Estimation of Production Costs for Energy Resources

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Introduction

The use of fossil fuels largely depends on the costs of making these fuels available. Among these costs, the production expenses, which are influenced by numerous factors, are of prime importance. The aim of this study is to determine the unit costs of production from the currently used deposits and to estimate the unit costs of production from deposits that will be tapped in future. An exact definition of production costs is exceedingly difficult to make. Therefore, the average production costs for mineral oil, natural gas and black coal determined in this study must be seen as approximations of reality. For the determination of the production costs of currently used deposits and for the estimates of the costs of future deposits, recourse is made primarily to existing studies and estimates in the literature.

Energy production costs of great importance

In the present and future use of fossil energy sources, the costs of making them available play a key role, among which the production costs, which are influenced by numerous determinants, are crucial. In addition to the geological, technical and economic factors, the political conditions of extraction are also of major importance. This study seeks to determine the unit costs of production at currently used deposits and to estimate the unit costs of production from deposits that will be tapped in future. An exact definition of production costs is very difficult for several reasons. Since the production costs are an important competitive factor for individual enterprises, they are usually not made public. In addition the costs are highly dependent on the factors of the individual deposits such as their location and size, and can therefore differ greatly. Finally, during extraction of the raw materials additional, unanticipated expenditures such as strikes, storms or subsequently imposed regulations may occur so that the actual production costs can often only be precisely determined after the fact.

In the following the production costs for the dominant fossil energy sources – mineral oil, natural gas and black coal – will be identified. These costs include the costs for the extraction of the energy resources, i.e. for the operation of the extraction facilities (especially wage and intermediate material costs) and the capital costs allocated to the service life of the facility, which result from the expenditures for the exploration and the construction of the facilities for the extraction of the energy sources from the site of the deposits. Included in these capital costs are also the expenditures that accrue in the course of the depletion of the raw materials in order to counter the gradual decline in the production output and to be able to keep extraction at a high level. This applies especially to oil and gas deposits, for example, by the application of secondary and tertiary procedures to increase the degree of exploitation.

Not included are the so-called user costs, i.e. the costs from the loss in value of the remainder of the *in-situ* resources that arise as a result of the extraction of the resource itself, as well as the royalties that precisely reflect these users costs if the extracted resources are not the sole property of the extracting company.

For the determination of the production costs of the currently used deposits, recourse is made to several currently available studies and estimates in the literature, where the production costs are given in the form of unit costs. The information available in the literature for various years is converted uniformly to a price basis of 2009. The estimation of the unit costs of deposits exploited in the future is also carried out by means of the information in the literature and on the basis of forecasts of the requirements for the individual energy sources in the coming decades as well as by using estimates of the probable development of investments for accessing new deposits or for the continuation of production.

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Mineral oil: the dominant energy source

Mineral oil continues to be the most important energy source worldwide. It clearly stands in first place in terms of both consumption and traded volumes. The high trading volume of mineral oil is attributable mainly to the fact that the worldwide concentrations of consumption and the areas with the highest crude oil production, which frequently have a high export potential, are at a comparably far distance from each other. Furthermore, the most important exporting countries are also those with the most extensive conventional oil reserves. At the end of 2008 the worldwide reserves amounted to ca. 182 billion toe (tonnes of oil equivalent). With an annual consumption of currently ca. 3.9 billion toe, a static range of 46 years of oil reserves can be calculated. Of total reserves, 101 billion toe are concentrated in the Middle East, and the annual consumption of these countries in 2008 amounted to 0.3 billion toe (ExxonMobil 2009). The leading position of mineral oil is based on its specific advantages, especially its broad application spectrum as well as its favourable transportation and storage. Because of its overriding importance, mineral oil is a strategic raw material. Most analyses and forecasts of developments on the world energy markets conclude that demand for mineral oil will continue to increase also in the coming years. However, smaller growth than only a few years ago is expected, for example by the International Energy Agency (IEA), because of the increasing difficulties in accessing deposits and the associated high costs.

The great number of analyses and forecasts are understandable in light of the extraordinary importance of mineral oil. However, the great majority of studies deal with questions of available quantities, of the technical possibilities of extraction, price developments and the political implications of greater oil consumption when faced with the insecurities of the supply. Studies of the costs of exploration, accessing and extracting crude oil are considerably less numerous. There are objective reasons for this, especially the geological differences and the size of the individual deposits as well as the different technical efforts for oil extraction. In addition, companies often treat their data on the costs of oil production confidentially. Under these circumstances, the published numbers on production costs are usually estimates of the respective authors. Nevertheless, these estimates are probably fairly accurate. Because of the considerable differences between the oil fields, however, the production costs cover a fairly wide range. This is also a result of the strong increase in the price of oil in recent years that made it possible to extract oil from sites with comparatively high extraction costs. In the following, the present and expected future production costs are presented as a whole as well as their two components: capital costs and operating costs. The focus will be particularly on the presentation of average values.

A recent study was conducted by Deutsche Bank (Deutsche Bank 2009), containing estimates of current production costs (OPEX) for 90 percent of world oil production without capital costs, royalties and exploration costs for 2009. For the large oil fields, which account for ca. 70 percent of worldwide production, these average costs stand at 6.20 US dollars/bbl (bbl = barrel; 1 bbl = 159 litres). The range of these costs extends from 1 US dollar/bbl in the Arabian Gulf states to about 26 US dollars/bbl crude in the Canadian oil sands, the latter not being of much importance in current production volume. The direct production costs of the smaller fields – about a sixth of worldwide production – amount to 8.30 US dollars/bbl, on average. The production costs for all the fields examined in the study, which determine the development of the worldwide oil market, average 6.60 US dollars/bbl.[1]

For 2007, the Deutsche Bank study shows in addition the total costs of oil production (technical costs). These costs are derived from information – also without royalties or user costs – of large mineral oil companies and display a considerable range. On average, these total costs without taxes amounted to 15.20 US dollars/bbl; they contain the direct production costs (share: approximately 39 percent), the capital costs (about 47 percent) as well as the costs for exploration (14 percent). Total costs increased in the last five years by an annual average of 14 percent. Since for the estimate of these production costs only the data of the mineral oil companies were used, the calculation does not include the corresponding data of the national oil companies, which are of great importance for the oil market and determine, for example, the supply of the OPEC countries. It is, however, to be assumed that many of these national providers are able to produce at relatively low capital and exploration costs. For this reason it can be presumed that global average produc-

[1] The average is calculated by weighting the production costs with the respective shares of the production volume.

tion costs for 2007 were below the 15.20 US dollars/bbl mentioned above.

For comparison reference is made to a study by Dresdner Kleinwort (2006), in which also the oil production costs of large oil companies are listed for 2005. Average production costs of these companies of 10.5 US dollars/bbl can be derived from a graph in this study; for 2007, with the above-mentioned yearly rate of increase, production costs of 13.5 US dollars/bbl result. According to the estimates of Dresdner Kleinwort (2006), the average production costs of the Russian companies examined in the study were less than half as high. These estimates are an indication of the oft-times favourable production conditions of national oil companies.

Informed by these studies, we turn to another approach to estimating current oil production costs. The study by Aguilera *et al.* (2009) calculates total production costs in US dollar prices of 2006 for crude oil extracted in the future. In this approach, which is based on a study by the United States Geological Survey in 2000, the expected costs for all relevant oil producing areas are given, and for most of the deposits total production costs are divided into (average) capital and operating costs. An amount-weighted assessment of these total costs showed that 56 percent of the total costs are accounted for by the operating costs. Taking this percentage as approximately valid also for current production, then global operating costs – as listed in the study of Deutsche Bank (2009) – of 6.6 US dollars/bbl result in total production costs of 11.8 US dollars/bbl; this corresponds to a share of the world market price for crude oil in the fourth quarter of 2009 of approximately 16 percent. This value for total oil production costs is comparably close to the result found in the study of Jojahrt (2008), in which for 2006 an average value of 9 US dollars/bbl was indicated (2009: almost 11 US dollars/bbl) in a range of between 3.38 and 20.79 US dollars/bbl. The production costs estimated by Remme, Blesl and Fahl (2007) are at about the same level; a weighted average of ca. 8.8 US dollars/bbl in prices of 2000 can be derived from the data of this study. This corresponds to production costs for 2009 of nearly 11 US dollars/bbl crude oil. Altogether, average production costs are currently approximately 11 to 12 US dollars/bbl for crude oil.

Rise in oil production costs expected

For estimating the unit costs of crude oil production from future deposits, there are different possibilities. On the one hand, the study of Aguilera *et al.* (2009) can be used directly, in which the oil still available in the future and the additional accessible reserves are indicated at a total of 3.561 trillion bbl; this corresponds to approximately 486 billion toe and thus almost 2.7 times the reserves that were listed by ExxonMobil (2009) for the end of 2008. These total reserves are comprised of the 2.713 trillion bbl from the amounts derived from the United States Geological Survey and 848 billion bbl from additional fields. For the production of the quantities found in the United States Geological Survey, average costs are calculated at 6 US dollars/bbl in 2006 prices; the range of these costs extends from 1.08 US dollars/bbl for deposits in the Arabian Gulf states to 15.27 US dollars/bbl for on- and offshore oil from Kazakhstan. The costs for the additional oil production quantities average 18.9 US dollars/bbl with a range of between 15.41 US dollars/bbl in Europe and 26.72 US dollars/bbl in Sub-Saharan Africa and in Antarctica.

For the total amounts of oil under consideration, average production costs at 2006 prices can be calculated amounting to approximately 9.1 US dollars/bbl. At annual price increases of 14 percent, as listed by Deutsche Bank (2009) for 2002 to 2007, nominal average production costs for 2007 are 10.4 US dollars/bbl. Since the cost increases have slowed down considerably, production costs for 2009 are estimated to total 11 US dollars/bbl. This appears to be comparably little in light of the above estimated production costs at deposits used today of 11.8 US dollars/bbl, and can only be explained by the fact that the production costs listed by Aguilera *et al.* (2009) are to be understood as static; they include neither the technical progress that leads to a reduction of costs over time nor do they take cost increases, as witnessed particularly between 2006 and 2008 into consideration, since they are regarded to a considerable extent as cyclical.

In the study by Remme, Blesl and Fahl (2007) average weighted production costs of between 8.6 and 22.9 US dollars/bbl in prices of 2000 – or an average of 15.8 US dollars/bbl – are calculated for oil deposits to be tapped in the future; in prices of 2009 this amounts to 20 US dollars/bbl. Within this range of production costs lie the costs for the extraction from oil sands and heavy oil deposits. The production costs for the extraction of the oil resources, however, are somewhat below the production costs of enhanced oil recovery (EOR) of known deposits. Extraction from oil shale is by far the most expensive.

In addition there is also the possibility of estimating the unit costs of deposits to be tapped in future by means of the 2008 projections of the IEA.[2] These projections see the worldwide supply increasing from 84.3 mb/d (million barrels a day) in 2007 to 94.4 mb/d in 2015 and 106.4 mb/d in 2030. Via the upstream investments in this period, however, not only the increasing oil requirement must be satisfied but also offset with the natural decline in production of the presently exploited deposits. The IEA assumes a decline in production of present oil wells of an average of 6.7 percent per annum; this rate will increase in the coming years and, according to the estimates of the IEA, will amount to ca. 10.5 percent per annum in 2030. This means that, on the one hand, because of the decline in production of present deposits, oil wells producing 64 mb/d must be tapped by 2030 and, on the other hand, because of the increase in the rate of decline, the production capacity must be raised by an additional 23 mb/d. With an increase in the supply of ca. 22.1 mb/d, production capacities must be increased by ca. 110 mb/d by 2030. For this, the IEA estimates necessary investments of 5.036 trillion US dollars in 2007 prices; this breaks down to 4.604 trillion US dollars for conventional oil and 432 billion US dollars for non-conventional oil.

Thus, in this period, 45,780 US dollars (2007) will be invested, on average, for the creation of an additional production capacity of 1 b/d. Under the assumption of a typical service life of 25 years for an oil field (see International Energy Agency 2010), investments of 5 US dollars/bbl can be calculated. There are, however, considerable differences depending on the deposits: in the Middle East investments, according to IEA information, amount to ca. 12,000 US dollars/b/d; converted to the total amount of crude oil produced, this corresponds to ca. 1.3 US dollars/bbl. For oil extraction in the Gulf of Mexico, 30,000 US dollars/b/d (3.3 US dollars/bbl) must be calculated, in the North Sea 40,000 US dollars/b/d (4.4 US dollars/bbl) and for the oil sands approximately 70,000 US dollars/b/d (7.7 US dollars/bbl). As a comparison, reference is made to recent estimates by OPEC (2009), according to which investments for the development of additional production capacity of 1 b/d are much lower. For the period of 2010 to 2030, average investment costs of ca. 20,000 US dollars/b/d in 2008 prices are listed, whereby the lowest are in the OPEC countries at 12,000 US dollars/b/d and the highest required investments are in Western Europe at ca. 26,000 US dollars/b/d.

The 5 US dollars/bbl calculated on the basis of the IEA figures stand for the linear write-offs on the investments; the interest that accrues in addition during the life span of the projects is determined via the annual annuities. For this, starting from the total investment costs up to 2030 amounting to 5.036 trillion US dollars, capital costs for the produced amount of approximately 9.8 US dollars/bbl[3] are calculated at an interest rate of 6 percent.[4] Since the price level for upstream investments from 2007 to 2008 only increased by 1.5 percent, it is assumed that the price increase between 2007 and 2009 was approximately 3 percent, so that the capital costs in 2009 should amount to 10.1 US dollars/bbl. Together with the average operating costs of 6.6 US dollars/bbl, total average production costs in 2009 prices were 16.7 US dollars/bbl.

The following production costs – in each case in 2009 prices – are calculated using this method for deposits opened up in the future in selected regions:

- Middle East: 4.1 US dollars/bbl,
- Gulf of Mexico: 11.7 US dollars/bbl,
- North Sea: 20.3 US dollars/bbl,
- Canadian oil sands: 41.2 US dollars/bbl.

With the current projections of the IEA in the *World Energy Outlook 2009* there is a slight modification of the results. Because of the global financial market crisis, worldwide economic growth and with it also energy demand will be lower than initially predicted. The entire supply of oil in 2015, according to the current IEA estimate, will only increase to 88.4 mb/d – 6 mb/d less than in the estimate of 2008. In 2030, the supply of oil will be 105.2 mb/d, only 1.2 mb/d less than the earlier forecast. With this oil production costs will also tend to be lower since the capital productivity will be higher because of the higher share of oil extracted at lower expense. Hence, a production capacity of ca. 105 mb/d is to be attained by 2030 and investments

[2] Because of the recent recession, demand for oil will be lower than estimated in the report at the end of 2008. Current development is taken into account in the IEA report of 2009.

[3] These capital costs can only be given approximately because the underlying annuity refers to a time period, whereas actual oil production has a different chronological structure. Oil production over time generally follows an asymmetrical bell curve, with much of the activity occurring at the beginning of extraction. By placing capital costs in relationship to the extracted amount, it is assumed that the oil production is constant each year in the period examined and that no further investments are necessary in this period.

[4] The interest rate of 6 percent results from the long-term real capital market interest rate of approximately 4 percent, as calculated for Germany (Bundesbank 2001), and a risk premium as is derived in the Goldman Sachs (2008) study from the average of the total risk, comprised of the technical and the political risk.

are likely to be around 8 percent lower. For a production capacity of 1 mb/d, on average approximately 44,000 US dollars are to be invested; this is on the basis of a total volume of crude oil production of 4.8 US dollars/bbl. The capital costs that accrue for the amounts produced are 9.4 US dollars/bbl in 2007 prices. This corresponds to ca. 9.7 US dollars/bbl in 2009 and, together with average operating costs of 6.6 US dollars/bbl, leads to total average production costs of 16.3 US dollars/bbl. It is implicitly assumed here, however, that not least due to technological progress in oil extraction no strong increase in extraction costs will occur, as was observed in the years up to 2008.

In addition to the average oil production costs, consideration must also be given to the marginal deposits (e.g. oil sands, deep sea deposits), which are of key importance for pricing in the oil market. An impression of these marginal deposits can be gained from the reports of the major US oil and gas producers to the Energy Information Agency (2009) on their own production costs. For the period 2006 to 2008 they indicated that their average worldwide production costs (2008 prices) were approximately 34 US dollars/bbl.

The results of the research and considerations of average oil production costs as well as the shares of oil production costs in the average prices in recent years are given in Table 1. Future production costs refer in particular to the period up to 2030. In light of the averages listed in Table 1, it must not be overlooked that oil production costs vary considerably depending on the different deposits. Current production costs as a share of average oil prices for 2005 to 2009 lie between 3 percent and 67 percent.

Table 1
Production costs for crude oil and share of production costs in oil prices (in 2009 prices)

	Aguilera *et al.*	Remme, Blesl and Fahl	Jojahrt	Deutsche Bank/Ifo	IEA/Ifo[a]
Oil production costs of currently used deposits in USD/bbl		11.0	11.0	11.8	
Oil production costs of future deposits in USD/bbl	11.0	20.0			16.7 (16.3)
Percentage of production costs in the total oil price[b] of current deposits		16.0	16.0	17.2	
Percentage of production costs in the total oil price[b] of future deposits	16.0	29.1			24.3 (23.7)

[a] IEA (2008) in brackets IEA (2009). – [b] Average prices from 2005 to 2009.

Source: Listed studies; Ifo Institute.

Natural gas production influenced by the oil market and transport costs

The use of natural gas has expanding strongly worldwide in recent decades, and according to IEA estimates demand will continue to grow also in the coming decades. Natural gas is used predominantly for heating; its use as a fuel for transport is still of limited importance worldwide. The main reasons for the increasing use of natural gas are its favourable combustion qualities, its versatility and its better environmental compatibility in comparison with other combustibles. The extraction of natural gas is closely connected to mineral oil production, and often it is produced simultaneously. For this reason extensive analogies to mineral oil exist with regard to production conditions and production costs. However, there are far fewer studies available on the production costs for natural gas.

For the estimation of the production costs for natural gas from currently used deposits, the study by Remme, Blesl and Fahl (2007) can be used. According to this study, the cost of natural gas extraction (in US dollar prices of 2000) as a weighted average of all world areas is between 4 and 5.5 US dollars/boe (barrel oil equivalent). The mean value determined by this interval for natural gas production costs (in prices of 2009) is nearly 6 US dollars/boe. In contrast, an IEA study of 2009 gives the range of costs for natural gas production from conventional deposits; the range is between 2.7 and 32.5 US dollars/boe. Since it can be assumed that there is a tendency to use the better gas sources intensively first, for 2009 production costs of between 5 and 10 US dollars/boe are assumed; for the period up to 2030 a cost range of 8 to 20 US dollars/boe seems realistic. Here it must be pointed out, however, that the

transport costs for gas comprise up to 80 percent of total costs of producing gas. For this reason it is plausible to assume that a gas source that is cheaply accessible but far from the markets will only be tapped after an expensive field that is closer to the markets, if prices are high.

For the determination of future production costs for natural gas, recourse can also be made to the numbers of Remme, Blesl and Fahl (2007) and of Aguilera *et al.* (2009), and again, as with crude oil, to our own calculations made on the basis of the IEA reports of 2008 and 2009. In the course of the increasing depletion of the deposits classified as reserves, the extraction of natural gas from known resources takes on increasing importance. The costs of the natural gas production from these deposits are comparably low compared with the extraction from more remote and difficult to access deposits. The average production costs given by Remme, Blesl and Fahl (2007) in US dollar prices of 2000 are between 8.9 and 13 US dollars/boe. In 2009 prices, average production costs for natural gas stood at about 13.7 US dollars/boe.

In addition, according to Remme, Blesl and Fahl (2007), for natural gas production even further in the future, technologies and sources that are combined with considerably higher costs will be likely. Among these, ranked according to ascending costs, are the increased exploitation of known deposits (EGR – enhanced gas recovery), the extraction of gas from coal, tight gas (gas in rock strata), aquifer gas or gas hydrates. The costs of the natural gas extraction from gas hydrates is at the upper limit and lies between 55 and 100 US dollars/boe (in 2000 prices); this corresponds to a price range (in 2009 prices) of about 70 to 125 US dollars/boe.

The estimates of natural gas production costs by Aguilera *et al.* (2009) are much lower; for future natural gas production and the growing reserves they calculate average production costs of 4.8 US dollars/boe (in 2006 prices) on the basis of amounts estimated by the United States Geological Survey (2000). For additional deposits with higher extraction expense they calculate average production costs of 12.6 US dollars/boe. Thus, for the total amount of gas, production costs amount to 6.6 US dollars/boe (in 2006 prices); on the basis of 2009 prices this means costs of approximately 7.5 US dollars/boe. The gas quantities accessible at these costs are, as for crude oil, considerably higher than in other available estimates. Aguilera *et al.* (2009) use a gas production volume of 3,375 billion boe, which is three times the reserves of 1,115 billion boe that ExxonMobil (2009) indicated.

As was done for crude oil, we estimate the unit costs of deposits to be accessed in future by means of the 2008 IEA projections. Accordingly, worldwide natural gas production will increase from 2,959.3 in 2006 to 3,512 billion m^3 (2015) and 4,434 billion m^3 in 2030. With the upstream investments in this period, compensation must be made not only for the growing demand for gas but also for the natural production declines of currently exploited deposits. We assume a decline in the production of present gas wells of 5 percent per annum on average; this rate will increase in the coming years and will amount to approximately 8 percent per annum in 2030. This means that on the one hand because of the production declines of present extraction sites, gas deposits with an annual output of 2,000 billion m^3 to 2030 must be accessed and on the other hand that because of the rise in the rates of decline of production capacity, a further increase of approximately 1,225 billion m^3 will be needed. With an increase of the supply of 1,475 billion m^3, the extraction capacities must be expanded by 2030 by ca. 4,800 billion m^3 per annum, or converted into oil units by 30,258 mb/year. The IEA estimates investments of 3,322 billion US dollars will be needed for the period up to 2030 (2007 prices).

For an additional production capacity by 1 b/d, 40,070 US dollars (2007) must be invested, on average. Assuming a typical service life of a gas deposit is 25 years, investments are calculated at 4.4 US dollars/boe. There are, however, considerable differences depending on the deposits: In the OECD countries investments are estimated to be around 67,500 US dollars/b/d (7.4 US dollars/boe), whereas in the non-OECD countries only ca. 30,000 US dollars/b/d (3.1 US dollars/boe) needs to be invested. Assuming total investment costs of 3,322 billion US dollars and an interest rate of 6 percent, capital costs with reference to the extracted amount of 8.6 US dollars/boe result. In 2009 prices, this means capital costs of ca. 8.9 US dollars/boe. Together with the average operating costs[5] of approximately 4.6 US dollars/bbl, total average production costs of 13.5 US dollars/bbl result for 2009.

Here too, using the 2009 IEA projections there is a small modification of future production costs. Total

[5] Here, the average operating costs of Aguilera *et al.* (2009) for 2009 were used.

natural gas production, according to current IEA estimates, will only increase to 3,395 billion m³ in 2015 – 117 billion m³ less than in the forecast for 2008. In 2030 gas production at 4,313 billion m³ will be 121 billion m³ below the earlier forecast. Accordingly, also the gas production costs will tend to be lower since capital productivity will be higher because of the higher share of natural gas extractible at a smaller expense. With this in mind, an annual gas production capacity of ca. 4,600 billion m³ must be attained, which in oil units corresponds to approximately 29,000 mb/year, by 2030; investments should be around 10 percent lower. For achieving a production capacity of 1 mb/d, ca. 37,700 US dollars must be invested on average; in terms of the total extracted amount of natural gas this amounts to investment costs of 4.1 US dollars/boe. Capital costs calculated on the basis of the total amount of gas produced amount to 8.1 US dollars/boe in 2007 prices. This corresponds to ca. 9.3 US dollars/boe for 2009 and together with average operating costs of 4.6 US dollars/boe amounts to total production costs of 12.9 US dollars/boe. As is the case for oil, there is also a large range of production costs worldwide for gas; because of the high share of transport costs and the prevailing link to oil prices, the marginal sources have a weaker influence on gas price formation.

The results of the available cost estimates and our considerations are summed up in Table 2. With reference to the average costs listed in Table 2, it must be pointed out that because of the distribution of the production costs, their share in prices currently fluctuates between 4 percent and 35 percent.

Table 2
Production costs for natural gas and share of production costs in the gas price (in 2009 prices)

	Aguilera *et al.*	Remme, Blesl and Fahl	IEA (2009)/Ifo[a)]	IEA/Ifo[b)]
Natural gas production costs for current deposits in USD/boe		6.0	7.0	
Natural gas production costs for future deposits in USD/boe	7.5	13.7	13.0	13.5 (12.9)
Percentage of production costs in the total gas price[c)] for current deposits		14.1	16.5	
Percentage of production costs in the total gas price[b)] for future deposits	17.6	32.3	30.6	31.8 (30.4)

[a)] Conventional deposits. – [b)] IEA (2008) in brackets IEA (2009). – [c)] Gas prices from 2005 to 2009.

Source: Listed studies; Ifo Institute.

Large black (bituminous) coal reserves dampen cost increases

According to IEA information, coal's share of worldwide primary energy consumption was 26.5 percent, making it the most important energy source after mineral oil (34 percent). The importance of the coal as a source of energy has increased since 1990; its share in energy consumption grew in this period by one percentage point. Included in the different sorts of coal are brown coal and black coal. Whereas brown coal is primarily used locally because of its lower energy content, for black coal there is an active worldwide trade that has continuously expanded in recent decades. Here, a distinction must be made between coking coal, which is mainly employed in steel production, and steam coal, which is used in the heating market. The by-far largest share in the worldwide coal market is for steam coal, with a share of more than three quarters. For this reason we only list the production costs for steam coal, and only for those countries that dominate the world coal market. This country group includes Indonesia, Colombia, Venezuela, South Africa, China, Australia, the United States and Russia. Here, it must be noted than in Europe and the United States, coal is used mainly in large plants for the production of electricity and heat; direct final consumption only plays a subordinate role. For this reason, the high degree of competition is often greater in the coal markets than for oil and gas.

In supply costs found in the literature, the haulage costs to the consumers or to the export ports are often included. This is because haulage is very important for determining total production costs or the differences in price for coal. As a result the proximity of coal deposits to ports is a considerable site advantage for coal. Here, however, we only take into consideration the costs that are immediately associated with production, that is the costs for capital, labour, operations and processing. These are the costs free at

the site of deposit, as they have been analysed by Schulz (1984a and 1984b) for different types of open-cast and below-surface mining operations.

The average production costs for steam coal from present deposits, in prices of 2006/2007, according to Ritschel and Schiffer (2007) were between 5.5 and 10.3 US dollars/boe, which in prices of 2009 is ca. 6 to 11 US dollars/boe or, on average, ca. 8 US dollars/boe. The production costs calculated by the IEA (2009) are of a similar order of magnitude. Adjusted approximately for the haulage costs contained in these numbers, production costs of 7.2 US dollars/boe result; this number also includes the production costs of export-relevant mines in China and the United States, in contrast to Ritschel and Schiffer (2007). Following Remme, Blesl and Fahl (2007), production costs for steam coal of 8.5 US dollars/boe for the current production can be derived; for future production they indicate costs of about 13.5 US dollars/boe.

Currently approximately 5.6 Gt coal is produced per annum at an average cost of about 8 US dollars/boe. Production costs for additional black coal will increase to a relatively small extent in the coming decades (International Energy Agency 2010). The costs for the development and production of the first 100 Gt of the global coal reserves amount to between 5 and 25 US dollars/boe, according to current estimates. For the next 500 Gt, production costs are estimated to fall in a range of 8 to 40 US dollars/boe. During the production of the last 110 Gt of the known reserves, a strong increase in costs is likely, the estimates ranging between 13 and 123 US dollars/boe. These coal reserves together would enable the present annual output to continue for a period of more than 120 years. Table 3 shows the production costs for steam coal from currently used deposits and for the mined amounts in the period up to about 2030. In contrast to the average values in Table 3, the share of production costs of coal in the average price of steam coal is currently between 28 percent and 61 percent.

That the conditions for an expansion of the worldwide coal supply are quite favourably can be seen in the 2009 IEA report. An expansion of coal consumption of around 1.9 percent per annum between 2007 and 2030 would require investments – in prices of 2008 – of 661 billion US dollars. The demand for oil and gas in these years will increase less strongly, but will require total investments of 5,919 billion and 5,149 billion US dollars, respectively. Thus it would not be surprising if the share of coal in the total worldwide energy supply increased disproportionately on a long-term basis and if mineral oil and natural gas is used even more strongly in areas, e.g. fuel for transport, in which they have comparative advantages. Currently the use of coal is increasing strongly in Asia, in particular in China. However, the comparably high carbon dioxide emissions connected with coal argue against the increasing use of this source of energy. Since carbon dioxide is regarded as the primary cause of the worldwide climate change, the increasing used of coal can only be regarded as responsible if it is done with high combustion efficiency or if the sequestration of emissions prevents the carbon dioxide from entering the biosphere.

Table 3
Production costs for steam coal and share of production costs in the coal price (in 2009 prices)

	Ritschel und Schiffer	Remme, Blesl and Fahl	IEA (2009)/Ifo[a)]	IEA[b)]
Coal production costs for current deposits in USD/boe	7.9	8.5	7.2	8.2
Coal production costs for future deposits in USD/boe		11.5		10.0
Percentage of production costs in total coal price[c)] for current deposits	44	47	40	46
Percentage of production costs in total coal price[b)] for future deposits		64		56

[a)] IEA (2009); selected countries. – [b)] IEA (2010) (expected), up to 100 Gt. – [c)] Coal prices between 2005 and 2009.

Source: Listed studies; Ifo Institute.

Conclusion

In light of the great differences in extraction and the qualitative differences of energy resources from the individual deposits, the determination of average production costs for the total production of an energy source can only be understood as an approximation of actual costs. Table 4 contains the average values of present and future production costs for crude

Table 4
Production costs for energy sources and share of production costs in the price of the energy source (in 2009 prices)

	Oil	Gas	Steam coal
Average production costs for current deposits in USD/boe	11.4	6.8	8.0
Average production costs for future deposits in USD/boe	16.0	11.6	10.0
Percentage of production costs in the total price of the energy source for current deposits	17	16	45
Percentage of production costs in the total price of the energy course for future deposits	23	27	56

Source: Listed studies; Ifo Institute.

oil, natural gas and steam coal, expressed in each case in barrels of oil or oil equivalent, as well as the respective share of the average production costs in the average energy source prices for 2005 to 2009.

For crude oil there are similarly clear circumstances, since world market prices exist for the different oil qualities. For 2009 average production costs crude oil of ca. 11.4 US dollars/bbl were determined. This corresponds to a 17-percent share in the average oil price of 2005 to 2009 of ca. 69 US dollars/bbl. The production costs for oil that will be produced in the period up to 2030 is likely to amount to 16 US dollars/bbl in 2009 prices, on average.

With regard to natural gas, the situation is somewhat less clear especially because of the existence of several regional markets. The weighted average production costs of natural gas amounted to 7 US dollars/boe in 2009. With an average natural gas price of ca. 42.5 US dollars/boe, a ca. 16-percent share of production costs can be calculated. For natural gas provided in the period up to about 2030, production costs will probably amount to 11 to 12 US dollars/boe, in 2009 prices.

The production costs for steam coal refer only to the conditions in the most important exporting countries. For 2009 and based on available studies, current costs of ca. 8 US dollars/boe can be calculated. Based on the current average price of steam coal of ca. 18 US dollars/boe, this amounts to a 45-percent share of production costs, whereby the great differences among the providers must be kept in mind. The future production costs for steam coal will increase at a comparably lower pace and will probably be of an order of magnitude of 10 US dollars/boe in the period up to 2030.

References

Aguilera, R.F., R.G. Eggert, G. Lagos C.C. and J.E. Tilton (2009), "Depletion and the Future Availability of Petroleum Resources", *The Energy Journal* 30, 141–174.

Deutsche Bank (2009), *The Cost of Producing Oil,* London: Deutsche Bank Global Markets Research.

Deutsche Bundesbank (2001), "Realzinsen: Entwicklung und Determinanten", *Monatsbericht* Juli, 33–50.

Dresdner Kleinwort (2006), *Russian Oil and Gas: Key Trends and Investment Opportunities*, November.

Energy Information Administration (2009), *Performance Profiles of Major Energy Producers 2008,* http://www.eia.doe.gov/emeu/perfpro/0206(08).pdf.

ExxonMobil (2009), *Oeldorado*, http://www.exxonmobil.de/unternehmen/service/publikationen/downloads/files/oeldorado09_de.pdf.

Goldman Sachs (2008), *Global: Energy, 190 Projects to Change the World,* London.

International Energy Agency (2003), *World Energy Investment Outlook 2003,* Paris.

International Energy Agency (2005), *Resources to Reserves, Oil & Gas Technologies for the Energy Markets of the Future,* Paris.

International Energy Agency (2008), *World Energy Outlook 2008,* Paris.

International Energy Agency (2009), *World Energy Outlook 2009,* Paris.

International Energy Agency (2010), *Resources to Reserves*, forthcoming.

Jojahrt, C. (2008), *The End of Easy Oil: Estimating Average Production Costs for Oil Fields around the World,* Working Paper 72, Program on Energy and Sustainable Development, Stanford University.

OPEC (2009), *World Oil Outlook 2009*, Vienna.

Remme, U., M. Blesl and U. Fahl (2007), *Global Resources and Energy Trade: An Overview for Coal, Natural Gas, Oil and Uranium,* IER-Forschungsbericht 101, Universität Stuttgart, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Stuttgart.

Ritschel, W. and H.W. Schiffer (2007), *Weltmarkt für Steinkohle,* Essen-Köln: RWE Power.

Schulz, W. (1984a), "Die langfristige Kostenentwicklung der Steinkohle am Weltmarkt (Teil I)", *Zeitschrift für Energiewirtschaft* March, 8–20.

Schulz, W. (1984b), "Die langfristige Kostenentwicklung der Steinkohle am Weltmarkt (Teil II)", *Zeitschrift für Energiewirtschaft* June, 108–117.

United States Geological Survey (2000), *World Petroleum Assessment,* Washington DC.