip can be done in one day (considering the download time in La Rabìda).

ANNEX III – CODES FOR COUNTRIES AND WORLD REGIONS

TIAM Region code	Country code	Country names
EUR		Europe as EU27+
	AT	Austria
	BE	Belgium
	BG	Bulgaria
	CY	Cyprus
	CZ	Czech Rep.
	DK	Denmark
	EE	Estonia
	FI	Finland
	FR	France
	DE	Germany
	GR	Greece
	HU	Hungary
	IE	Ireland
	IT	Italy
	LV	Latvia
	LT	Lithuania
	LU	Luxembourg
	MT	Malta
	NL	Netherlands
	NO	Norway
	PL	Poland
	PT	Portugal
	RO	Romania
	SK	Slovakia
	SI	Slovenia
	ES	Spain
	SE	Sweden
	CH	Switzerland
	GB	United Kingdom
	GL	Greenland
	IS	Iceland
AFR		Africa
	DZ	Algeria
	EG	Egypt
	LY	Libya
	MA	Morocco
	TN	Tunisia
	…	
AUS		Oceania (Australia, New Zealand)
CAN	**CA**	Canada
CHI	**CN**	China

TIAM Region code	Country code	Country names
CAC		Central Asian Countries
	KZ	Kazakhstan
	KG	Kyrgyzstan
	TJ	Tajikistan
	TM	Turkmenistan
	UZ	Uzbekistan
OEC		Other European Countries
	AM	Armenia
	AZ	Azerbaijan
	BY	Belarus
	GE	Georgia
	MD	Moldova
	UA	Ukraine
	AL	Albania
	BA	Bosnia-Herzegovina
	HR	Croatia
	MK	Macedonia
	RS	Serbia
IND	**IN**	India
JAP	**JP**	Japan
MEA		Middle East
	BH	Bahrain
	IR	Iran
	IQ	Iraq
	IL	Israel
	JO	Jordan
	KW	Kuwait
	LB	Lebanon
	OM	Oman
	QA	Qatar
	SA	Saudi Arabia
	SY	Syria
	TR	Turkey
	AE	United Arab Emirates
	YE	Yemen
MEX	**MX**	Mexico
ODA		Other Developing Asia
SKO	**KR**	South Korea
USA	**US**	USA
CSA		Central & South America
RUS	**RU**	Russia

ANNEX IV – GLOSSARY

BP	British Petroleum
CH_4	methane
CO_2	carbon dioxide
CSP	Concentrating Solar Power
DCW	Digital Chart of the World Ph.D. Associates Inc., Toronto, Canada
DNI	Direct Normal Irradiance
EIA	Energy Information Administration
ENCOURAGED	Energy Corridor Optimisation for the European Markets of Gas, Electricity and Hydrogen, EU project
EOR	Enhanced Oil Recovery
ETOPO2	2-minute Gridded Global Relief by NGDC and NOAA
FAO	Food and Agriculture Organization of the United Nations
FRS	Financial Reporting System
FT Diesel	Fischer-Tropsch Diesel
GALSI	Gasdotto Algeria Sardegna Italia
GHG	GreenHouse Gases
GLCC	Global Land Cover Characterization Database, USGS
GLOBE	Global Land One-km Base Elevation - digital elevation model
GNS	GEOnet Names Server of National Geospatial-Intelligence Agency, USA
HVAC	High-Voltage Alternating Current
HVDC	High-Voltage Direct Current
IEA	International Energy Agency
ISL	In-Situ Leaching
IUCN	World Conservation Union
LandScan	LandScan Global Population Database, Oak Ridge National Laboratory, Oak Ridge, USA
LNG	liquefied natural gas
MEG	Maghreb-Europe Gas Pipeline
MENA	Middle East and North Africa region
NGDC	National Geophysical Data Center, Boulder, USA
NGL	natural gas liquids
NOAA	National Oceanic Atmospheric Administration, Boulder, USA
NO_x	nitrogen oxides
OGP	International Association for Oil and Gas Producers
OME	Observatoire Méditerranéen de l’Energie
OPEC	Organisation of Petroleum Exporting Countries
OWH	Other Western Hemisphere
PET	Pan European TIMES Model
PP	Power Plant
PPA	Power Purchase Agreements
REC	Reference Energy Corridor for TIMES model
RESy	Reference Energy System for TIMES model

TIAM	TIMES Integrated Assessment Model
TIMES	The Integrated MARKAL-EFOM System
Transmed	Trans-Mediterranean Pipeline
TSO	Transmission System Operators
UCTE	Union for the Coordination of Transmission of Electricity
UHVDC	Ultra High-Voltage Direct Current
UNEP-WCMC	United Nations Environment Programme - World Conservation Monitoring Centre
USGS	U.S. Geological Survey
WDPA	World Database on Protected Areas by IUCN and UNEP-WCMC

bbl	billion barrels = 10^9 barrels
Tm^3	Tera cubic meter = 10^{12} m^3
TWh	Tera watt hours = 10^9 kWh
bm^3	billion cubic metres = 10^9 m^3
boe	barrel of oil equivalent
kb/d	kilo barrel per day = 1000 barrels per day
dwt	dead weight tonnage
yr	year
MMBtu	million British Thermal Units = 1055 MJ