THE FUTURE OF COAL

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PREFACE

The objective of the Sustainable Energy Technologies Reference and Information System (SETRIS) at Directorate-General Joint Research Centre of the European Commission is to collect, harmonise and validate information on sustainable energy technologies and to perform related techno-economic assessments to establish, in collaboration with all relevant national partners, the scientific and technical reference information required for debate on a sustainable energy strategy in an enlarged EU and with a view to global sustainable development.

Produced for SETRIS, this study aims to estimate the supply prospects for coal by 2030 and beyond as a function of likely demand. The goal of the study is not to project future coal demand, supply and prices, but rather to highlight some facts and trends that may seriously affect coal supply in the future. The analysis is based on a critical review of a number of literature sources, complemented by the author's analysis. Marc Steen, Fred Starr and Aliki Georgakaki (JRC-IE) are thanked for their contribution with comments, remarks and suggestions.

This report is complemented by an additional report entitled "Coal of the Future", EUR 22644 EN, prepared by Energy Edge Ltd (UK) as external consultants. The latter report aims at further clarifying some important techno-economic points identified in the present report in relation to coal supply.

GUIDANCE FOR THE READER

In addition to the Executive Summary, there is a summary box at the beginning of each chapter. Bibliographical references for literature or other sources where more information can be found on a given subject are given in square brackets []. For the sake of simplicity, these references are numerical, although the data and information sources themselves are listed in alphabetic order.

TABLE OF CONTENTS

LIST OF FIGURES & ABBREVIATIONS USED

CIF – cost, insurance and freight
CO2 – carbon dioxide
CTL – coal-to-liquid
EU – European Union, (European) Community/ies[1]
EU-15 – the 15 member states of the European Union until 30 April 2004
EU-25 – EU-15 plus the 10 new Member States of the European Union as from 01 May 2004
EU-27 – EU-25 plus Bulgaria and Romania, which joined the EU on 1 January 2007
FSU – Former Soviet Union
GHG – greenhouse gas(es)
GTL – gas-to-liquid
R/P ratio – reserves-to-production ratio

[1] Although from a strict legal standpoint, the European Union and European Community/ies are different entities, in this report they are assumed to be identical, reflecting the widely established understanding in Europe.

EXECUTIVE SUMMARY

The sharp increase in oil and gas prices in 2005-2006 and the temporary cutback in natural gas supplies from Russia at the end of 2005 have boosted concerns about the security, diversity, reliability and affordability of energy supplies in the EU. After many years in the shadows, coal has recently come back into fashion owing to three advantages over oil and gas: lower prices per energy unit, different geopolitical distribution of reserves and a higher reserves-to-production ratio. The advances in novel and more environmentally friendly technologies for coal utilisation — Clean Coal Technologies — have further increased the interest in coal. The full implementation of Clean Coal Technologies will represent a new era in coal use that might strengthen its market position, especially if coal remains cheaper than oil and gas. Nevertheless, such a scenario raises three important questions that are sometimes overlooked:

1. If Clean Coal Technologies achieve large-scale penetration, will the required coal supply be secured in the long term?
2. If the coal supply is secured, where will it come from?
3. What will the corresponding trends be in coal costs and prices?

In view of these questions, this study aims to estimate the supply prospects for coal by 2030 and beyond as a function of likely demand. The goal of the study is not to project future coal demand, supply and prices, but rather to highlight some facts and trends that may affect coal supply in the future. The analysis concentrates on steam coal used to generate electricity, since the power generation sector is by far the largest user of coal worldwide. It covers the main coal producing, supplying and/or using regions and countries in the world, with a particular focus on the potential implications for the EU.

A review of recent market trends suggests the following:

1. The supply base of coal is being continuously depleted. World proven reserves (i.e. the reserves that are economically recoverable at *current* economic and operating conditions) of coal are decreasing fast, unlike world oil and gas reserves, which are proportionally enhanced and are maintaining their levels.
2. The bulk of coal production and exports is getting concentrated within a few countries and market players, which creates the risk of market imperfections.
3. Coal production costs are steadily rising all over the world, due to the need to develop new fields, increasingly difficult geological conditions and additional infrastructure costs associated with the exploitation of new fields.

More specifically:

- ✓ Hard coal production in the EU generally suffers from largely depleted deposits, declining coal quality and excessively high production costs. Although indigenous lignite production is still cost-competitive with hard coal imports, the reserves of the main EU lignite producers are not plentiful and are being continuously depleted.
- ✓ The lion's share of world proven coal reserves is concentrated in a few countries. Six countries (USA, China, India, Russia, South Africa, Australia) hold 84% of world hard coal reserves. Four out of these six (USA, Russia, China, Australia) also account for 78% of world brown coal reserves.
- ✓ The immense growth in coal consumption since 2000, driven mainly by China, has not been matched by a corresponding development of proven coal reserves, despite the increase in world coal prices. From 2000 to 2005, the world proven reserves-to-production ratio of coal in fact dropped by almost a third, from 277 to 155 years. Conversely, over the same period of time, the world proven reserves-to-production ratio of oil and gas remained constant (≈45 and ≈65 years, respectively), despite the large growth in demand. If the

2000-2005 evolution in the proven reserves-to-production ratios for coal, gas and oil continues, the coal ratio could relatively quickly decrease to those of natural gas and oil, while the world could run out of economically recoverable (at *current* economic and operating conditions) reserves of coal much earlier than widely anticipated. Although such an evolution appears unlikely, these trends raise concerns given that the record high coal prices in 2004 and 2005 have not yet stimulated further development of world proven coal reserves. The recent trends are worrying also because coal is projected to be the energy source with the largest growth in use worldwide at least up to 2015[2]. The fast-growing economies of China and India pose particular uncertainties on the demand side, owing to the size of their consumption and the relatively poor quality of their indigenous coal reserves. Amongst other possible consequences, these trends suggest a likely significant increase of world coal prices in the coming decades.

- ✓ Over the past 10-15 years, investment in the development of existing and new coalfields has been hampered by industry fragmentation, low prices and poor return on the investment. Catching up with the recent boom in consumption will take time.
- ✓ Australia is gradually becoming the ultimate global supplier of coal. Other traditional key exporters like South Africa, Indonesia and USA face significant challenges in the development of their coal reserves and export capabilities. The USA and China — former large net exporters — are gradually turning into large net importers with an enormous potential demand, together with India. By way of illustration, all of Australian steam coal exports are equal to only 5% of Chinese steam coal consumption. Exports from other possible large producers (Russia, Kazakhstan, Colombia) face substantial logistics problems.

To improve the situation, considerable efforts must be devoted to enhancing the world's coal supply base by converting resources into reserves and reserves into proven reserves. The investment climate in the coalmining sector and related logistics sectors needs to be improved. This includes a long-term horizon and stable regulatory frameworks. In particular, the uncertainties related to post-2012 greenhouse gas emission policies worldwide need to be lifted.

Technically and technologically, the coal supply base could be enhanced by: development and implementation of improved mapping technologies for coal resources and reserves; improvement of existing underground coal mining technologies; accelerated research and development of novel coal exploitation technologies to give access to "non-conventional coal", such as underground coal gasification and utilisation of coalmine methane gas[3].

These regulatory and techno-economic measures to enhance the coal supply base will most likely result in higher production costs.

Owing to advances in energy conversion technologies, which allow the production of a large variety of end products from different feedstocks, the world oil, gas and coal markets are becoming increasingly inter-related. The energy market of the future will thus tend to become a market for hydrocarbons rather than one differentiated by energy sources. This is expected to have important implications for coal supply and demand patterns in the future. While in the past coal has been traditionally perceived as an abundant, widely available, cheap, affordable and reliable energy source, the coal of the future may look quite different.

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[2] US DOE International Energy Outlook 2006, IEA World Energy Outlook 2006.

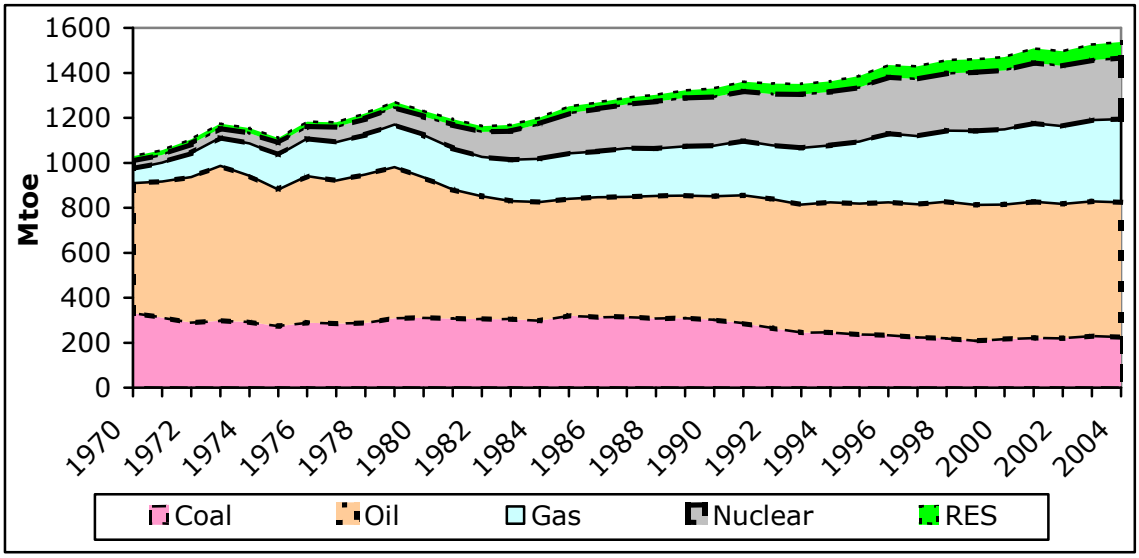
[3] Technical and technological ways of enhancing the coal supply base are not discussed in this report, but they are thoroughly analysed in the complementary report "Coal of the Future" EUR 22644 EN, prepared by Energy Edge Ltd (UK) as external consultants.

1. INTRODUCTION: WILL COAL BE A FUEL OF THE FUTURE?

The security and diversity of energy supply is causing growing concern in the EU. A renaissance in coal use — the major energy source 50 years ago, but currently with a modest and continuously declining contribution to the EU's energy supply — could potentially improve the energy balance of the EU. However, the recent trends in coal markets make the long-term supply prospects for coal uncertain. This study aims to estimate the supply prospects for coal by 2030 and beyond as a function of likely demand by answering three basic questions: 1) Is there enough coal? 2) If so, where will this coal come from? 3) What will be the trends in coal costs and prices?

The sharp increase in oil prices in 2005-2006 and the temporary cutback in natural gas supplies from Russia at the end of 2005 have boosted concerns about the security, diversity, reliability and affordability of energy supplies in the EU. The EU is particularly vulnerable to such market events and trends, as it holds extremely modest shares of world oil and gas reserves — less than 1% and less than 2%, respectively [12]. Conversely, oil and gas are the largest components in the EU's gross inland energy consumption — Figure 1.

Figure 1
Gross inland energy consumption in EU-15[4] over 1970-2004 (Mtoe)

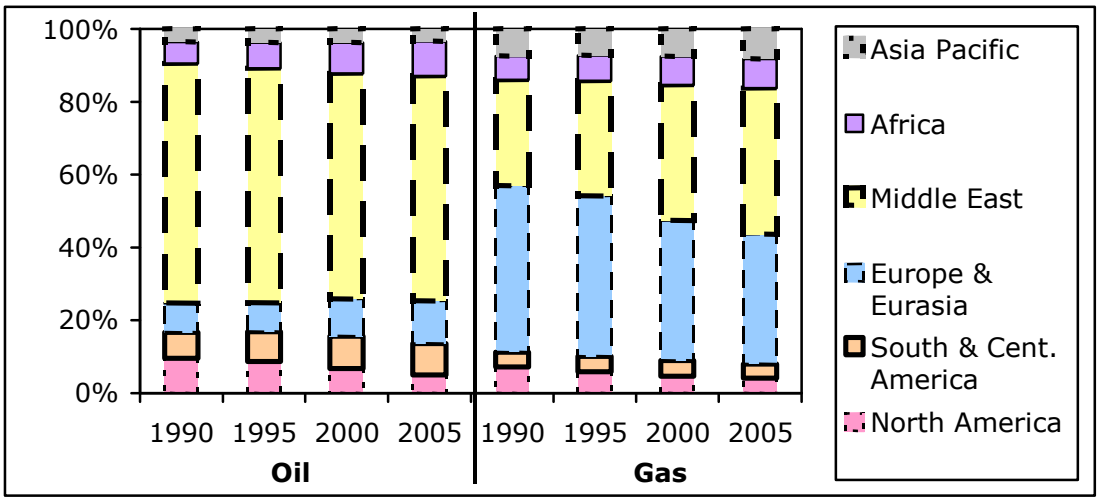


Source: Adapted from [18]

These concerns are triggered by the fact that the increasing energy needs of the EU are being met by imports from a limited number of countries. The situation is even more complicated when we consider that the geopolitical distribution of natural gas reserves is now beginning to resemble that of oil reserves. As Figure 2 indicates, most new discoveries of economically exploitable natural gas since 1990 have been in the Middle East. These trends are exerting a growing pressure on the EU. The EU's policy-makers are thus considering various preventive measures — an EU common energy policy[5], improved energy efficiency[6], larger penetration of renewable energy sources, etc.

[4] Due to the fundamental political and economic transformations in the 12 new Member States of the EU in the 1990s, it is not appropriate or sometimes not even feasible to derive similar retrospective long-time data series for them.
[5] COM(2006) 105
[6] COM(2006) 545

Figure 2
Breakdown of proven world oil and gas reserves over 1990-2005[7] (%)



Source: Adapted from [12]

Greater use of coal is also an option. Coal was the main energy source not only in Europe but also worldwide until the 1960s. Owing to advances in oil extraction, conversion and application technologies, coal then began to lose market share to oil. The entry of natural gas and nuclear power into the energy market at the beginning of 1970s put further pressure on coal. All these new energy sources were cleaner to use and in some cases even cheaper. Gradually, coal started to be perceived as a dirty and old-fashioned fuel for use in poorer countries. As a result, despite the rising energy demand, gross coal consumption in the EU-15[8] has been declining since 1970 (Figure 1), while the share of coal in gross inland energy consumption has more than halved — from more than 30% to approximately 15%. In contrast, coal retained a 25% share in gross inland energy consumption globally over the period 1970-2000.

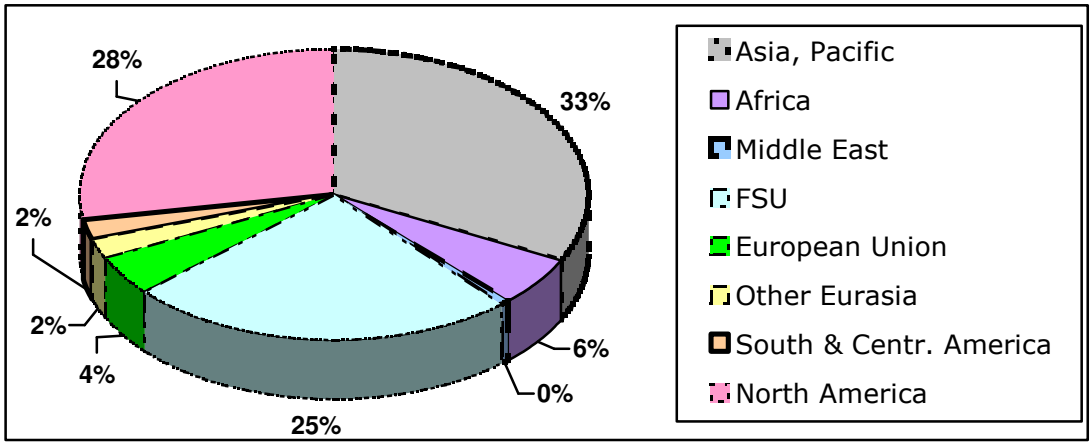
The main reason for the renewed interest in coal as an energy source in the EU is the wide perception of it as an abundant, widely available, cheap, affordable and reliable energy source, owing to the following factors:

- ✓ There is more coal than oil and gas worldwide. With current consumption trends, the reserves-to-production (R/P) ratio of world proven reserves of coal is higher than that of world proven reserves of oil and gas — 155 years versus 40 and 65 years respectively (Remark: Various categories of deposits are explained in the Annex to this report). World coal reserves are also more evenly distributed around the globe compared to oil and gas reserves. The geopolitical distribution of world coal reserves differs from that of oil and gas, with the Middle East playing no role in coal supply — Figure 3 and Figure 2.
- ✓ Historically, coal prices have been lower and more stable than oil and gas prices, owing to the more even spread of coal reserves and hence the smaller room for price manipulation — Figure 4.
- ✓ The EU has larger reserves of coal than of oil or gas, even though it does not hold a large share of world coal reserves — Figure 3. Consequently, import dependence on solid fuels (i.e. mainly coal) is lower than the dependence on gas and oil — Figure 5. A more complete and efficient exploitation of indigenous coal reserves would reduce the EU's overall energy import

[7] The former Soviet Union, in particular Russia, holds the vast majority of oil and gas reserves in Europe / Eurasia.
[8] See footnote 4.

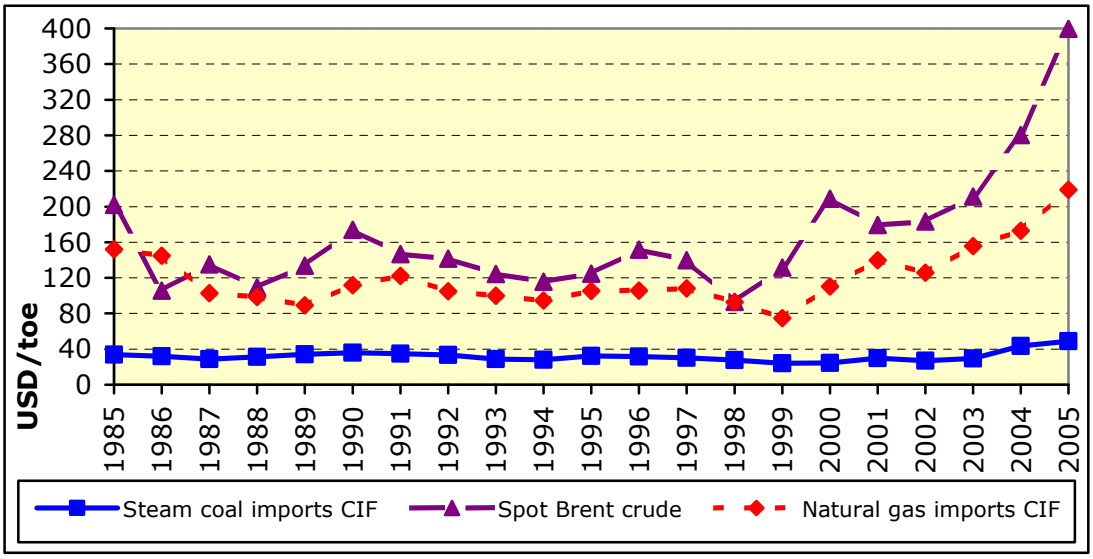
dependence. This would also bring additional synergy benefits, e.g. increased employment.

Figure 3
Breakdown of proven world coal reserves at the end of 2005 (%)



Source: Adapted from [12]

Figure 4
Selected oil, gas and coal prices in Europe over 1985-2005 (recalculated in USD/toe)

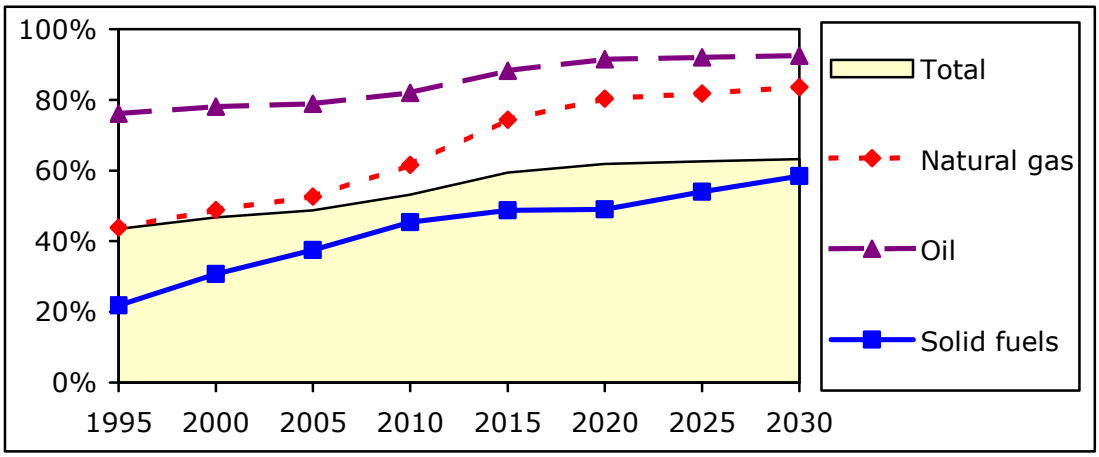


Source: Adapted from [12, 18, 57]

- ✓ The development of novel, more environmentally friendly coal technologies — Clean Coal Technologies. Designed to enhance both the efficiency and the environmental acceptability of coal *extraction, preparation* and *use* [101], these technologies are believed capable of bringing coal back into fashion. This is because the environmental concerns with coal are associated with the ways in which coal is used rather than with coal itself. Although some Clean Coal Technologies are still at the research and development stage, they are enjoying growing interest worldwide.

All these facts suggest that coal could have a bright future, undergoing a real renaissance and becoming once again a preferred fuel option. Such a perspective

Figure 5
Retrospective (1995-2000) and projected (2005-2030) import dependence of EU-27 – total and by fuels (%)

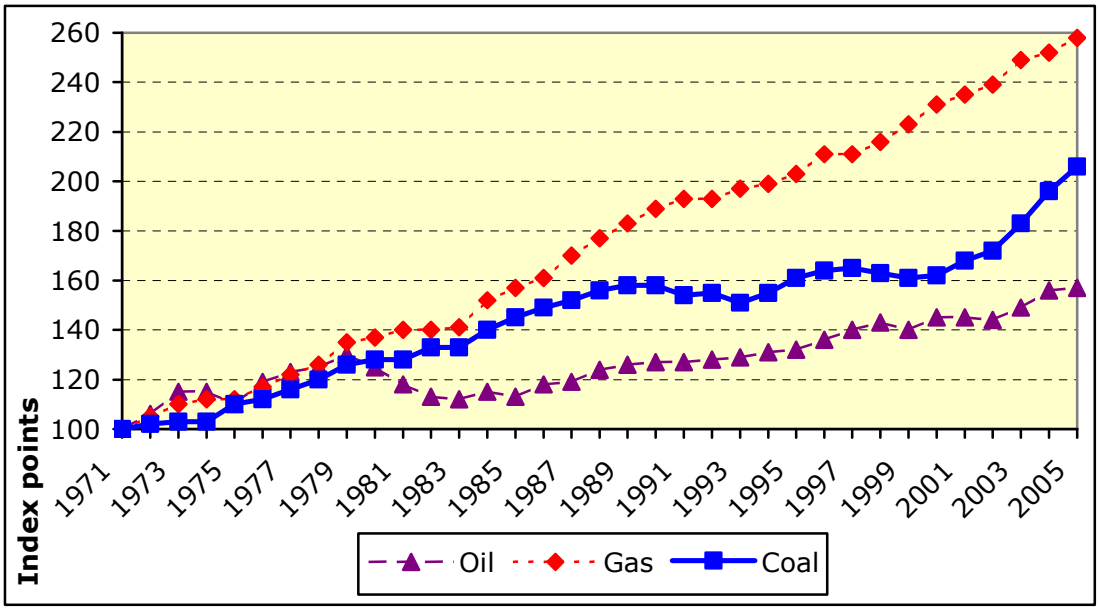


Source: Adapted from [30]

could become reality, *but*… a few other very important facts that are often overlooked should be taken into account as well:

- ✓ Coal has been the energy source with the fastest growing consumption and production in the world since 2000 — Figure 6. The largest growth in consumption has been in the developing economies[9]. In addition, coal is projected to be the fastest growing energy source worldwide by 2025 [26].

Figure 6
Index of world oil, natural gas and coal primary production over 1971-2004 (index points, 1971=100)



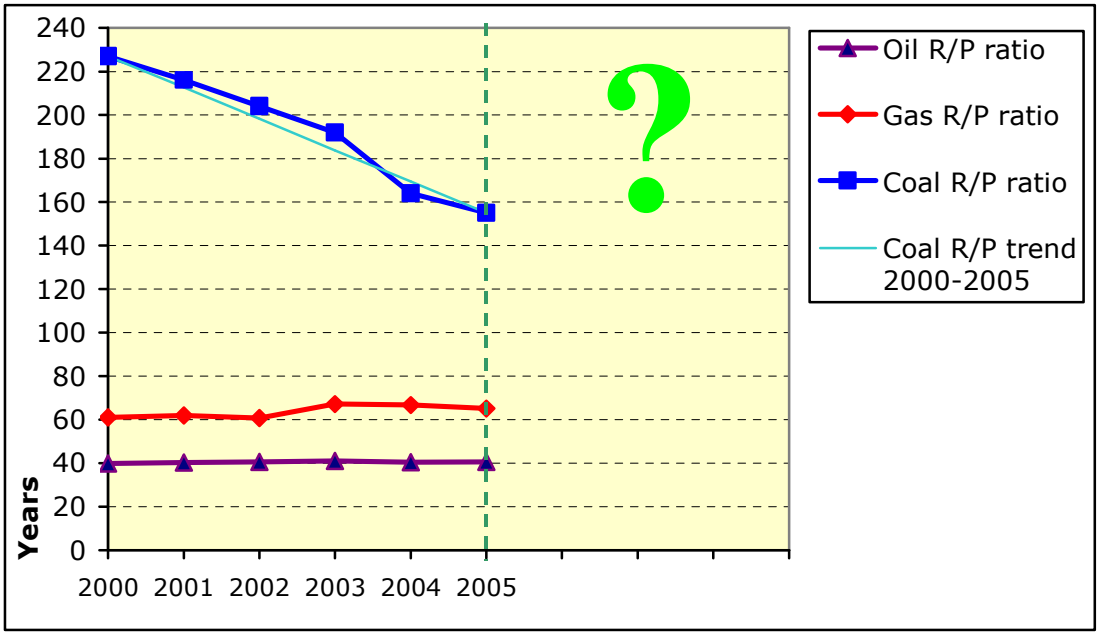
Source: Adapted from [12, 18]

- ✓ The recent immense growth in coal consumption has not been matched by a corresponding development of the supply base, unlike with oil and gas. Consequently, the coal R/P ratio, which had remained constantly above 200

[9] China alone accounts for about 80% of the recent growth in hard coal worldwide [57].

years for several decades, plunged from 227 years in 2000 to only 155 years in 2005. Conversely, over the same period of time, the world proven R/P ratio of oil and gas remained basically constant despite the large growth in demand — Figure 7. If the 2000-2005 evolution in the proven reserves-to-production ratios for coal, gas and oil continues, the coal ratio could relatively quickly decrease to those of natural gas and oil, while the world could run out of economically recoverable (at *current* economic and operating conditions) reserves of coal much earlier than widely anticipated. Although such an evolution appears unlikely, these trends raise concerns given that the record high coal prices in 2004 and 2005 (Figure 4) have not yet stimulated further development of world proven coal reserves.

Figure 7
Oil, gas and coal reserves-to-production (R/P) ratios in the world over 2000-2005 (years)



Source: Adapted from [7, 8, 9, 10, 11, 12]

In the light of the above reflections, this study aims to estimate the supply prospects for coal by 2030 and beyond as a function of likely demand. The goal of the study is *not* to project future coal demand, supply and prices, but rather to highlight some facts and trends that may affect coal supply in the future. The study thus endeavours to answer the following three questions:

1. If Clean Coal Technologies achieve large-scale penetration, will the required coal supply be secured in the long term?
2. If the coal supply is secured, where will it come from?
3. What will be the corresponding trends in coal costs and prices?

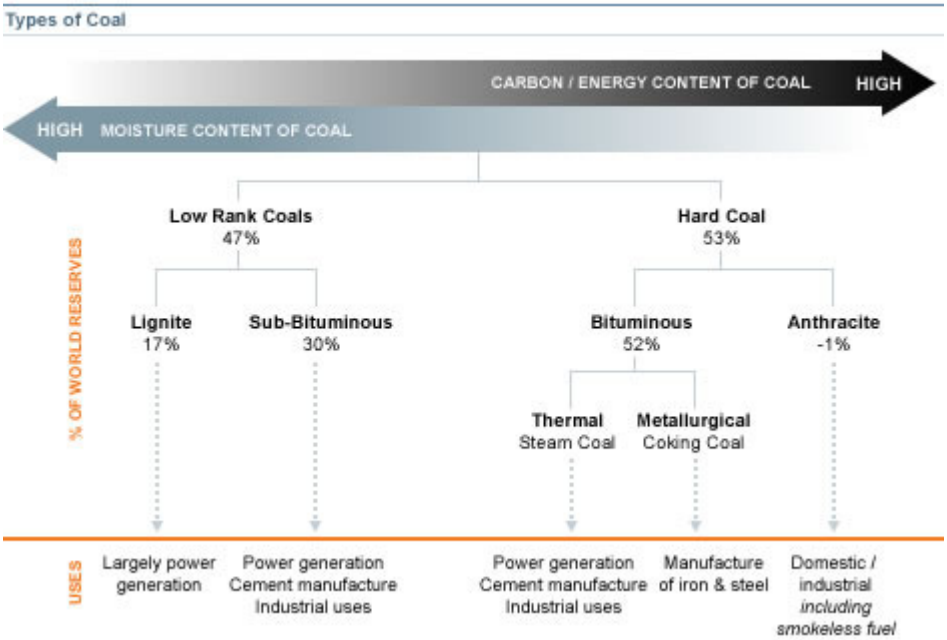
The analysis covers the main coal producing, supplying and/or using regions and countries in the world, with a particular focus on the potential implications for the EU. Where possible, the analysis has been performed for the EU-27, i.e. incorporating the brand-new EU members Bulgaria and Romania. Other upfront assumptions and limitations in the analysis are explained in the following chapter.

2. COAL: BASIC FACTS, INFORMATION AND ASSUMPTIONS

In terms of composition, there are several grades of coal suitable for different applications. This analysis covers mainly the power generation sector, as it is by far the largest coal user. Special emphasis is given to patterns in the electricity market and the related natural gas market, since natural gas is the main competitor of coal in power generation. The high-quality hard coal for steam generation (steam coal), also traded internationally, is the main coal grade analysed.
Although relatively more diversified than e.g. natural gas reserves, world coal reserves tend to be concentrated in a small number of non-EU countries. Proven coal reserves, i.e. the technically or economically exploitable share of coal deposits, are not static, but grow when coal prices increase and/or following advances in mining technologies and/or discoveries of new deposits. Conversely, they can decrease if coal prices fall.

Coal is the fossil fuel with the highest carbon intensity[10], having carbon content of 50-98%. Other coal components are hydrogen (3-13%), oxygen, and small amounts of nitrogen, sulphur and other elements. Coal also contains different proportions of water and inorganic matter that remain as residue (ash) upon burning [97]. These large variations in coal composition determine the type of coal available for different applications — Figure 8.

Figure 8
Types of coal depending on carbon/energy and moisture content, with their shares in total coal reserves and typical applications[11]



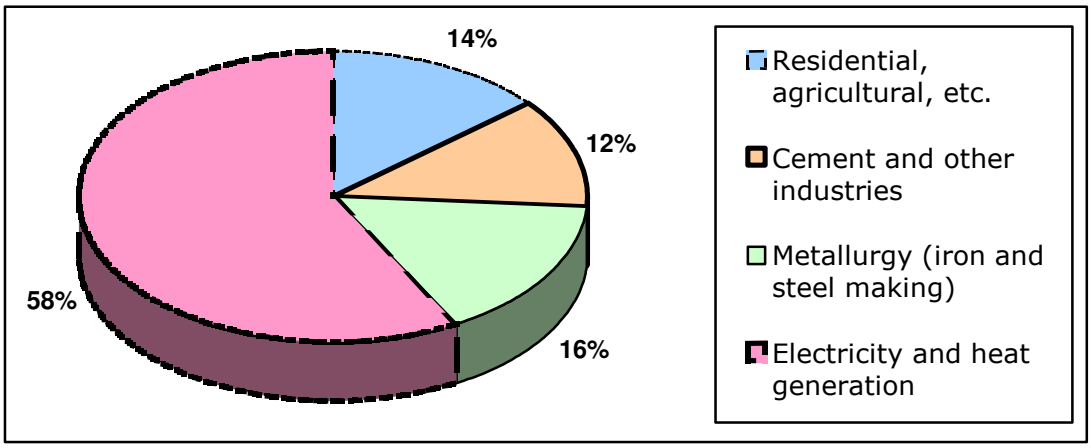
Source: [104]

Figure 8 shows the electricity generation sector to be the main consumer of coal worldwide. This is not surprising as power and heat generation account for more than half of global coal demand — Figure 9. The metallurgical sector comes next,

[10] Expressed in carbon content per energy unit.
[11] Low-rank coals are often called "brown coal" [57]. Sub-bituminous, bituminous and anthracite coals are sometimes called "black coal" [78].

mainly for the production of pig iron and to a lesser extent steel[12]. Worldwide, coal accounts for about 40% of fuel inputs to power generation and 70% of fuel inputs to iron and steel making [97].

Figure 9
Main applications of coal



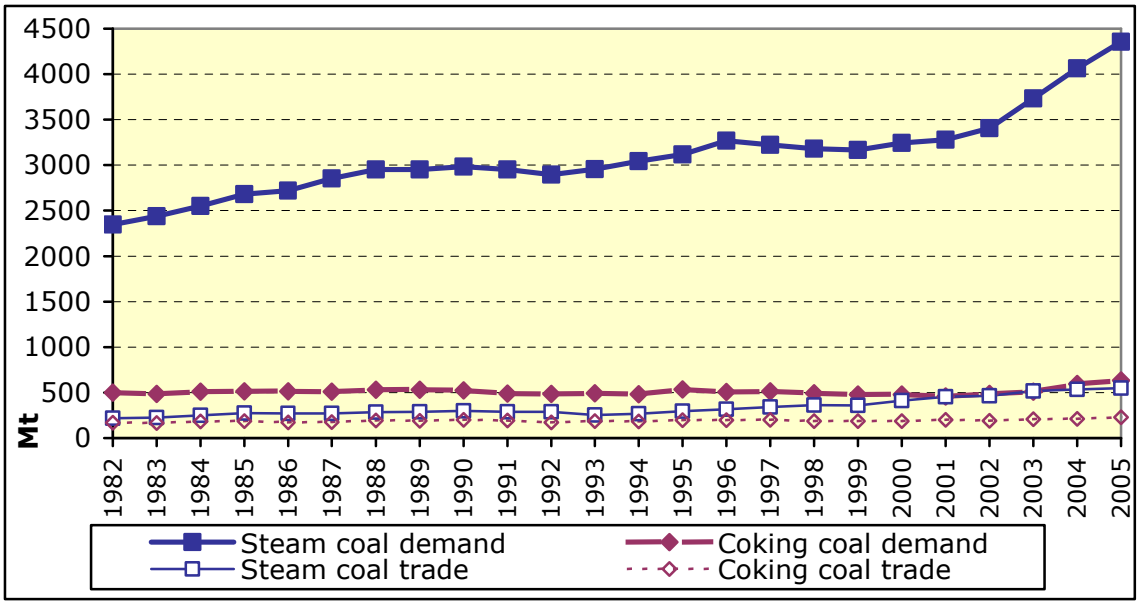
Source: Adapted from [27]

This study looks at coal use in the electricity (and heat) generation sector only. A thorough analysis of this sector is therefore undertaken to examine the prospects for coal use. The main competing fuel inputs to power plants, especially natural gas, are also analysed in detail. Other coal applications, in particular the production of iron and steel, are not considered for the following reasons:

- ✓ Iron and steel making requires coal with very specific properties — coking coal. Coking coal is of superior quality to steam coal and, if not available naturally, is produced from steam coal. Because of its superior qualities, coking coal is far more expensive than steam coal. It does not make sense to use coking coal where steam coal can be employed. The market niche for coking coal is therefore very narrow. World demand for coking coal is about nine times smaller than world demand for steam coal, being roughly equal to world trade in steam coal — Figure 10 [27, 90, 97].
- ✓ Unlike steam coal demand, coking coal demand has remained virtually flat over the past 20 years — Figure 10, despite the impressive growth in iron and steel making. This is due to the large energy savings achieved in iron and steel manufacturing over that period. Additional large efficiency gains (25-35%) can be still attained in a number of countries [59]. Novel iron and steel making technologies, e.g. Pulverised Coal Injection (PCI) for Direct Reduction of Iron (DRI), where the conventional blast furnace is bypassed and steam coal quality is employed, will most likely further restrict the market for coking coal [15, 27, 57, 78, 97].
- ✓ World trade in coking coal is less than half the world trade in steam coal, and it is of little relevance to the EU. The very specific qualities of coking coal limit the number of potential suppliers. The players in the world coking market are very few and the trade itself is concentrated in the Pacific region. On the supply side, Australia is basically the key supplier, responsible for more than 50% of world coking coal exports [91]. On the demand side, Japan accounts for 30% of imports, followed by South Korea and India, each responsible for 10% [57][13].

[12] Steel is typically produced from pig iron in oxygen steel furnaces [57].
[13] Europe imports small quantities of coking coal mainly from Canada.

Figure 10
World steam and coking coal demand and trade 1982-2005, (Mt)



Source: Adapted from [57]

- ✓ Cement manufacturing and other industrial sectors, along with residential and agricultural uses of coal, are not considered in this study since they account for much lower shares of total coal use compared to power generation and steel making, especially in the EU.

Figure 8 also suggests different logistics chains for brown and hard coal. The main quality parameter for coal is the carbon/energy content — the higher, the better. While the transportation of hard coal over long distances could make sense under certain conditions, it seems economically inefficient for lower-grade coal with a high impurity content. Brown coal should be therefore consumed either on-site or only within a short distance from the coalfield.

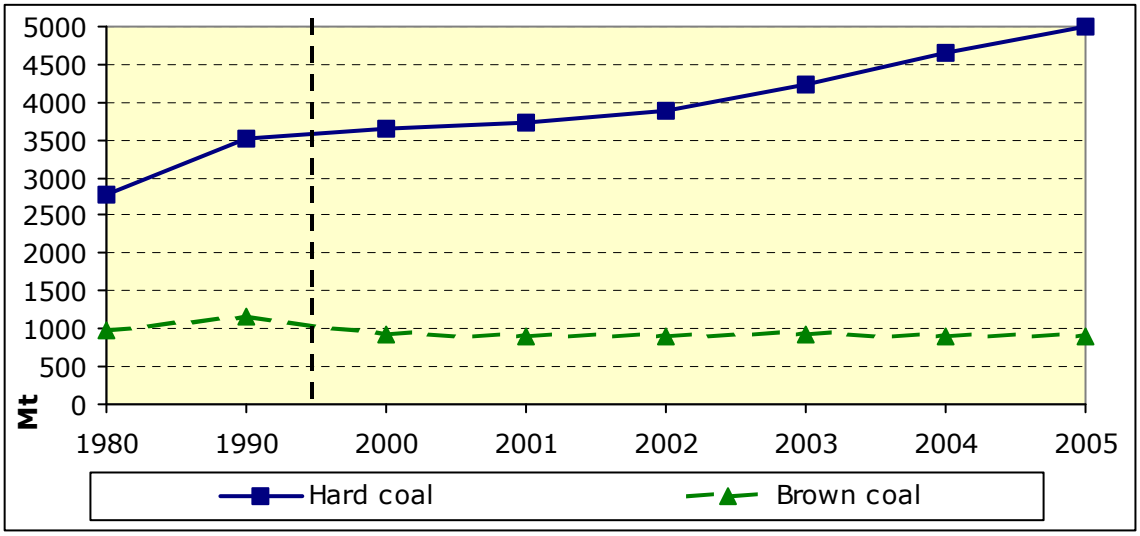
As indicated by Figure 10, world steam coal trade has more than doubled since the beginning of 1980s. More than 85% of all traded coal travels by sea, as this is the cheapest transport mode for mass cargoes such as coal. Consequently, seaborne trade in steam coal has registered an 8% annual growth over the past 20 years [104]. Minimising transport costs is paramount for the competitiveness of suppliers to the world coal market, since transport costs can account for up to 70% of final delivery costs [91]. Nevertheless, the world freight market for bulk dry cargoes and the structure of transport costs are not analysed in this study for the following reasons:

- ✓ With a 20% share, coal accounts for a significant part of the dry cargo segment of the world freight market, but not the major part. Larger cargoes, mainly ores, define freight rates in this segment. Thus, coal freight rates are not autonomously determined.
- ✓ For many years, the world freight market has functioned close to a situation of perfect competition. There are no cartels or single ship-owners with excessive market shares. The supply of vessel capacity and freight rates typically reflects the actual demand/supply balance in the freight market. Consequently, the dry cargo freight market has been more or less stable over several decades, with freight rates usually fluctuating within a margin of +/- 25% [46].

- ✓ Despite the long-term stability, however, sharp short-term variations in freight rates are possible, as the freight market is very sensitive to changes in demand and supply for vessel cargo carrying capacity. These rapid fluctuations, combined with the secondary nature of freight markets in general (as they depend on goods markets), make even medium-term forecasts extremely challenging[14].

Although the world reserves of low-rank and hard coal are similar (Figure 8), their consumption trends are quite different. The world consumes much more hard coal than brown coal and the gap is growing continuously — Figure 11. In addition, the preference is naturally for coal that is easier (and cheaper) to recover [78]. Without a corresponding increase in hard coal reserves, which will most likely be more difficult and more expensive to exploit than hard coal deposits in the past, the world is going to run out of higher-quality coal much earlier than it will of lower-quality coal[15].

Figure 11
World hard and brown coal demand 1980-2005 (Mt)



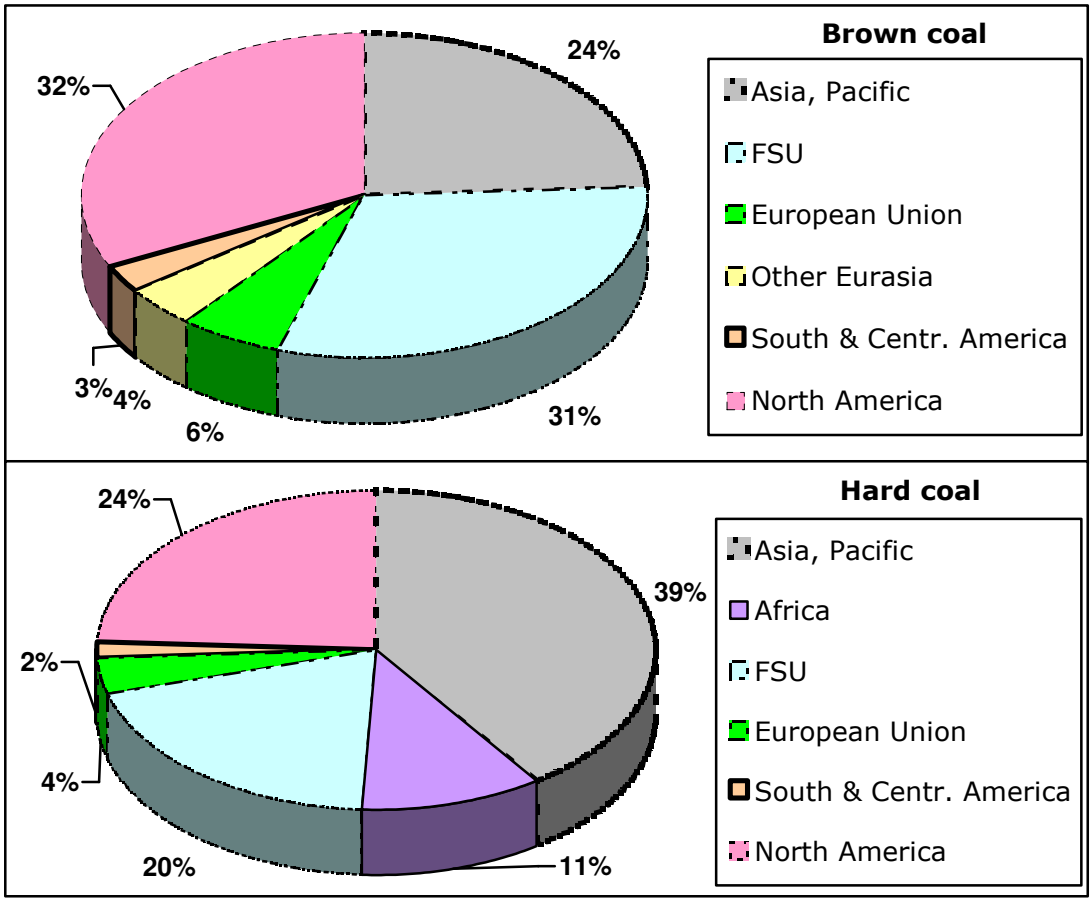
Source: Adapted from [57]

Depending on the geology of deposits, in particular the depth of seams, coal is at present recovered in two ways: surface (open-cut) or underground (deep) mining. Surface mining is economic only when the coal seam is relatively close to the surface. It allows high coal recovery rates from deposits — 90% and more. Surface mining is more frequently used for lower-quality coal types. The majority of world coal reserves (≈60%) are recoverable only by deep mining. This is true especially for hard coal, where deep mining accounts for ≈2/3 of all recovery worldwide. The recovery rates in underground mining are much lower than those for open-cut mining — from 50-60% for the cheaper room-and-pillar technology to ≈75% for the far more expensive long-wall technology[16] [97, 104]. Standard calculations of coal reserves, and hence R/P ratios, do not take into account feasible recovery rates. The amount of actual recoverable coal is therefore less than the widely published estimates of reserves, and the real R/P ratios are also lower[17].

[14] A more complete discussion of the impact of the freight market on the international coal market is provided in the complementary consultants' report "Coal of the Future", EUR 22644 EN.
[15] Calculating R/P ratios separately for brown and hard coal is not feasible, as the statistical sources used in this study [12] and [57] employ different classifications for brown and hard coal reserves.
[16] Room–and-pillar allows coal production to start much more quickly using mobile machinery that costs under $5 million, while long-wall mining machinery can cost $50 million [91].
[17] Not re-calculated, as [12] and [57] use different classifications for brown and hard coal reserves.

In addition to the consumption patterns, the geopolitical distribution of brown and hard coal differs as well. Figure 12 shows that Europe, including the EU, holds mainly lower-quality coal. This is due partly to unfavourable geology, but also to the long history of coal extraction in the industrialised EU countries. The majority of easy-to-recover hard coal reserves in the EU have already been exploited. Thus, the EU is today forced to opt either for expensive and technologically complicated underground extraction of high-quality coal at great depths, or for the exploitation of existing lower-quality reserves, or for imports of hard coal[18].

Figure 12
Breakdown of world proven brown and hard coal reserves at the end of 2005 (%)



Source: Adapted from [12]

The breakdown of coal reserves by types and world regions in Figure 12 is slightly misleading as regards their actual diversity. Indeed, in almost all regions coal deposits are concentrated in one or a few countries — Figure 13. Consequently, world coal reserves and especially those of the tradable high-quality grades are in fact concentrated in a small number of countries. Six countries (USA, China, India, Russia, South Africa, Australia) thus hold 84% of world hard coal reserves. Four out of these six (USA, Russia, China, Australia) also account for 78% of world brown coal reserves — Figure 13.

As already explained in the Annex to this report, proven reserves tend to increase in periods of rising market prices. Proven reserves can also increase as a result of new discoveries and/or techno-economic improvements in mining technologies. All these give access to deposits that were previously not economic to exploit, thus converting reserves into proven reserves. In this light, the key technical and

[18] A more detailed discussion on the EU's indigenous coal production is included in Chapter 4.

Figure 13
Regional and world shares of the top 10 richest countries in hard and brown coal reserves worldwide (%) /Note: the relative ranking is given in brackets/

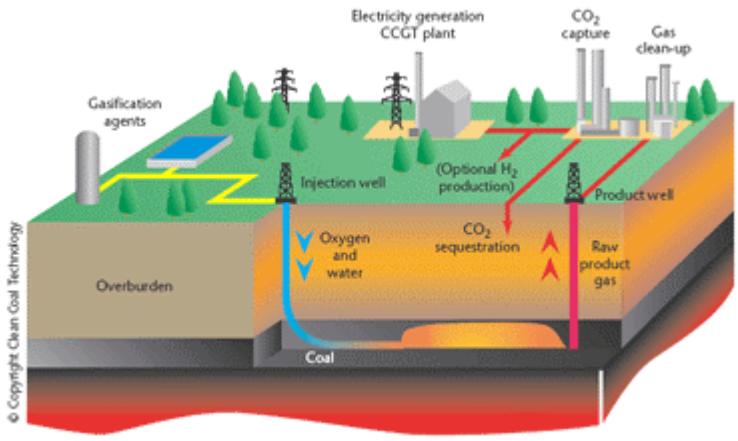
Region	Country	Regional share		Global share	
		Hard coal	Brown coal	Hard coal	Brown coal
North America	**USA**	96.3	97.5	23.3 **(1)**	31.4 **(1)**
South & Centr. America	Brazil	-	82.9	-	2.4 **(6)**
	Colombia	80.9	-	1.3 **(10)**	-
Europe & Eurasia	Kazakhstan	25.1	-	5.9 **(7)**	-
	Czech Rep.	-	2.0	-	0.8 **(10)**
	Germany	-	3.7	-	1.5 **(7)**
	Greece	-	2.2	-	0.9 **(9)**
	Poland	12.5	-	2.9 **(9)**	-
	Russia	43.7	61.7	10.3 **(4)**	25.1 **(2)**
	Turkey	-	2.2	-	0.9 **(8)**
	Ukraine	14.5	10.2	3.4 **(8)**	4.2 **(5)**
Africa	South Africa	96.4	-	10.2 **(5)**	-
Asia Pacific	**Australia**	20.0	38.2	8.1 **(6)**	9.3 **(4)**
	China	32.3	50.1	13.0 **(3)**	12.2 **(3)**
	India	46.8	-	18.8 **(2)**	-
Share of top 5 in world total				**75.6**	**82.2**
Share of top 10 in world total				**97.2**	**88.7**

Source: Adapted from [12]

technological routes to increasing world proven coal reserves appear to be:

- ✓ Development and implementation of improved mapping technologies for coal resources and reserves;
- ✓ Improvement of existing underground coal mining technologies;
- ✓ Accelerated research and development of novel coal exploitation technologies to give access to "non-conventional coal", e.g. underground coal gasification (Figure 14) and the utilisation of coalmine methane gas[19].

Figure 14
Underground Coal Gasification



Source: [104]

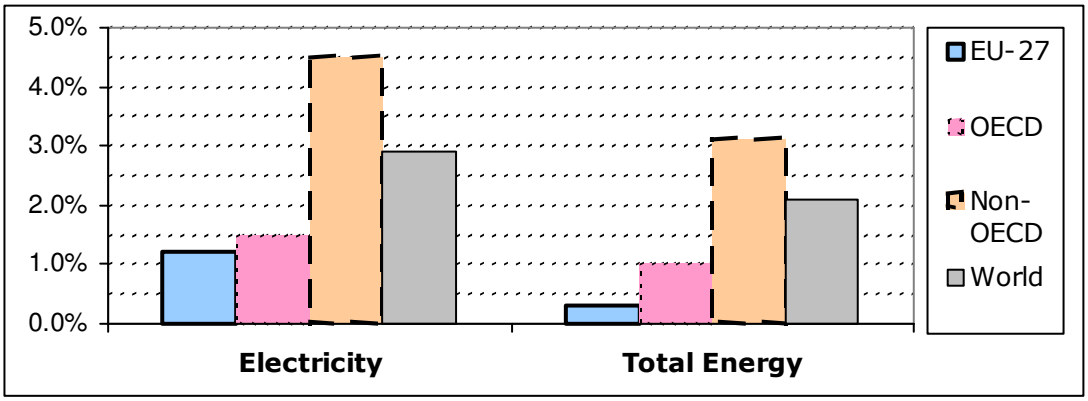
[19] These technical and technological paths are not explored further in this report, but are thoroughly assessed in the complementary consultants' report "Coal of the Future", EUR 22644 EN.

3. COAL: USE AND COMPETITION

Since coal is the most carbon-intensive fossil fuel, its use for electricity generation is heavily dependent on future GHG-reduction policies — the stricter the policies, the lower the expected use of coal and vice-versa. As regards competition with other fuels, the share of coal in gross fuel inputs to power generation will depend on the relative price gap with natural gas — the cheaper the coal compared to gas, the greater the use of coal and vice-versa. The relative fuel price gap is of crucial importance for coal, since its lower fuel costs have to compensate for the higher investment costs of coal-fired power plants compared to gas-fired plants. The ongoing liberalisation of electricity and gas markets in the EU and other developed economies favours greater use of gas for electricity generation at the expense of coal, as gas is associated with lower and more easily managed risks for power plant operators. However, this growing reliance on gas creates security and diversity of supply risks for the EU, as it is becoming increasingly dependent on gas imports from Russia. Furthermore, take-overs of gas companies by electricity companies may create risks of monopolies and oligopolies. On equal terms, coal will most likely remain a key fuel for power generation in countries that possess abundant indigenous coal resources.

As Figure 9 indicates, power generation accounts for by far the largest share of coal use. It is widely agreed that electricity consumption is going to grow faster than total energy consumption both in the EU and worldwide — Figure 15. This is driven by two factors — one general and one regional. The general factor is that electricity is by far the preferred energy option, as it is arguably the easiest, safest and cleanest form of energy. The regional factor is that electricity consumption per capita in the less developed (non-OECD) countries is currently far lower than in the industrialised (OECD) countries. However, this is about to change, as a clear empirical link has been found over the years between increasing electricity consumption per capita and decreasing poverty [60].

Figure 15
Projected annual growth in consumption of total energy and of electricity in EU-27, OECD and non-OECD countries, and worldwide, over 2010-2030 (%)



Source: Adapted from [26, 30]

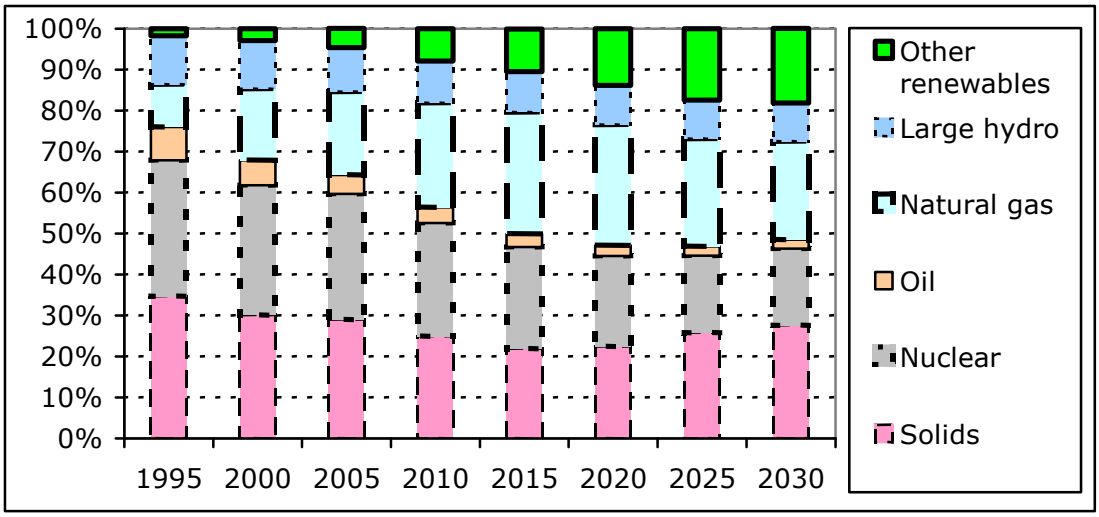
The electricity market is governed by several factors. The most important for this study and within the European context are analysed below.

Electricity demand is characterised by large variations over the day and the week. It is difficult to predict whether these differences in consumption will grow or decline in future, but one thing is sure — they will not disappear. With current technologies, the economic and energy-efficient storage of large amounts of

electricity is still a challenge. Reserves of generating capacity and fuels therefore have to be built up to cover peaks in demand. This brings additional costs — in the latter case, these are the costs of building and operating extra fuel transhipment and storage facilities. In the former case, the investment in spare generating capacity is recouped at a slower rate, as this extra capacity is used exclusively during demand peaks. Other tools are a diversified electricity pricing policy and improved grid management (electricity transmission networks). The importance of the latter component, sometimes underestimated in the past, is recently enjoying increasing attention [54, 60].

The emissions of greenhouse gases (GHG) and the related phenomenon of global warming and climate change are raising growing concerns all over the world. The power sector is the largest GHG emitter among the industrial sectors. The signatories of the Kyoto Protocol to the United Nations Framework Convention on Climate Change aiming to reduce world GHG emissions, including the EU-15, therefore have to look carefully at the GHG emission performance of their electricity generation sectors. Coal is the most carbon-intensive of all fossil fuels. Other things being equal, burning coal results in the largest CO2 and GHG emissions per generated unit of electricity[20]. In countries where the reduction of GHG emissions is a policy priority (such as the EU member states), coal use for power generation is thus under pressure. In the EU, therefore, coal has been gradually replaced with natural gas (Figure 16), which is the least carbon-intensive fossil fuel. The virtually carbon-free nuclear and renewable pathways offer other options to cut GHG emissions. In short, GHG reduction policies have and will have a major impact on the future use of coal. However, the uncertainty regarding GHG policies in the post-Kyoto period (after 2012) complicates the investment perspective for coal. This investment uncertainty is particularly important for Europe, where most coal-based electricity generation capacity is over 25 years old (Figure 17) and hence, has to be replaced within 15-20 years [51, 80]. The energy chain choice, whether e.g. gas, nuclear or again coal[21], will have a major long-term impact on electricity supply. In any case, if GHG policies

Figure 16
Retrospective and projected breakdown of fuel inputs to electricity generation in EU-25 over 1990-2030 (%)

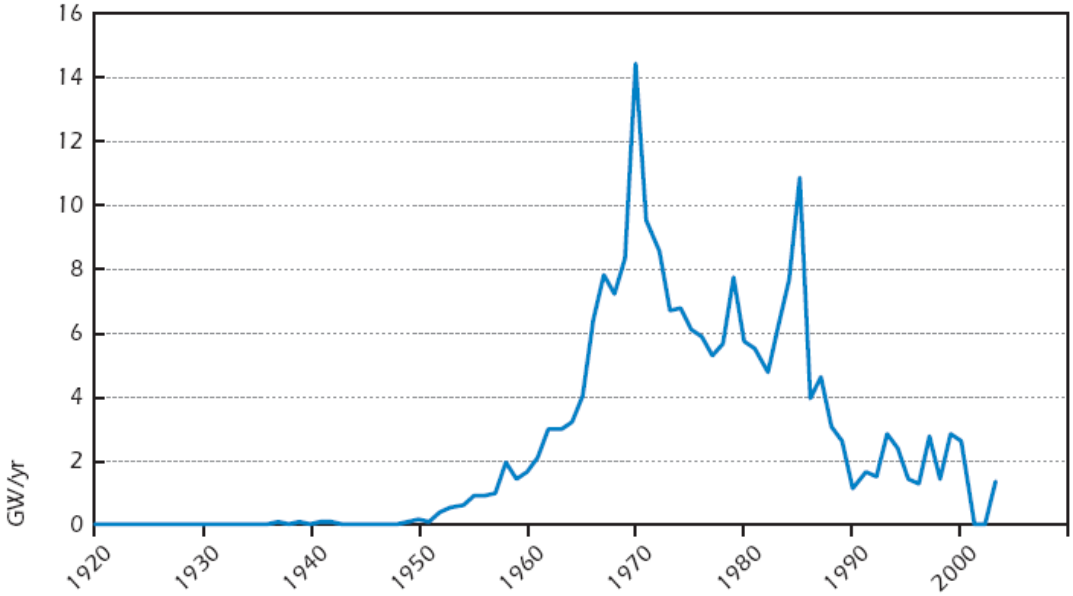


Source: Adapted from [29, 30]

[20] CO2 accounts for by far the largest share of all GHG emissions. Even the most advanced integrated gasification combined-cycle (IGCC) coal-firing power plants emit approximately two times more CO2 than similar natural gas combined-cycle (NGCC) plants [59].
[21] With or without carbon capture and storage.

are tightened, coal will most likely lose out again, at the expense of natural gas, renewable energy sources and, under certain conditions, nuclear power [70].

Figure 17
European coal-fired power plant building activity 1920-2000



Source: [51]

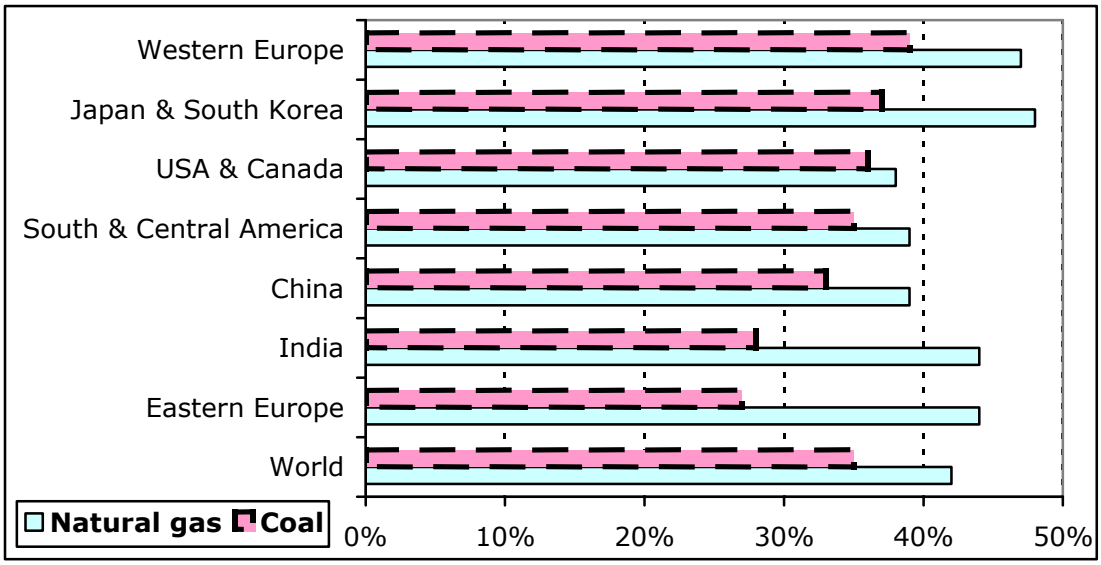
Other environmental concerns and regulations, e.g. for local pollutants from large combustion plants [35], have a major impact on investment decisions in the power sector as well. Due to the content of sulphur, nitrogen and inorganic matter, coal is again at a disadvantage compared to natural gas, which contains virtually only carbon and hydrogen. As with GHG policies, the strengthening of such environmental protection regulations or, even worse, the uncertainty as to the limits they will impose further increases the reluctance to invest in coal power stations.

Another advantage of natural gas over coal is the typically higher electricity generation efficiency — Figure 18. Even modern and novel coal-based electricity generation systems are not likely to surpass the efficiency of current natural gas power plants. The marginal efficiency gains will be offset by the marginal increase in on-site energy consumption to comply with stricter emission standards[22]. It should also be remembered that these more sophisticated coal plants will cost even more than conventional coal plants, which are already more expensive than natural gas plants. Last but not least, efficiency improvements can also be expected for natural gas facilities. All in all, coal-based power plants will most likely remain less efficient than natural gas-based power stations [51, 59].

As Figure 18 indicates, electricity generation efficiencies vary from region to region. Apart from external reasons (e.g. a poor coal quality or a warmer climate reduces efficiencies), there are also intrinsic reasons for this variation. These are primarily to do with the technical and technological level of power stations. As they have more financial resources, the richer OECD countries generally have more up-to-date facilities with higher efficiencies than non-OECD countries. Higher investment costs are offset by smaller fuel inputs, which reduce GHG emissions and lower overall generation costs [51].

[22] For instance, it is believed that the introduction of carbon capture and storage technologies will reduce the total electrical efficiency of such advanced coal plants to 42% [51].

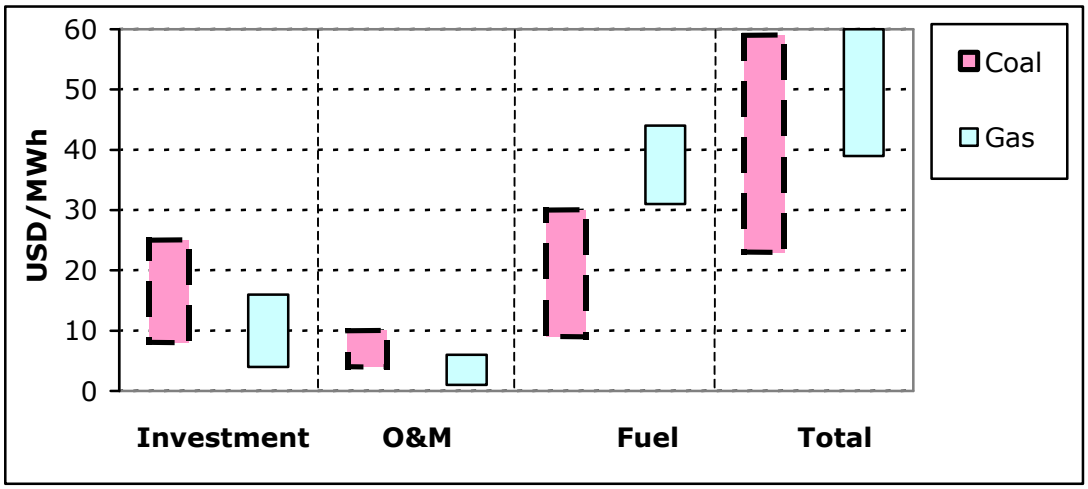
Figure 18
Average electricity generation efficiencies for centralised coal and gas-fired power plants in various countries, regions and worldwide (%)



Source: Adapted from [51, 62]

The process of liberalising electricity markets, under way in many countries around the world, is happening in the EU as well. As from 1 July 2007, the electricity market in the EU will be fully liberalised [36]. These new "rules of the game" completely change the investment climate in the sector. Electricity generation is a highly capital-intensive business, although the various fuel pathways have a different breakdown of fixed and variable costs. Amongst the key fuel pathways (Figure 16), nuclear power has the largest share of fixed costs, followed by coal, while natural gas comes last. Conversely, the highest variable costs, the main component being the cost of the fuel itself, are for natural gas, followed by coal — Figure 19, while nuclear power has the lowest [80]. Obviously, the higher the share of fixed costs, the higher the risk in a liberalised market environment, as the recouping of fixed costs requires continuous operation at maximum load. In brief, the natural gas pathway, though more volatile, is associated with lower long-term investment risks than the coal pathway. The

Figure 19
Average costs of natural gas and coal-fired power plants



Source: Adapted from [59]

natural gas pathway is subject mainly to the risk of short-term market disturbances on the fuel supply side, as natural gas prices tend to fluctuate more than e.g. coal prices (Figure 4). However, the risk of higher natural gas prices can be more easily covered by raising electricity prices[23] compared to the risk of running a coal plant at partial load for long periods of time[24]. In any case, investing in the traditional mid- and base-load electricity chains, such as coal and nuclear, is becoming less attractive [49, 70].

Natural gas for electricity generation has an additional advantage over coal and nuclear power. The economic scale of natural gas power plants is lower than that for coal and especially nuclear facilities. Natural gas plants are therefore more flexible as regards location. They are appropriate both for smaller-scale decentralised and for large-scale centralised power generation. Conversely, the coal and nuclear options are suitable only for large-scale power plants.

In brief, a power generation strategy based on natural gas under the conditions of liberalised electricity markets is indeed flexible, but creates long-term risks for the stability, reliability and affordability of electricity supply [52].

The strategy of liberalising electricity markets is particularly sensitive for peak-load capacities, which are operated at a low utilisation rate and hence a low rate of return. Without explicit rules, power operators on open markets may decide simply not to provide electricity above certain peak levels that are no longer economic. Regulatory counter-measures to meet such peaks in electricity demand at affordable prices could give extremely negative signals to investors in such immature open markets. The experience so far indicates that price caps could work, but only for a certain period of time and if fixed at a sufficiently high level [49]. One also has to keep in mind that electricity distribution is often not liberalised — which may create market imperfections [53].

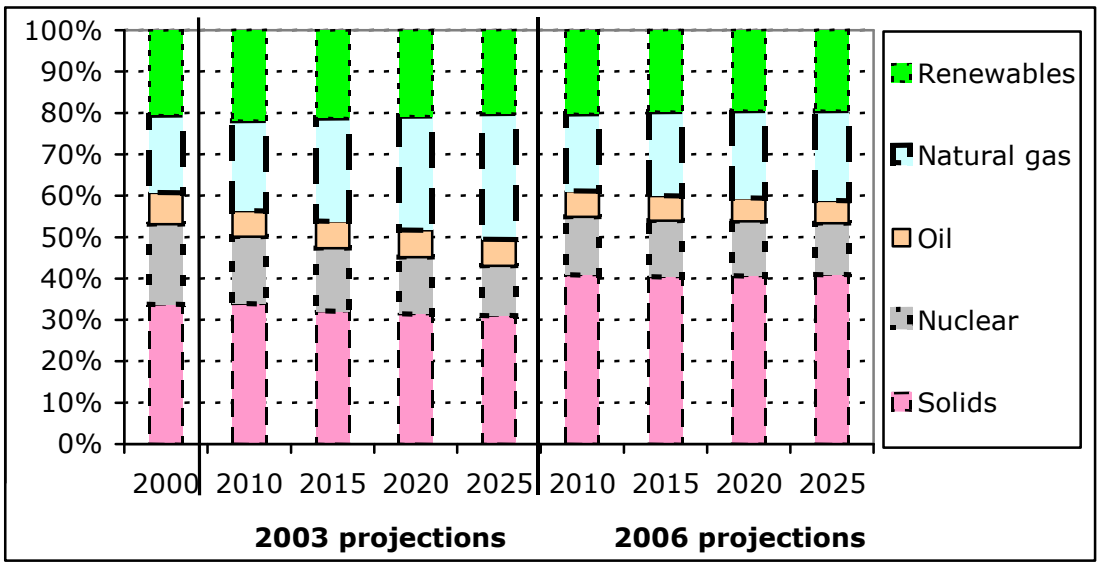
The dynamics of natural gas prices have a substantial impact on the structure of the power generation sector. The fast penetration of natural gas in the power sector in the 1990s was largely driven by the relatively low price of natural gas — Figure 4. Conversely, the rising natural gas prices since 1999 have slowed down its penetration in the electricity sector, pushing up coal use. The influence of variations in natural gas prices is also evident in various energy projections. When relatively lower gas prices prevail, energy forecasts are more favourable to natural gas, and vice-versa — Figure 20.

The fuel breakdown for power generation is also governed by other factors — regional availability of fuels and/or of infrastructure for their transportation and storage, geopolitical factors, established traditions, etc. Coal-rich countries, such as China, Australia, India and USA, obviously tend to have large coal shares in their national power generation systems (79%, 77%, 68% and 51%, respectively [59]). Wealthier countries tend to use more sophisticated fuel pathways with a less direct environmental impact (e.g. natural gas, nuclear, modern clean coal) compared with less developed countries, where the emphasis is on low-cost energy — Figure 21.

[23] Owing to increased living standards, most electricity uses in the OECD countries today in fact lack alternative and competitive substitutes that can quickly replace them. Hence, consumers are basically forced to accept any increase in electricity prices, unless they are willing to change their consumption patterns (with a corresponding decline in living standards). In short, electricity demand tends to be extremely inelastic.

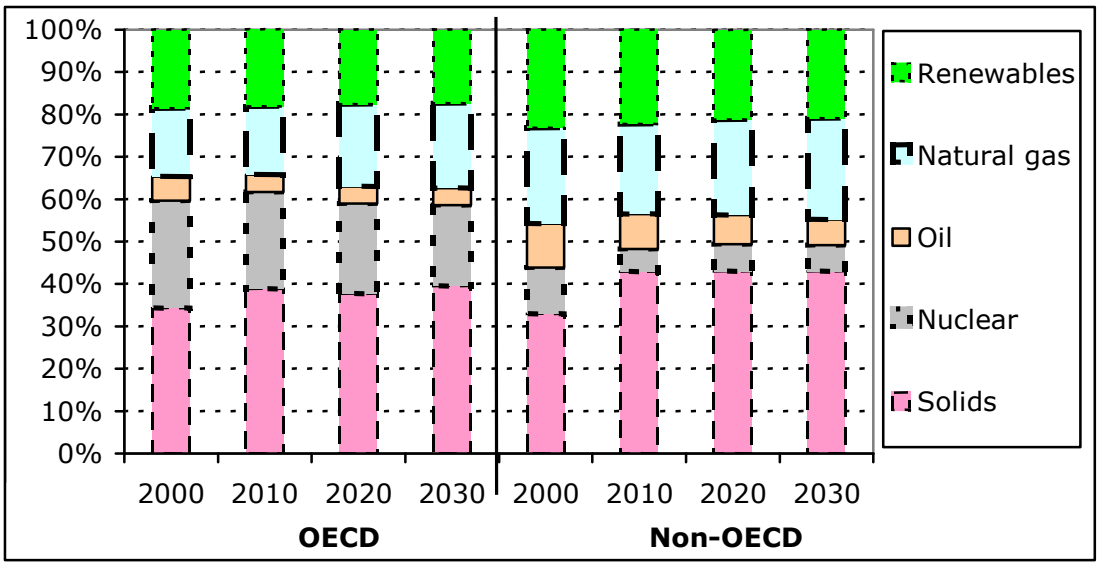
[24] Another disadvantage of coal versus natural gas is that while constructing a coal power plant takes approximately 4 years, a natural gas power station needs only 2-3 years [80].

Figure 20
Retrospective and projected breakdown of fuel inputs to electricity generation worldwide over 2000-2025 — 2003 projections (when natural gas prices were lower) and 2006 projections (when natural gas prices were higher), (%)[25]



Source: Adapted from [25, 26]

Figure 21
Retrospective and projected breakdown of fuel inputs to electricity generation in OECD and non-OECD countries, 2000-2030 (%)



Source: Adapted from [25, 26]

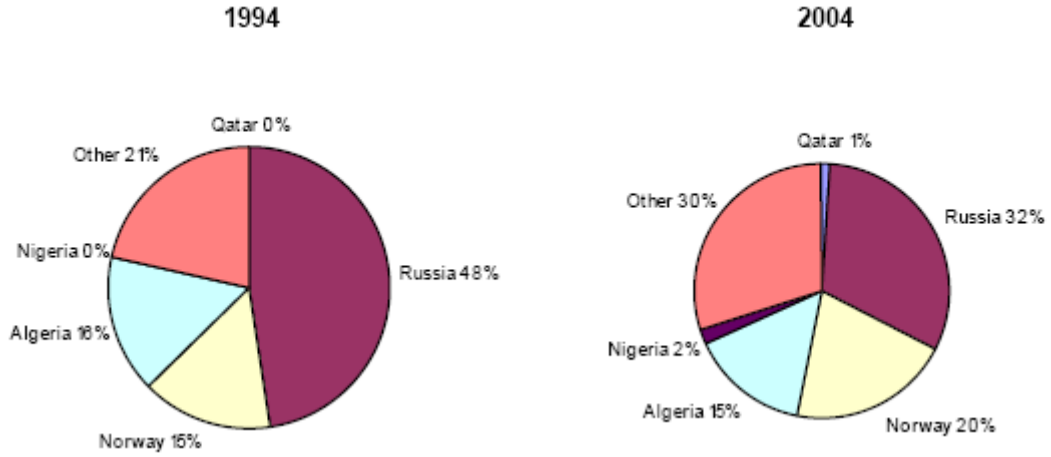
Along with electricity market liberalisation, the EU market for natural gas will also be fully liberalised as from 1 July 2007 [37]. As natural gas is becoming increasingly important for power generation, this will increase the risk for power plant operators, moreover that especially since the natural gas market is also capacity-bound. The solution is either to move to other fuel inputs or to hedge the market risk by acquiring some control over natural gas supply [47, 49, 52]. A trend for players in the electricity market to take over natural gas companies has

[25] Similar, however less pronounced trends are observed also for the EU when comparing projections from 2003 [29] and 2006 [30].

thus been observed in several EU member states (UK, Germany) [70]. Such mergers could, however, create monopolies or oligopolies that could pose threats to the proper functioning of electricity markets [42, 49].

An over-reliance on natural gas for electricity generation hides another risk for the EU. Although the EU has managed to diversify its natural gas imports to some extent over the past 10 years, 1/3 of all its natural gas imports still comes from Russia — Figure 22. On the other hand, Russia is currently even more dependent on the EU, as the EU is basically its only large gas market. Such a situation raises a number of worries on *both* sides. In the EU, apart from the familiar political and economic concerns, the future ability of Russia to fulfil its international commitments for natural gas deliveries is recently being increasingly questioned. The old giant fields, supplying low-cost natural gas today, are getting depleted. To meet future commitments to Europe, new fields that are more difficult to exploit need to be developed. These fields are moreover smaller than those currently exploited, and hence production costs will in any event be higher. The corresponding pipeline infrastructure has to be built as well. Pursuing an aggressive expansion policy, Gazprom (by far the largest gas company in Russia) has committed to large deliveries to the EU. The investment to match these commitments, however, has so far not been secured. There are some suspicions that this is deliberate, so as to increase the pressure on gas prices [43]. In addition, it is so far not clear where the necessary investment funds will come from, especially given the particular sensitivity of opening the Russian natural gas system to foreign investment. Nonetheless, the lion's share of natural gas deliveries to the EU's liberalised market will still come from Russia, whose gas market is far from liberalisation [52, 62, 63]. The plans announced lately to boost Russian energy and in particular natural gas exports to Asia from 3% today to 30% in 10-15 years, with the aim of diversifying Russian energy exports, raises additional worries in the EU about the security and prices of Russian natural gas supplies [1, 41]. Last but not least, the recent memorandum of understanding on cooperation in upstream activities, signed between the national gas giants of Russia (Gazprom) and Algeria (Sonatrach), raises concerns about the potential creation of an OPEC-like natural gas cartel and price fixing for natural gas exports to the EU [42, 43, 44, 45, 64].

Figure 22
EU-25 gas imports by country of origin in 1994 and 2004 (%)



Source: [34]

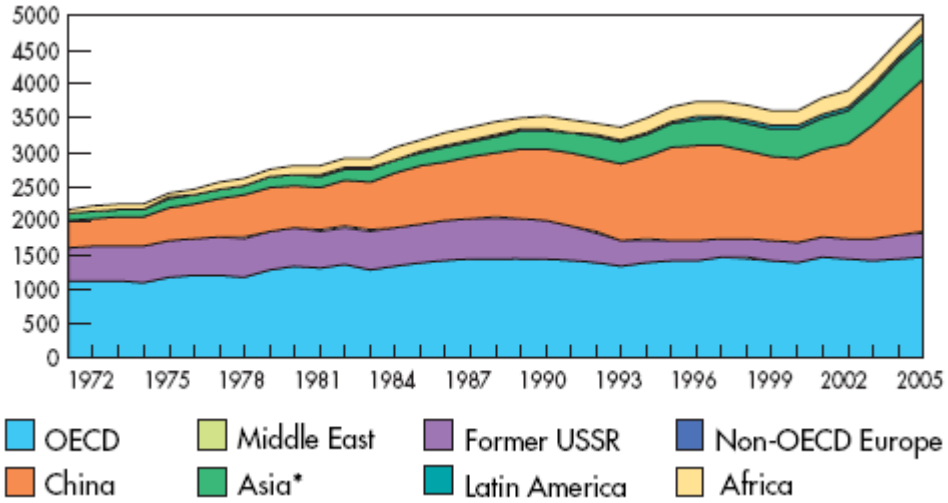
4. COAL: POTENTIAL THREATS TO SUPPLY BY REGIONS

Hard coal production in the EU generally suffers from largely depleted deposits, declining coal quality and extremely high production costs. Indigenous lignite production is still competitive with hard coal imports, but the economic reserves of the main EU lignite producers might be depleted earlier than widely anticipated. On the other hand, coal exports are getting concentrated in the hands of a few countries. Australia is gradually becoming the ultimate global supplier of coal. Other traditional key exporters like South Africa, Indonesia and USA face significant challenges in the development of coal reserves and export capabilities. The USA and China — former large net exporters — are gradually turning into net importers with an enormous potential demand, together with India. Exports from other possible large producers (Russia, Kazakhstan, Colombia) face substantial logistics problems.

The aim of the following exposition is *not* to provide a full and complete overview of coal supply and demand by countries in the world. Such information is widely available from several reliable sources, e.g. the IEA, including its Coal Industrial Advisory Board (CIAB), the US Department of Energy, Eurostat, etc. The goal of this section is rather to highlight some facts and circumstances in selected countries and regions, which may affect coal supply in the future. As such, it does not pretend to provide a complete analysis, but concentrates more on the implications for the EU.

As Figure 23 indicates, world coal production has been steadily expanding over the past few decades. Since 2000, growth has accelerated owing to the huge increase in Chinese coal production, driven mainly by the sharp increase in power generation. All in all, over the period 1971-2005 the share of industrialised (OECD) countries in world coal output has declined at the expense of the share of developing countries and emerging economies. Coal production has also decreased in the countries of the former Soviet Union, due to the major socio-economic upheavals there in the 1990s.

Figure 23
Absolute (Mt) and relative (%) evolution of world hard coal production by regions over 1971-2005



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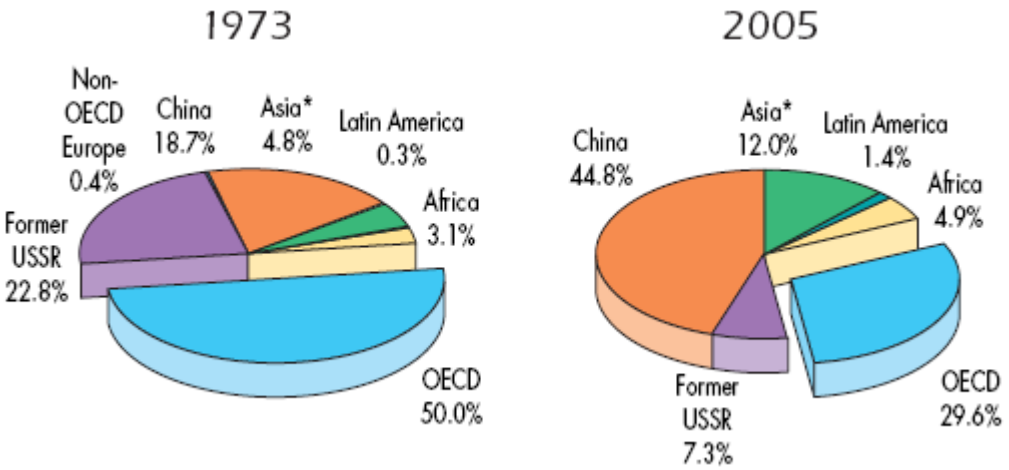
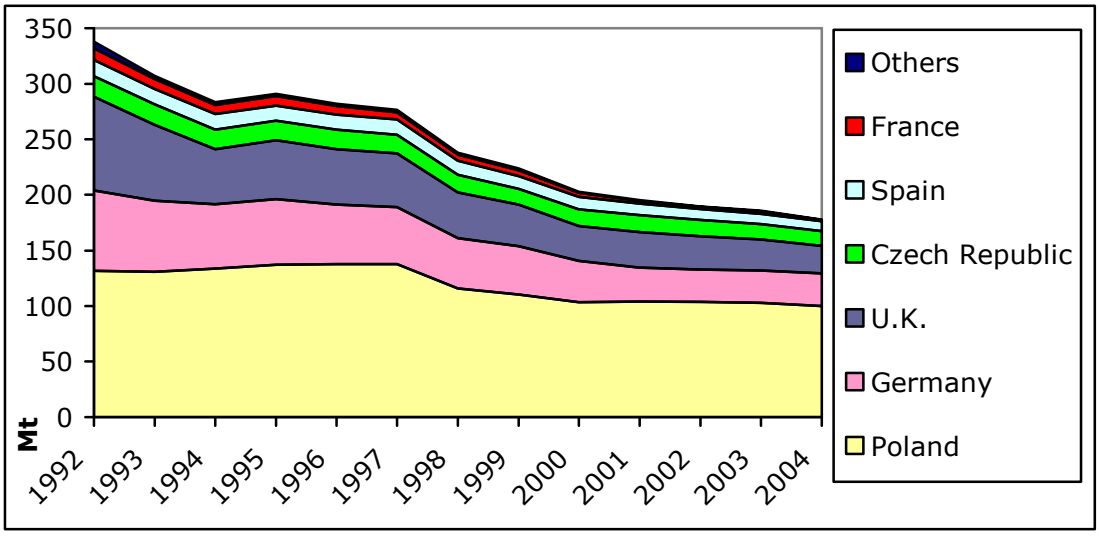


* Asia excludes China, which is shown separately
Source: [61]

4.1. EUROPE

At present, the prospects for European coal production are quite clear. Indigenous hard coal production in the EU will continue to decline (Figure 24) for several reasons. Hard coal has been intensively mined in Europe for more than a century and the easier accessible deposits of good quality have already been exploited [47]. As hard coal in Europe can be recovered mainly from underground deposits[26], European coal miners are forced to go for deeper and more difficult to recover reserves of poorer quality, which increases costs [15, 28, 47, 90]. European indigenous hard coal production is two to three times more expensive than imported coal [47, 75]. Some EU countries have therefore ceased hard coal production. In the countries where hard coal production still exists (mainly for socio-economic reasons), it is heavily subsidised[27] [50, 75, 85, 90], but the subsidies are gradually being phased out. The expiry of the European Coal and

Figure 24
Hard coal production in EU-27 over 1992-2004 (Mt)



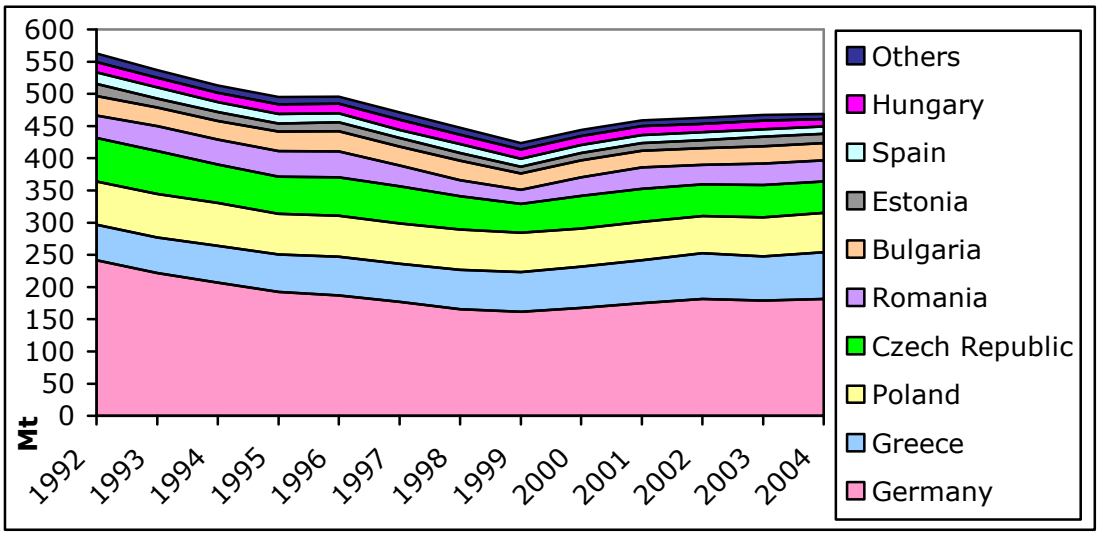
Source: Adapted from [18]

[26] With the exception of the UK, where hard coal is recovered also via surface mining
[27] Again with the exception of the UK, whose indigenous hard coal production is generally competitive (without large subsidies) to imported hard coal.

Steel Community[28] in 2002 has accelerated this process.

The case of lignite is different. The EU has greater reserves of lignite than of hard coal (Figure 12), and reserves are available and exploited in a larger number of countries (Figure 25). Lignite in Europe is typically mined open-cut, which keeps extraction costs low. European lignite production is generally cost-competitive with imports of hard coal without subsidies [50, 75]. Consequently, lignite recovery in the EU will most likely survive, unlike hard coal production. Lignite represents an important energy source for the EU, as it helps to reduce its energy import dependence. Nevertheless, the R/P ratios (under *current* economic and regulatory conditions) in the major EU lignite producers are rather low, e.g. Germany — 33 years, Greece — 54 years [12].

Figure 25
Lignite production in EU-27 over 1992-2004 (Mt)



Source: Adapted from [18]

All in all, it is projected that overall European coal production will continue to decline. By 2010, its share in total primary energy production will drop below 20% [30]. The gap between consumption and internal production will be covered by increasing imports (Figure 5). For those imports, Europe will not have many suppliers to choose from since most world steam coal exports today (≈85%) come from just eight countries — Figure 26.

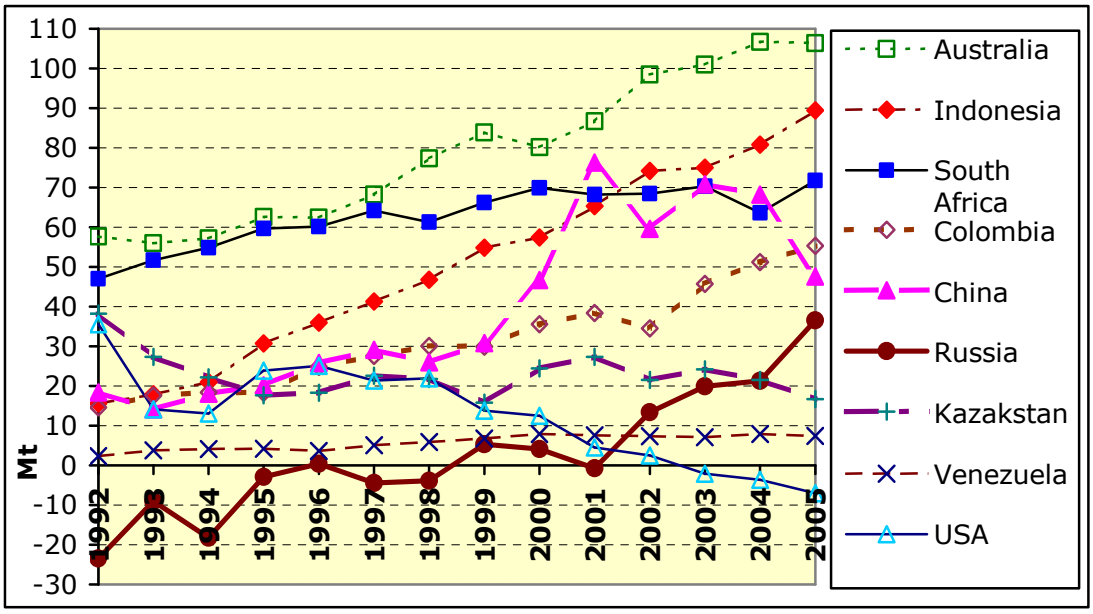
4.2. AUSTRALIA

Australia is nowadays the largest single exporter of steam coal, accounting for about 20% of world trade. Although coal was discovered in Australia in the 18th and 19th centuries [85], it is a relatively young player in the world steam coal market — it first started exporting at the end of 1970s. The Australian coal industry has always been export-oriented. The share of exports in gross production has increased from 60% in 1990s to more than 80% today [15]. Coal deposits are plentiful and of very high quality [4, 94]. They are suitable for surface mining, which ensures high recovery rates, possibly the highest productivity in the world [90], and competitive production costs (Figure 27). All

[28] In brief, the goal of the ECSC was to support and coordinate coal and steel production in the EU. The ECSC has been replaced by the Coal and Steel Research Fund, whose tasks are different.

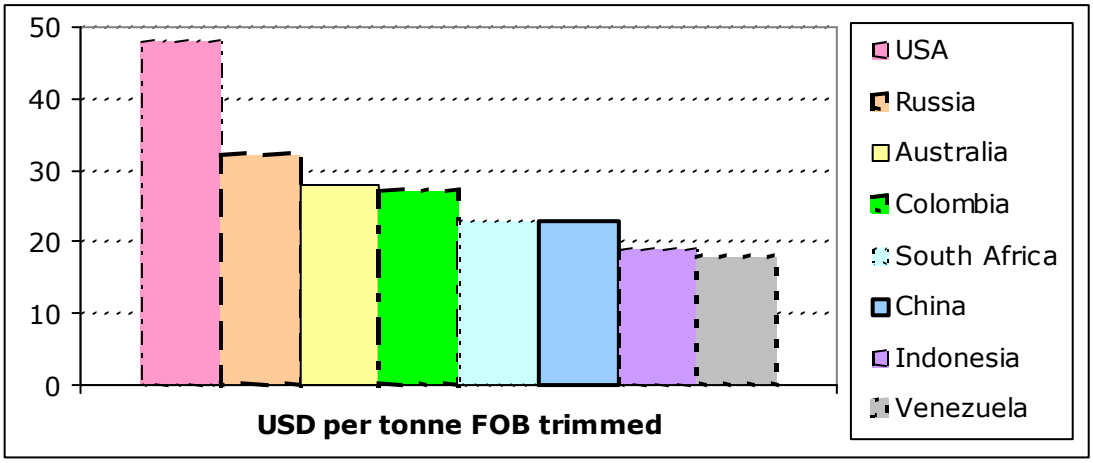
these factors point to bright prospects for the Australian coal industry and exports. Most likely, Australia will consolidate its leading position on the world export market for steam coal [26, 76] and will be the supplier that meets any unexpected rises in global demand [46].

Figure 26
Major steam coal exporting countries in the world over 1992-2005 (Mt net exports)



Source: Adapted from [18, 57]

Figure 27
Indicative steam coal values on FOB trimmed basis (USD per tonne)



Source: Adapted from [64]

The recent sharp increase in world coal demand and hence trade has cut the Australian R/P coal ratio by almost 40% — from 297 years at the end of 2000 to 213 years at the end of 2005 [7, 12]. If these trends continue, proven reserves should still be sufficient by 2020. In view of the healthy status of the national coal sector, the conversion of additional reserves into proven reserves should not prove difficult [2]. These hopes are based on the recent major restructuring of the sector, which has resulted in improved efficiencies [15, 50]. Nevertheless, the cost of developing new coalfields will certainly be higher, as the new deposits

tend to be located further away from the major exporting facilities. Of more concern is the need to expand export facilities, mainly the seaport infrastructure. The recent troubles and delays in vessel handling in the major Australian coal exporting terminals have strengthened these fears [15, 46].

4.3. INDONESIA

Indonesia emerged as a key steam coal producer and exporter only in the beginning of 1990s. Since then, production and exports have grown exponentially — Figure 26. The fast expansion of production and exports is due to favourable geology — almost all coal comes from open-cut mines with fairly low capital costs. Even so, maintaining the present high output rates and export volumes may quite soon pose challenges. First of all, Indonesia's proven reserves are not as plentiful as those of other major coal exporters. The fantastic growth in production over the past two decades has been achieved mainly thanks to intensive exploitation of the easily accessible deposits. As a result, the coal R/P ratio has almost halved over only six years — from 68 years at the end of 2000 to just 37 years at the end of 2005 [7, 12]. With these trends and with no additional investment in the coal sector, Indonesia would run out of economically recoverable (at *current* economic and operating conditions) reserves of coal much earlier than widely anticipated [76]. On the other hand, the investment needed, if made, will almost certainly raise coal production costs, with a corresponding negative impact on the country's international competitiveness [50]. Substantial improvements (and investments) are also urgently needed in the seaport infrastructure, which has recently become the main bottleneck for Indonesian coal exports [15, 46, 50]. The availability of coal for export could come under further pressure from the widely expected significant increase in domestic consumption, along with economic growth [2, 46].

4.4. SOUTH AFRICA

South Africa is amongst the most mature and stable world coal exporters. The development of the national coal industry goes back to World War II and the following international apartheid embargo on oil supplies. Coal exports began in the late 1970s, as a response to the changing energy world and the much higher oil prices after 1973. Since then, the country has proven itself to be a reliable supplier of high-quality steam coal worldwide. Proven reserves are plentiful and production has been matched over the years by the development of new deposits. Consequently, the R/P ratio is still above 200 years despite the long history of coal extraction.

Nevertheless, increasing and even maintaining production and export volumes in the future may pose challenges for several reasons:

- ✓ About 60% of coal production comes from underground mines, and this share will increase in the future [90]. Most currently operated mines are approaching the end of their economic life. There is a common consensus that the development of new reserves will be much more costly than the development of the old deposits (Figure 27). In addition, the quality of the coal from these new reserves is considered to be less than the quality of coal from existing fields. Taken together, these factors may result in proven reserves lower than the current estimates [21, 46, 50, 69].
- ✓ The plans for a partial switch to gas in the national energy system may have an adverse impact on the prospects for indigenous coal demand, with knock-on effects for export potential. Since South Africa has traditionally used a lot

of coal, the critical factor for developing new mines has so far at least been the internal market, while the export potential has been regarded as a secondary priority [69].

- ✓ The majority of the new deposits tend to be located further away from the main export terminals. This implies the need to develop completely new logistics chains and costly infrastructure. The capacity of the railway network, operated by the state-owned company Spoornet, is of particular concern [15]. Securing sufficient port handling capacity, along with the related investment funds, is another important challenge for South African coal exports [21, 46, 50].
- ✓ The wide spread of AIDS/HIV amongst mineworkers presents another very serious risk for the coal industry in South Africa [68, 78].

4.5. SOUTH AMERICA

Like Indonesia, South America is a relatively young player in the steam coal export market — significant exports started only in the mid-1980s. Colombia is by far the largest producer and exporter in the region, although Venezuela also has stable, though much smaller exports — Figure 26. Steam coal from these two countries enjoys a good market for two main reasons. First, it is of good quality, with a high calorific value and low contamination [90]. Second, Colombia and Venezuela enjoy a favourable geographical location, being closer to the large USA and European markets than other major exporters such as Australia, Indonesia and South Africa [21, 46]. Venezuela seems to be the lowest-cost producer and exporter worldwide, being the only country together with Indonesia to have export costs below USD 20 per tonne FOB trimmed — Figure 27. The impressive growth in Colombian production and exports has resulted in a reduction in the country's R/P ratio (falling from 177 years at the end of 2000 to 112 years at the end of 2005 [7, 12]), but sufficient additional reserves appear to be available. The major issue in this respect seems to be the security of sufficient foreign investment [90]. The key challenge for the Colombian coal export industry is the timely development of adequate export logistics and infrastructure (railways and ports) [15, 46]. This is also a prime concern for Venezuela [50], which however has in addition administrative impediments to the development of deposits to exploit the full production and export potential [85].

4.6. CHINA

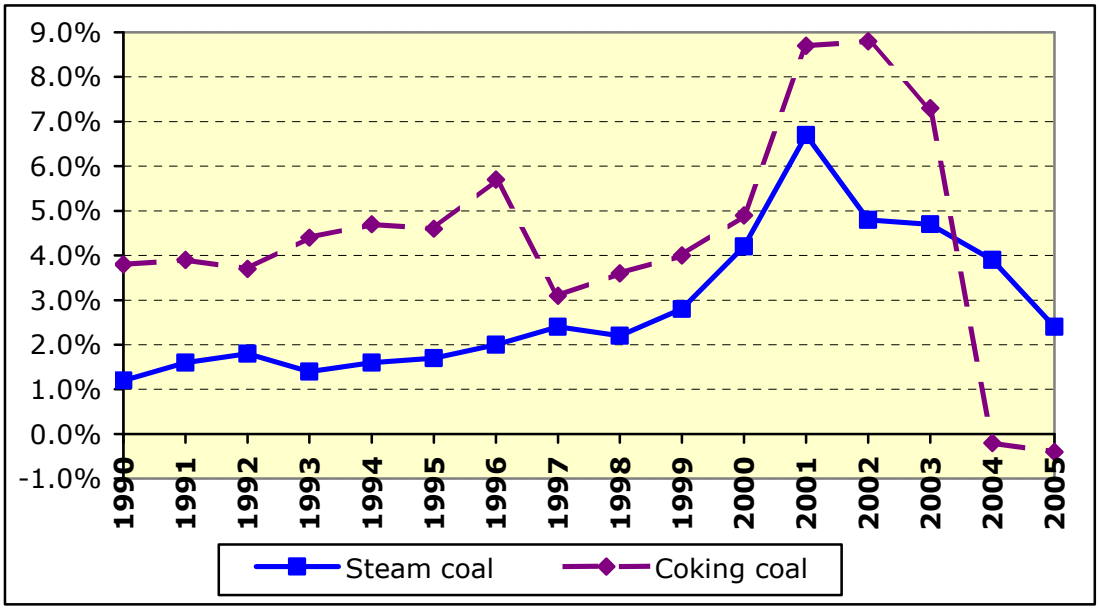
China holds the third largest reserves of hard and brown coal worldwide (Figure 13), and is by far the largest single producer (Figure 23) and consumer of coal globally. China alone is responsible for about 40% of world coal demand today, while coal accounts for 70% of Chinese primary energy consumption [3, 57, 77]. Almost 80% of Chinese electricity generation is based on coal [3, 56]. Unlike in other countries, coal is used widely as a fuel for households as well. Although the percentage of household consumption in total coal use is small, it is remarkable in absolute terms, especially when compared to the developed (OECD) countries [1, 77]. In view of these impressive numbers, even modest changes in Chinese coal production and consumption patterns could have a tremendous impact on world coal supply and demand. Just by way of illustration, all of Australia's steam coal exports are equal to only 5% of Chinese steam coal consumption. The analysis of the Chinese coal sector therefore merits particular attention.

China emerged as a key exporter of steam coal in 2000. Since then, export volumes have been fluctuating, but the most recent figures indicate roughly the

same level of exports as in 2000 — Figure 26. There are many different views as to how Chinese coal exports will develop in the future. The assumption in the current study is that the pessimistic scenario, i.e. China turning from a large net exporter to a huge net importer of coal, is far more probable in the medium term, because of the reasons explained below.

Although China has been amongst the leading exporters of coal over the past few years, the share of exports in its total coal production has been modest. The recent huge growth in production, driven by consumption for electricity generation, has reduced the share of exports in gross output — Figure 28. The share of exports has been brought down basically to the levels before the boom in indigenous production (Figure 23). A level of reserves of less than 2.5% of total production for exports cannot be perceived as sustainable in the long term, because any slight increase in indigenous demand will be taken from the export market, resulting at the same time in a parallel increase in imports [3, 21, 26, 76].

Figure 28
Share of Chinese exports of steam and coking coal in indigenous steam and coking coal production over 1990-2005 (%)



Source: Adapted from [18, 57]

As Figure 28 indicates, this has already occurred for coking coal. In 2004, China turned from a major coking coal exporter into a modest importer, with nonetheless an immense potential, driven by the fast growth in the domestic iron and steel industry[29]. Obviously, coking coal exports could restart and steam coal exports could once again increase, provided there is enough spare production capacity. The indications, however, are that the economic reserves to boost indigenous coal production have already been largely exploited, and if such an increase occurs, it will be achieved at a much higher cost.

While China's coal reserves seem plentiful in absolute terms, they are just 50% of the world average per capita [95]. This fact is of particular concern, as China is amongst the countries most heavily dependent on coal. The Chinese coal R/P ratio amounted to only 50% of the world average before the post-2000 explosion

[29] Over 2000-2003, the Chinese iron and steel industry grew by 73%, and China is currently the world leader in steel production with a 23% share [77, 78, 104].

in production. The development of new deposits has been lagging far behind the growth in output. Consequently, the R/P ratio has halved over just 6 years – from 116 years at the end of 2000 [7] to just 52 years at the end of 2005 [12]. With such trends and with no additional investment in the coal sector, China would run out of economically recoverable (at *current* economic and operating conditions) reserves of coal much earlier than widely anticipated. These negative tendencies can be offset by the accelerated development of additional reserves. However, such development will pose challenges for the following reasons:

- ✓ The great majority of coal reserves are deep (average depth 330 metres) and are suitable only for sophisticated and expensive underground mining. Underground mining accounts for about 95% of total coal output — a proportion likely to remain stable in the future. Developing new underground mines takes 4-5 years on average. This means that no major incremental growth in reserves can be expected by 2010 [66, 70].
- ✓ Any intensive development of new coalfields will put equipment suppliers and markets under enormous pressure. For strategic reasons, China has always preferred national coal mining technologies to foreign technologies[30]. It is rather uncertain whether even domestic and foreign manufacturers of mining equipment together will be able to meet such a huge increase in demand. Even if they manage to do so, it would anyway be achieved at much higher prices, which will subsequently be reflected in coal production costs.
- ✓ Productivity and recovery rates in Chinese mines are much lower than the world averages[31]. Other things being equal, this means that deposits twice as large are needed to extract the same amount of coal.
- ✓ For decades, China has had the worst coalmine safety records in the world[32]. With the increase in living standards, poor coalmine safety is becoming a growing issue in the country.
- ✓ Indigenous coal is of acceptable, but not very high quality. It has a relatively high sulphur and ash content that lowers the calorific value. Coal washing is one way of overcoming this problem, but it is difficult, increases costs and causes large energy losses [47, 66].
- ✓ The vast majority of coal deposits in China are located in the north and northeast of the country, while the main consumption centres are in the south and southeast [46, 56, 66]. This involves long-distance, expensive transport by railway[33], which significantly pushes up the final delivery cost. For the southern coastal regions, therefore, it is more cost-effective to go for imports from Indonesia, South Africa or Australia than for indigenous coal from the north [77].
- ✓ Although the recent projections foresee a slower marginal growth in power generation and consequently in coal consumption, China is still hungry for electricity. The relative electricity consumption per capita is only 50% of the world average. The rural areas are of particular concern [56]. Thus, the building of new power plants will continue more or less at the same pace and, given the lack of other large-scale fuel options in the near to medium term, there is a wide consensus that coal will continue being the main fuel input for electricity generation in the foreseeable future [1, 3].
- ✓ Also not to be ignored is the extremely high rate of growth in the iron and steel industry, which accounts for a large proportion of indigenous coal consumption. As with power generation, this growth is projected to continue

[30] Approximate ratio 9 to 1 [77].
[31] The average recovery rate in Chinese underground mines is 30-32% — less than half the world average [50, 66, 95].
[32] Almost 6,000 coalmine victims in 2003 [77].
[33] Over 60% of coal is transported by railway over an average distance of 550 kilometres [77].

in the future. Obviously, this will put further pressure on indigenous coal reserves.

There are two ways in which internal demand for coal could be eased and hence export potential at least be maintained at current levels. These are improving efficiency and fuel switch. Both approaches, however, do not look feasible in the near to medium term.

Although the efficiency of coal-based power plants has recently increased considerably, it is still lagging behind those in industrialised countries — Figure 18. It has been estimated that if China manages to bring the average electrical efficiency of its power plants up to that of the industrialised countries, this would result in a ≈20% reduction in coal demand [59, 86]. The lower electricity generation efficiency is due to several reasons: the poor performance of old power plants, many of them being too small, the poor quality of coal, etc. [66]. Another challenge is the inefficient grid distribution system. Huge investments will be needed to improve all these aspects. This might be a key constraint, not so much because of a deficit of funds, but for economic reasons. The marginal cost of upgrading old power plants has to be seen against the alternative incremental fuel cost. If coal remains relatively cheap, the incentives to raise electrical efficiency will weaken. Another hindrance to investment in increasing power plant efficiencies is the still heavily regulated national electricity market [56, 77]. Deliberately keeping electricity prices close to and sometimes even below generation costs does not provide investment incentives [2]. In any case, the priority for power plant operators is cost efficiency, not electrical efficiency. As in the power sector, there is a large scope for improving energy efficiency in the iron and steel industry as well, where Chinese energy consumption is again much higher than that in the industrialised countries [66].

Fuel switching in power generation may be a feasible solution, but mostly in the long term. China is generally poor in natural gas. The prospects of increasing the share of natural gas are mainly linked to pipeline deliveries from Russia and LNG supplies from the Middle East. Neither option is expected to become a real large-scale alternative in the next 10-15 years. Nuclear power is also an option, but needs huge capital investment, whose recuperation may be challenging in an environment of centrally regulated, low electricity prices. Hydro is already exploited in China, but its share of total electricity output is declining for a number of reasons [56]. One of the most important causes is the already noticeable impact of climate change, leading to low river levels, which also affect nuclear power [69].

4.7. FORMER SOVIET UNION

As Figure 13 indicates, the three largest countries in the former Soviet Union (Russia, Kazakhstan and Ukraine) hold almost 20% of the world's hard coal reserves and 30% of brown coal reserves. Even so, they are not major players in the world coal market. After the substantial economic changes in the 1990s, Ukraine has become a net importer of coal, Russia has re-started exports just recently and only Kazakhstan has managed to keep a noticeable presence on the world market, but with a gradually declining volume and share — Figure 26. The future of coal exports from Russia and Kazakhstan remains uncertain, but they will most likely play only a minor role in the coal market. The reasons for this assumption are the following:

- ✓ Except for the coalfields currently in operation in the Kuzbass region (Western Siberia), the great majority of Russia's other coal reserves are located in the central and eastern parts of the country, away from both the main consuming

centres in the western (European) part of the country and the seaports in the far east. Bringing that coal to either destination involves expensive rail transport. Rail transport is also required for the currently operated Kuzbass coalmines. Consequently, Russia is a relatively expensive producer of coal (Figure 27), competitive on the world market only when international coal prices are high [4, 46, 47, 50, 70, 85, 90]. Kazakhstan faces similar problems, and its competitiveness depends on keeping railway costs as low as possible [85].

- ✓ Russia's railway system is generally in a poor state. There is a particular dearth of railway infrastructure in the low-populated Siberian regions, where the major coalfields are located. The seaport infrastructure is not any better either. Significant investment is needed to overcome these shortcomings, but the funds have not been secured [21, 46, 50].
- ✓ Coal production and exports suffer from a generally low level of mechanisation and productivity, as well as poor mine safety [47].

Taking into account all the above factors, Russia no longer appears to be a coal–rich country [47, 85]. The most feasible option, which however would not boost coal exports, would be to use the coal from remote fields for internal energy needs. This could be done either by building coal-fired power plants near the remote deposits and then transmitting or exporting the electricity ("coal-by-wire") or via gasification of the coal reserves with subsequent transhipment of the coal-derived gas. In both cases, significant investment is needed to improve and/or construct new transmission networks and/or pipelines. This option might be attractive for Russia from a strategic point of view, since it would release additional natural gas for export — maybe the country's most strategic export commodity. Indications of an intention to construct such coal-based power plants have already been expressed in public [4, 26, 84].

4.8. USA

The USA has the greatest reserves of both hard and brown coal worldwide (Figure 13) and is the second largest global consumer of coal after China [57]. Power generation absorbs about 90% of indigenous coal production, coal accounting for more than a half of US electricity [50, 70, 90]. Production has a long tradition, and with minor exceptions has seen stable growth since the 1960s [85]. High-quality hard coal obtained from open-cut mining dominates total output. So far, extraction costs have been kept relatively low owing to high mine productivity. With such a large and attractive internal market, exports have traditionally had a lower priority for the national coal industry. In the past, the USA has acted mainly as a "swing supplier" to the world coal market [46, 50].

However, the future of USA coal extraction may not be as bright as its past, even though absolute coal reserves are plentiful with an R/P ratio of 240-250 years over the past few years [7, 8, 9, 10, 11, 12]. An indication of the troubles likely to affect coal production is the recent transformation of the USA from a net exporter to a net importer of steam coal[34] – Figure 26. Some analysts suggest that this trend could become even more pronounced in the future [26, 46, 76]. The key challenge for the US coal industry in the coming decades is the rising cost of production, due to the following reasons:

- ✓ The productivity of coalmines is steadily decreasing. After many years of exploitation, the old coalfields are getting depleted and output is decreasing. Their further exploitation is associated with higher costs. Since high

[34] However, exports of coking coal have remained virtually at the same level since 1999 [57].

productivity has been the main asset of the US coal industry, such a development will turn the USA into a high-cost producer (Figure 27) no longer competitive on international markets [1, 21, 26, 64].

- ✓ The only large potential so far unexploited lies in Alaska. However, these deposits may not come on stream until after 2015 [46]. Further delays are possible due to the generally low return on US coal investment, which also affects the upgrading of existing coalfields [91].
- ✓ As with China and Russia, the majority of coal has to be transported inland by rail, which further boosts delivery costs. Railway network capacity is also often insufficient even for current flows [19, 64].

Taken together, the above factors favour cheaper imports, especially from nearby Colombia and Venezuela, thanks to low freight rates.

4.9. INDIA

India ranks second in global hard coal reserves (Figure 13) and is amongst the largest coal users worldwide. 70% of indigenous coal production goes on electricity generation, coal accounting for 2/3 of fuel inputs to the Indian power sector. Coal output has been rising at a steady rate of about 4% per year since 1990 [57]. The development of proven reserves has followed the growth in extraction. The coal R/P ratio has declined only marginally and still exceeds 200 years, well above the world average [7, 8, 9, 10, 11, 12]. About 75% of coal comes from open-cut mines. The factors that may adversely affect the security of coal supplies in India are the following:

- ✓ Most Indian coal is of poor quality because of the rather high content of ash (30-50%) and water (4-7%) and consequently a low calorific value (13-21 MJ/kg). When such coal is directly employed in power generation, the resulting electrical efficiencies are low. Alternatively, coal can be pre-treated (washed), but this adds to the costs and results in an 8-15% energy loss [67].
- ✓ Although the gross R/P ratio is high, the amount of realistically exploitable reserves is uncertain. At present, most Indian coal is mined at depths of 150-300 metres. The deposits at such depths may be sufficient for 50-60 years only [94]. The recovery of deeper reserves may be precluded by excessively high costs.
- ✓ Most coalmines are state-owned, a fact that constrains private investment in the sector. Investment in coal supply is particularly impeded by distribution regulations and control over foreign investment. The operation of coalmines is outdated and productivity is very low compared to international standards, especially in underground mining [50, 67].
- ✓ Most coal deposits are located in the northeast part of the country, while the major consumption centres are in the west and southwest (including coastal) areas of the country. Bringing coal to the major consumers, especially in unwashed form, involves expensive transport by rail over large distances (500-750 km). Transport costs may account for up to 70% of total delivery costs. For a number of reasons, including the presence of three different gauges, the condition of the Indian railways is far from perfect. Improving the railways calls for huge investment, which does not seem realistic in the foreseeable future. For these reasons, and also to improve average coal quality, many power plant operators in the west and southwest parts of India are importing increasing volumes of higher-quality steam coal[35] [67].

[35] For fuel quality reasons, India has already for some years now been importing large amounts of coking coal for its domestic, fast-growing steel industry.

- ✓ The power generation sector is heavily regulated and electricity prices are kept at very low levels that basically preclude investment [50]. Power plant operators have little incentive to invest in improving coal quality, the development of logistical infrastructure or the modernisation of power plants [67]. Most power plants are over-aged, outdated and consequently inefficient (Figure 18).

The current 10% share held by imports in India's total coal supply may increase in the future, driven by several factors. Electricity demand is set to expand along with the fast-growing economy [70]. Another aspect driving electricity demand is the low electrification rate especially in rural areas, where the grid connection level is only 30% [67]. Increasing the share of imports may be the preferred option, not only because of the poor quality of indigenous production but also because surface mining, which is suitable for the majority of indigenous coal reserves [70], requires the relocation of population and activities. Such relocation might pose challenges in view of the country's high population density [78]. On the other hand, imports may be impeded by the generally poor state of port infrastructure and the resulting port congestion and vessel delays, on top of the usual heavy delays during the monsoon season [47]. All in all, however, considering the size of the country, even a modest increase in imports will most likely give very strong signals to the regional and world coal markets.

5. THE WAY FORWARD: COAL IS NOT WHAT IT SEEMS

The enhancement of the world coal supply base will most likely result in higher production costs. Owing to advances in energy conversion technologies, which allow a large variety of end products to be produced from different feedstocks, the world oil, gas and coal markets are becoming increasingly inter-related. The energy market of the future will tend to become a market for hydrocarbons rather than one differentiated by energy sources. In turn, this is expected to have important implications for coal supply and demand patterns in the future.

The analysis in the preceding chapters indicates that coal might not be so abundant, widely available and reliable as an energy source in the future. Building on these findings, this chapter tries to investigate the future cost and price trends for coal, as well as its affordability. The analysis concentrates on the factors that may affect coal demand and supply and their implications for coal costs and prices, rather than on projections of given coal price levels.

From an economic point of view, the perception of cheap coal is somewhat misleading. The categories "cheap" and "expensive" always have to be regarded in relative terms, not as absolute values. *Product X* is cheaper or more expensive compared to *Product Y* based on certain evaluation criteria. Applying other evaluation criteria, *Product X* may no longer be cheaper or more expensive than *Product Y*. In the case of energy, the relative cost ranking of various fuels has to be evaluated on the basis of the whole energy chain — from fuel extraction to final energy use. This approach reveals why, although the fuel cost of coal is lower than that of gas (Figure 4), the costs of the coal and gas electricity pathways are similar due to the higher investment costs for coal — Figure 19.

In addition, *Product X* could be cheaper than *Product Y* even if the production and final delivery costs of *Product X* are higher than those of *Product Y*. Prices do not always reflect costs. Often they are driven by other factors, e.g. the volume, structure and restrictions of demand and supply. The world natural gas and, especially, oil markets represent very good examples of such phenomena.

The demand for energy is not only driven by fuel cost and price levels. It also depends on the marginal relative preference for one fuel over another. It is influenced by the level of technological progress and by other, non-energy-related factors as well. Faster progress in certain technologies may boost the demand for certain fuels and vice-versa. Such progress can also lead to the emergence of new fuels that were of no use before and/or had no or negative value. Non-energy factors, such as environmental concerns, the regional availability of certain fuels and infrastructure for their utilisation, the existing structure of national energy systems, the security and diversity of energy supply, etc., often have a strong influence on energy consumption patterns.

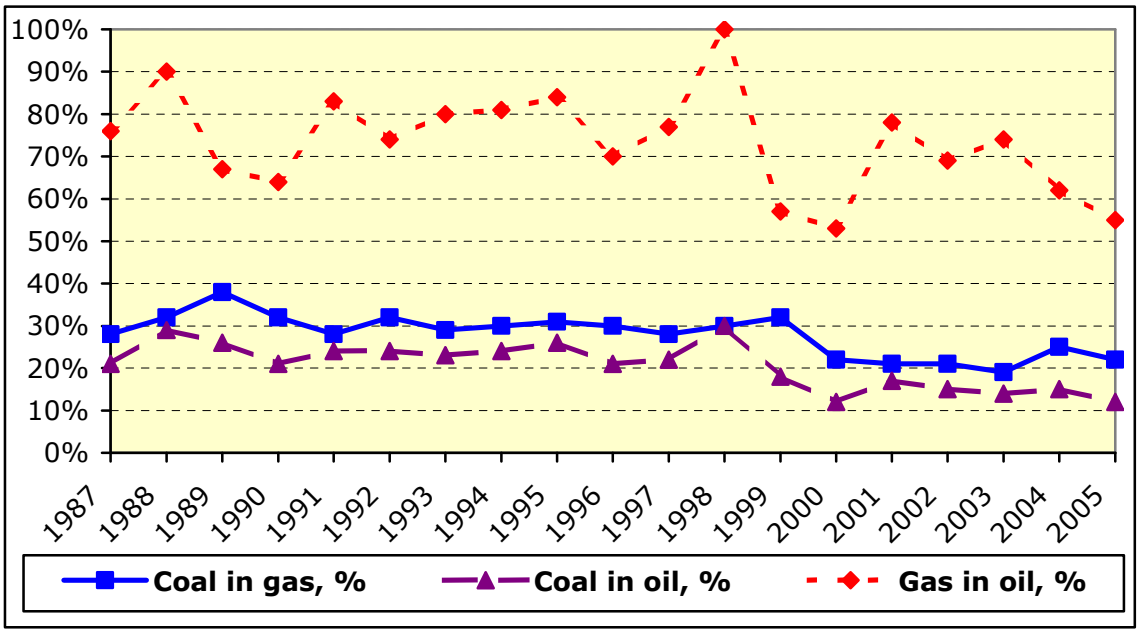
Going on from the slightly theoretical exposition above to the matter at hand, it is true that historically coal has been cheaper than oil and gas on an energy content basis. This may change, however, not only due to the higher cost of coal application technologies compared with natural gas (coal's main rival on the electricity market), but also because the following factors behind the lower price for coal may no longer be present in the future:

- ✓ Lower attractiveness (for environmental reasons) of coal compared to nuclear power and especially natural gas for electricity generation in industrialised countries. Nonetheless, energy demand in developing countries and emerging economies is rising faster than in industrialised countries. By definition, low costs are of higher priority than a clean environment for less developed

countries. The fact that the largest energy consumers amongst these countries have bigger reserves of coal than of oil and gas will give an additional impetus to coal demand and prices.

- ✓ Low concentration of supplies with a relatively large number of market actors. At present, the four biggest players in the coal business — BHP Billiton, Anglo-American, XSTRATA (owned by Glencore) and Rio Tinto — hold just 40% of the world steam coal trade [46]. In addition, several countries have been heavily competing on the world steam coal market over the past 10 years — Figure 26. As a cumulative result, absolute coal prices have not changed much over the past two decades (Figure 4), while relative coal prices (versus gas and oil) have steadily declined — Figure 29. The situation may change with the gradual concentration of export supplies in Australia, where the majority of coal production is in the hands of the four largest coal companies in the world [15, 78]. However, the emergence of an OPEC-like cartel for coal seems little probable in the foreseeable future. Its creation would also be difficult because the coal industry is much smaller and has far less economic power than the oil and gas industries [46, 78, 85].

Figure 29
Coal price as a percentage of gas and oil prices, and gas price as a percentage of oil price in EU-15 over 1987-2005, recalculated based on energy content (%)



Source: Adapted from [12, 18, 57]

- ✓ The regional and country overview in the preceding chapter has revealed that coal recovery in most countries will incur higher production costs in future. Since international coal prices are still linked to production costs (see above), an increase in the global price levels of coal can be expected. On the other hand, any enhancement of world coal reserves may be hampered by the poor return on investment in coal mining over the past few decades [46, 70]. The low profitability has been due to the strong price competition in the world market and correspondingly low coal prices. Although the investment needed to secure adequate reserves of coal by 2030 is estimated to be only 3% of all necessary investment in the energy sector by 2030 (compared, for instance, to 19% for gas) [64], the lack of a sufficient and stable cash flow may impede

a timely commitment [48][36]. Consequently, the coal supply base may be further squeezed and the pressure on coal prices reinforced by such pessimistic expectations. This phenomenon can be termed the "psychological" depletion of proven reserves, which always comes before physical depletion.

- ✓ Research and development (R&D) spending on coal mining has been steadily declining over the past 20 years. The privatisation of the coalmining sector in many countries has contributed further to this fall, as private companies usually operate with a shorter-term vision, subject to market pressures. The large know-how gaps cannot be eliminated overnight. Developing, demonstrating and implementing novel mining technologies will take time, along with the corresponding training in their use [73].

The future coal markets will be strongly influenced by the development of energy technologies, which are becoming increasingly sophisticated. Good and constant fuel quality is a crucial factor for their proper operation. While in the past coal prices have depended mainly on calorific value, in the future other factors such as sulphur and ash content will be important. The coal market will most likely become more diversified into sub-segments depending on particular coal properties, rather than constituting a single market for a single coal quality [20, 48].

Chapter 3 has revealed the growing dependence of coal markets on gas markets and vice-versa. As regards oil, coal has been related indirectly to it via natural gas, because in some regions, e.g. in Europe, natural gas prices have been linked to oil prices. These links will strengthen further with the implementation of novel energy conversion technologies, in particular for the production of oil-like fuels from alternative energy sources — gas-to-liquids (GTL) and coal-to-liquids (CTL) [62]. With the recent rise in world oil prices, GTL is starting to enjoy a growing interest. At present, several large GTL plants are at different stages of realisation. CTL has been known for decades, having already been applied on an industrial scale during World War II. Both GTL and CTL are less energy-efficient than oil refining. Nonetheless, GTL and CTL are increasingly popular because they allow diversification from oil. In particular, concerns about the security and diversity of oil supply are the key driving forces for GTL and CTL today. In addition, GTL and CTL provide fuels of a higher quality [74]. Where CTL is concerned, besides the facilities already operating in South Africa, China has recently indicated a significant interest in developing such plants [26, 59, 77, 104]. The key motive for China, in addition to its (still) abundant indigenous reserves of coal, is the opportunity to reduce its energy dependence on the Middle East. Unlike other regions, e.g. Europe, China is currently forced to import most of its oil *and* gas from the Middle East [3, 4, 26]. In view of the above trends, the future world oil, gas and coal markets will most likely become increasingly inter-related and the energy market will tend to develop into a global market of hydrocarbons [40, 78]. Consequently, the relative gap between coal prices and oil and gas prices will most likely narrow — Figure 29. This will be more pronounced for higher-quality coals, and a wider differentiation in coal prices, depending on quality specifications, may be expected.

The demand for energy can be drastically reduced if energy efficiency across all sectors improves. Since electricity generation is the prime consumer of coal, raising efficiency in this sector could shrink coal demand. However, efficiency improvements may be impeded or delayed, and the actual reduction in coal demand may be smaller than initially expected, because of the following reasons:

[36] The volatile return on investment and poor profitability were indeed the key reasons for the big oil companies to leave the coal business in the late 1990s [46, 78, 93].

- ✓ Efficiency can be increased either by upgrading existing power plants or by replacing old electricity generation facilities with new facilities. However, both options need significant additional investment that can be recouped only over a relatively long period of time. As already discussed in Chapter 3, the liberalisation of electricity markets has increased the investment risk for such initiatives. The priority for all power plant operators is to generate electricity cost-efficiently, not energy-efficiently. Unfortunately, these two objectives do not always go hand in hand. Investing in more energy-efficient plants also needs a long-term vision (10-20 years) and stability in regulatory frameworks, especially for GHG emissions and local pollutants. The shorter-term horizon of current GHG abatement policies and their only partial global coverage seriously hamper investment decisions. As it is generally safer to be exposed to short-term fuel risks than to long-term investment risks, investment in more energy-efficient technologies in such a situation of uncertainty will be driven exclusively by sound indications of a sustained growth in fuel prices over the long term. Recent estimates suggest that plenty of oil and gas could become available if the long-term oil price stays above USD 30 per barrel[37] [55]. Such a level does not appear high enough to boost large-scale investment in more energy-efficient technologies, in particular for power generation.
- ✓ Tougher environmental standards for the operation of power plants require the installation of additional and expensive flue-gas cleaning facilities. All these facilities consume energy. The efficiency gains from improved technologies can be partly or fully offset by the additional energy consumed by cleaning facilities. For instance, the widely discussed carbon capture and storage technologies will most likely result in an 8-12 percentage-point loss in electrical efficiency in the medium term, possibly falling to 4 percentage points in the very distant future [51, 59]. In parallel, carbon capture and storage may result in a significant (30-120%!) increase in investment costs for power plant [50].

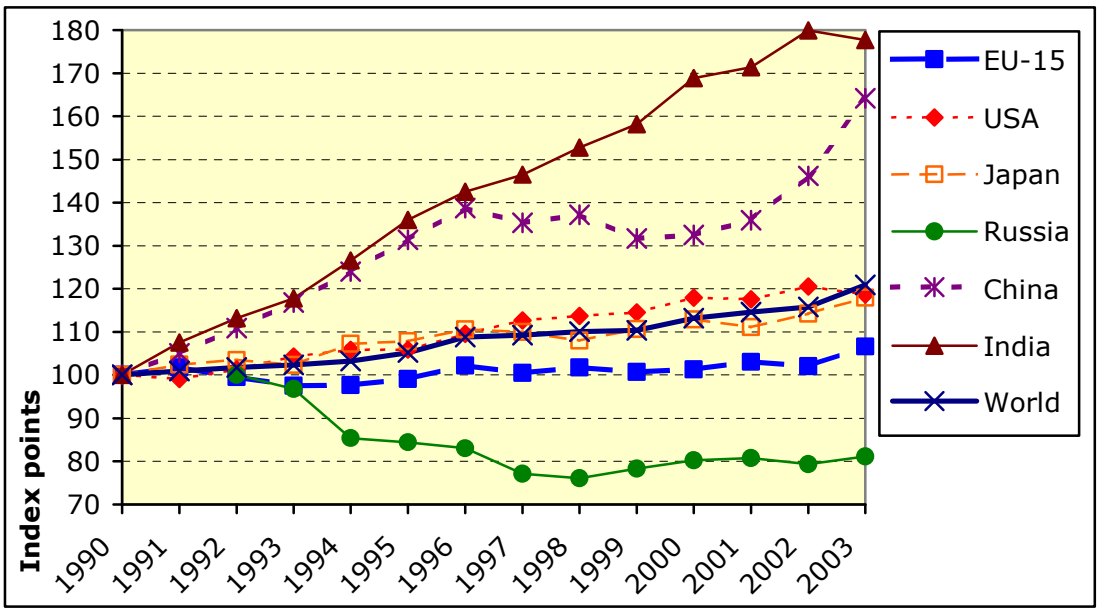
As already mentioned in Chapter 3, the future development of GHG abatement policies will have crucial impact on the market prospects of coal. Policies aimed at a further reduction in GHG emissions will generally weaken the position of coal at the expense of nuclear, gas and renewables, and coal prices are likely to fall. If GHG penalty and abatement policies do not have global coverage, but encompass only selected countries, regions or group of countries, GHG-intensive technologies will tend to migrate to countries and regions that are not committed to such policies [70]. Such a situation is already emerging and is very likely to continue, due to the following factors:

- ✓ Pursuing GHG reduction policies is in fact an investment strategy for future generations, where expenditure today pays off at some point in the future. Such an investment strategy involves spending substantial funds today — which many less developed countries simply cannot afford. In those countries, producing cheap and affordable electricity is more important than producing environmentally friendly electricity [51].
- ✓ The impact of GHG is not localised by region but is global. If a GHG reduction in one part of the world is accompanied by a greater increase in GHG emissions in another part of the world, the net global GHG balance will still be negative — something that we observe today (Figure 30). GHG reduction at global level remains uncertain, since some of the largest GHG emitters, such as the USA and Australia, have not ratified the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Other Kyoto Protocol signatories that are experiencing fast growth in GHG emissions, such as China

[37] In 2004 prices.

and India (Figure 30), do not have quantitative reduction targets [102]. The parallel GHG abatement initiative — the Asia-Pacific Partnership on Clean Development and Climate, which started in July 2005 and became operational in January 2006 — does not set GHG reduction targets. In brief, the aim of the initiative, which brings together Australia, China, India, Japan, South Korea and the USA, representing approximately 50% of world GHG emissions, energy use, GDP and population, is to establish technical and technological cooperation in the field of GHG abatement without compromising economic growth [64, 96].

Figure 30
Index of CO2 emissions from energy, in the world and by selected countries over 1990-2003 (index points, 1990=100)



Source: Adapted from [31]

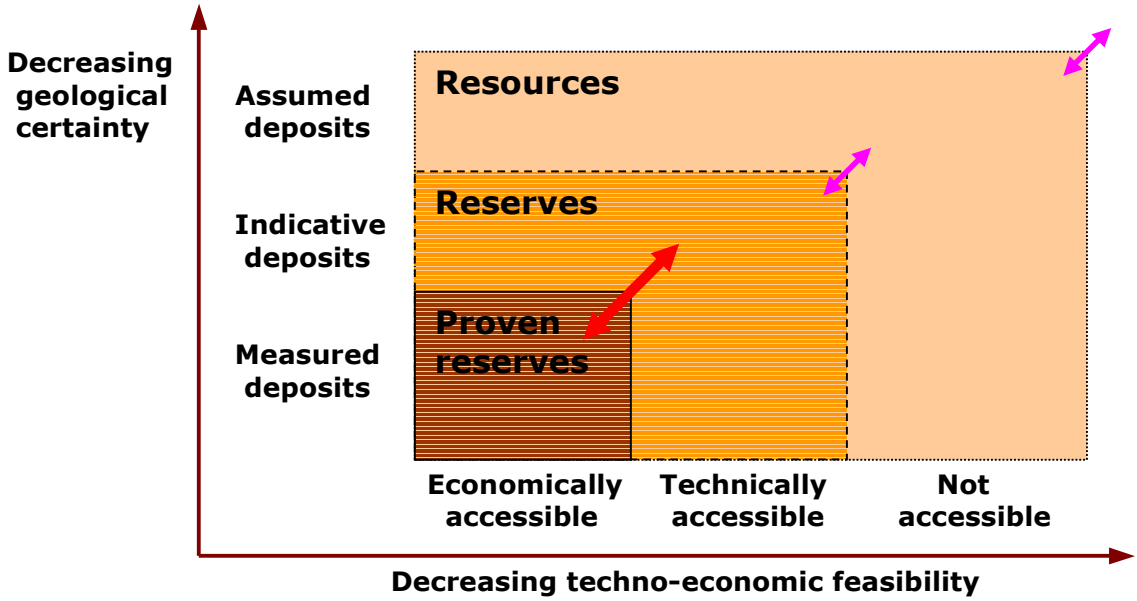
In a hypothetical situation with global joint efforts to curb GHG emissions, it is believed that carbon capture and storage can secure the survival of coal. However, such an assumption is somewhat doubtful for the following reasons:

- ✓ Carbon capture and storage technologies are still at the research and development stage. Their practical implementation will require a great deal of techno-economic, environmental and regulatory constraints and concerns to be overcome. Thus, a wide consensus has recently been emerging that carbon capture and storage may represent a viable industrial-scale technology option, but in the longer term only. By that time, other technology options may also become more broadly available, such as renewables (especially wind and solar) and more environmentally compliant nuclear power. The energy mix may therefore be different from the mix today, also because of changes in energy consumption patterns [51, 59].
- ✓ The largest techno-economic potential for carbon capture and storage is estimated to be in Europe, the USA and Australia [51]. However, the USA and Australia in particular are the two industrialised countries with the softest GHG reduction policies at present. Bringing them into a Kyoto-like target-based mechanism for GHG reduction, especially in view of their recently launched Asia-Pacific Partnership on Coal Development and Climate initiative, seems rather doubtful in the foreseeable future.

6. ANNEX

Three categories of coal deposits are commonly distinguished at all levels (from a single mine to the global scale): resources, reserves and proven reserves — Figure 31. The expression "coal reserves" as used in this report in fact refers to "proven reserves".

Figure 31
Resources, reserves and proven reserves



"Resources" are the widest category and designate the overall amount of coal that may be available. The quantification of resources is approximate. The figure for resources does not take into account the technical or economic feasibility of coal extraction.

"Reserves" refer to that part of resources that can be recovered with current technologies. This implies that reserves are more precisely quantified than resources. However, the figure for reserves does not take into account the economic feasibility of coal extraction.

This economic aspect is considered in the concept of "proven reserves". In brief, proven reserves express that share of coal reserves that can be economically recovered at current market prices [57, 91]. More specifically, proven reserves express those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions. In this light, if the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time – the reserves-to-production (R/P) ratio – that those remaining reserves would last if production were to continue at that level [12].

The above indicates that the "proven reserves" category is the most difficult to quantify, and the figures are indeed highly speculative. Proven reserves provide a rough estimate of the economically recoverable reserves at given extraction costs and market prices. This estimate sometimes can be highly subjective, depending on a number of non-market factors, e.g. government subsidies. In general, proven reserves tend to diminish in periods of low market prices for coal and tend to increase in periods of rising prices. There is some time lag in both cases,

though it is somewhat longer in the latter. This is because it always takes more time to bring additional facilities into operation than to reduce or stop coal production [47, 78]. Proven reserves can also increase as a result of new discoveries and/or techno-economic improvements in mining technologies. The latter give access to deposits that were previously not economic to exploit, thus converting reserves into proven reserves [104].

The three categories of deposits vary with time and are to some extent relative. The introduction of novel geological and mining technologies may boost resources and reserves, and may reduce extraction costs. Conversely, delays or cutbacks in R&D investment or in the development of existing or new mines may diminish reserves, if the recovery rates are sustained [22, 47]. The variation in proven reserves (both absolutely and vis-à-vis reserves) is more important for shorter-term market equilibrium, while changes in reserves and resources have a more pronounced influence on longer-term market perspectives.

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