“Value-at-Risk of Resource Scarcity - The Example of Oil”

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Value-at-Risk of Resource Scarcity – The Example of Oil

Timo Busch

Abstract

The actual discussion about high oil prices is seen as a temporary issue and thus not incorporated in a long-term risk perspective; but it should be, as natural resource scarcity is a crucial economic factor. In practical experience, more and more banks, insurance companies as well as investors realize that there are certain areas with a high correlation between sustainable development and corporate success, corporate risk exposure and corporate performance.

Environmental risk assessments in general so far have mainly emphasized – if at all – actual and possible impacts of the release of materials or emissions (external effects). But as all resources are limited, the risk of scarcity will rise. Indeed, scarcity is not tangible for all kinds of resources from a present point of view. Hence, a comprehensive and specified analysis is needed considering different market and supply conditions.

This paper illustrates the scarcity risk of the oil resource. Therefore, in terms of developing a practically oriented tool, the Value-at-Risk approach and its application to measure risks derived from oil scarcity are scrutinized. The conclusion is: once markets have acknowledged the depletion mid-point as a measure of oil scarcity, natural scarcity will result in a significant higher Value-at-Risk. The Value-at-Risk of one barrel of crude oil could then be as high as USD 15.5 in the short term and even USD 17.2 in the long term. Finally recommendations with a focus on strategic management decisions and financial performance analysis are given.

Key words: Risk assessment, oil scarcity, resource depletion, implications on financial markets, risk management.

1. Introduction

Environmental risk assessments so far in general have emphasized the possible impacts of the release of materials or emissions of a system. An overall risk assessment has also to take into account the risks related to the inflow of materials as well. The understanding of environmental risk assessment needs to be extended, as it was done in the context of corporate environmental management systems. Until the early 90's there was a clear focus on end-of-pipe technologies; with the upcoming discussion of eco-efficiency the focus switched to more comprehensive approaches such as integrated product policy or life cycle analysis.

The topic resource scarcity is not included in both, the discussion of sustainability and the risk assessment tools. But from an economic perspective the latter has to be considered: Once scarcity is on the rise and traders anticipate it, markets are going to react and price the risks. Companies' operations are determined and influenced by input factors; financial calculations and investment decisions are based on predictions and assumptions due to future price and availability conditions. If markets anticipate increasing resource scarcity, this will result in a tangible risk factor; and this needs to be incorporated in the analysis of corporations' profitability. The crucial question is whether this risk will emerge slightly or suddenly and prices will increase slowly or exponentially? Thus, the idea of this paper is to develop a sustainable risk management tool that takes into consideration the possible negative financial impacts of natural given oil scarcity. The latter is defined as scarcity risks derived from limited resources due to exploitation and restricted access[1].

Section two elaborates on oil as a risk factor due to it's predictable scarcity. In section three the Value-at-Risk (VaR) concept is presented as a tool for assessing oil scarcity. The oil price and the volatility are the main variables of the VaR function. These variables are explained for crude oil and linked with the VaR approach. In section four, different scenarios are developed

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[1] WRI 2002, p. 26.

based on existing forecasts and calculations. These scenarios cover different oil price estimations and show how the VaR of oil could develop. Finally, section five sums up the main findings and presents possible ways of integrating the developed tool into corporate and financial market risk management.

2. Risks of oil as an input factor

Oil can be defined as a "private exhaustible natural resource"[1] as it is in private ownership and not a public good. The existing stock can never increase, hence the supply is fixed and it is provided by nature[2]. World oil production increased to 78.6 million barrels a day in July 2003[3]. Up to now, world oil consumption has increased by 11.6% since 1992 and is likely to increase further[4]. The consumption in Asia (including China and Japan) even increased by 26.9% over the same period. Worldwide consumption of oil exceeds USD 500 billion and oil is the world's most actively traded commodity, accounting for about 10% of total world trade[5].

Oil's multiple applications in today's economy range from the source for different kinds of energy to the basic input factor for numerous production processes. Thus, it covers a wide range of economic sectors, which increases the universality of the topic. The importance does not only derive from the size of the market, but also from its strategic role for oil importing and exporting countries. Recent developments on the resource markets have already urged experts to warn for negative economic effects due to increasing prices; the supply of crude oil, increasing demand and the resulting oil prices are one major issue[6].

The particular characteristics of the oil market and economy's dependency on oil as an input factor create a highly complex and unpredictable environment. However, unless it is not possible to uncouple GDP-growth from oil consumption, higher economic growth will result in increased demand for oil. It can be presumed that this development will be reinforced by accelerated economic growth in emerging markets. If there is no significant action taken towards matching future demand and supply, this will end up in shortages and "shortages mean scarcity and higher prices"[7].

This environment bears immense risks for single companies and entire value chain as well as for actors in financial markets investing in this business sectors. The derived risk for business became evident in 1999, when Shell's operations in Nigeria were able to produce only 25% of capacity due to national and international protest movements and sabotage from local community[8]. Obviously, for many companies unstable oil prices already present a severe risk.[9] As a result, companies (not only petrochemical firms) engaged in risk management activities to protect their corporations from volatile input prices. This is indicated by the climb in trading volume of New York Mercantile Exchange (NYMEX)[10] crude oil future contracts. The annual trading volumes of No. 2 heating oil future contracts[11] grew from 25,910 in 1978 to 9.6 million in 2000[12]. And this development seems to continue because oil prices become more sensitive to rumors and misinformation. As there is an increasing need for accurate risk management, a comprehensive model for risk quantification is required. Estimations and calculations of future oil price volatilities are essential, not only for the derivative markets, but also for companies' budget planning.

In general, scarcity risks due to oil can be described in two dimensions: (1) In the short-run price fluctuations affect the delivery and distribution of oil and can thus interrupt or disturb single production processes. Ensuing supply delays or reduced production capacities result in higher costs from increased risk management activities or contract penalties. (2) In the long-run

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[1] Stiglitz (1979, p. 55).
[2] Stiglitz (1979, p. 37).
[3] BP (2003).
[4] IEA (2003).
[5] Sharma (2002, p. 3).
[6] Rettberg (2004a) and Rettberg (2004b).
[7] Campbell (1997, p. 81).
[8] Shell (2001).
[9] Fishhaut (2003).
[10] http//www.nymex.com.
[11] Heating oil futures are commodity futures, which are used in order to hedge price risks.
[12] EIA (2002, pp. 23-24).

uncertainty about future production conditions due to higher oil prices and increased volatility impede accurate and reliable investment planning for both managers and investors. Actual costs might increase the underlying calculations. Thus, expenditures for future investment projects cannot be calculated in an exact manner. It is more likely that expected returns on investments cannot be realized and therefore entire projects or investments are canceled or not conducted. Both, the short and long term risks related to oil scarcity can be derived from the availability and the oil price.

Risks of oil availability encompass all sources that could possibly irritate or prevent the needed – i.e. demanded – oil supply[1]. This paper primarily considers the risk of availability due to restrictions by nature. In the context of the scenarios options for substitutions, change of technology, and alternative inputs are discussed but not incorporated in detail. The following other possible restrictions are not contemplated in an explicit way and therefore considered to be constant:

- Taxes, levies and other government related measures
- Change of consumer preferences
- Political developments, especially in oil delivering countries

2.1. Oil endowment

The world's endowment with oil is structured into *reserves* and *resources*. Campbell (1997) refers to *reserves* as the amounts of petroleum that are estimated to be recoverable from a known petroleum accumulation as of a stated reference date on certain or implied economic and technological assumptions. Normally reserves describe the current or foreseen overall extractions of a field at the reference date. Another general accepted definition refers to reserves as the known amounts of a mineral that can be profitably recovered at current prices – for the mineral and the inputs used in extracting and processing it[2]. One common definition of *resources* is: resources cover a deposit as a whole; the quantity, which is already located for exploitation, is then defined as *reserves*[3].

The cumulative production is the total amount of oil produced in an area. The cumulative production worldwide, included all technical possible explorations over the time, is referred to as *ultimate recovery*. The figures of estimated ultimate recovery build the basis for world oil outlooks.

Table 2.1

Estimations on reserves, resources and ultimate recovery (bill. barrels)

Editor	Reserves	Resources	Estimated ultimate recovery
Int. Energy Agency (2002)	959	939	1898
BP Amoco (2002)	1047	-	-
Hubbert Centre (2002)	900	150	1050
ODAC (2000)	996	144	1140
United States Geological Survey (2001)			2568

2.2. Future oil supply

Hubbert explained oil discovery and production both form a bell-shaped curve over time, known as the Hubbert-curve. The production rate as a function of time starts at zero. After it has reached a peak it declines back again to zero. The area beneath the curve shows the graphical measurement for the cumulative production. The Hubbert-curve illustrates that the decline in oil production flattens by time. Hence, the question about the ultimate *last barrel* is less important and not much of practical use in the context of this survey. In light of scarcity it is important when the peak of the Hubbert-curve is reached and the cumulative production cannot be further increased. This peak is defined as *depletion mid-point.* At the depletion mid-point about half of the oil-field's, country's or world's reserves have been produced. In theory, peak production and the de-

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[1] Ströbele (1996, p. 347).

[2] Schanz (1976).

[3] Campbell (1997, p. 70).

pletion mid-point should coincide. But through technical interference or quota regulation production can be held up (or even increased) artificially for a few years.

Table 2.2

Estimations on peak production and depletion mid-point

Editor	Peak production (year)	Peak production (tons/year)	Depletion mid-point (year)
Odell (1997)	2025	6,5 bill.	2016
Campbell (1997)	2008	3,3 bill.	2000
Edwards (1997)	2020	4,8 bill.	2015
Hiller (1997)	2017	4,4 bill.	2013
ODAC (2001)			2005
L-B Systemtechnik GmbH (2000)	2005		

Source: Bundesanstalt für Geowissenschaften und Rohstoffe (2000) and L-B Systemtechnik GmbH (2000).

2.3. Future oil demand

Considering the future oil demand several factors have to be distinguished that determine the scope of demand:

- Development of the oil price
- Technological know-how, opportunities of substitution, alternative input factors
- Energy and supply structure
- Growth in GDP
- Political and social developments

These factors have to be considered for investigating the question how oil prizes are stimulated by the demand site. One forecast provides the following picture:

Table 2.3

Oil consumption prospects per capita, kg oil/year

Reference scenario	2000	2010	2020
Developing Countries	560	670	800
Transition Countries	2925	3590	4160
OECD Countries	4800	5200	5500
World Total	8285	9460	10460

Source: The Danish Board of Technology (2003).

In the short run the price elasticity of oil can be seen as quite low, as the substitution of assets using oil as input factor is time consuming and requires financial resources. Until now today's world economy is technologically unprepared for substituting oil as an input factor[1]. But in the long run the development of new, oil-independent technologies and the use of alternative energy sources are inevitable; the figures on oil endowment and future supply illustrate that the supply cannot match the demand in a sustainable way.

2.4. Oil scarcity is predictable

First of all, it has to be stated that it is difficult to analyze precisely physical oil conditions due to the uncertainty related to location, extent, and quality of deposits[2]. Furthermore, it is not easy – or almost impossible – to foresee the aforementioned restrictions in a precise manner.

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[1] The Danish Board of Technology (2003, p. 73).

[2] Fisher (1977).

Nevertheless, oil is one of the most tangible examples for a finite resource; there is general consensus that oil scarcity emerges sooner or later after oil production has peaked and demand for oil cannot be met. The question therefore is, when will the peak be reached and when can the demand not be met any longer? The amount of oil in newly discovered fields has been decreasing for the last four decades; and for the last two decades the discovery rate is smaller than the rate of oil production[1]. This could indicate that the downgrading has already started and the ensuring consequences have to be faced: "Depleting finite stocks of fossil fuels closes our future options in a way that depreciating a capital stock does not, in that the former is irreversible while the latter is not"[2]. In order to grasp this topic from a risk management perspective, the further focus is on the Value-at-Risk model.

3. Value-at-Risk of oil

For an effective risk management the impact of oil scarcity needs to be quantified in a figure and observed over time. Capital market models can be harnessed for modeling potential effects and transferring historical data into a new model. The Value-at-Risk (VaR) approach was developed for portfolio managers and analysts; the results express risk quantifications in monetary units[3]. This section focuses on the variables of the VaR method and how this model can be applied to the scarcity risk of oil. Thus, this risk is not defined and scrutinized as a single risk of increasing prices but also as a risk of uncertainty and volatile markets. This approach is based on Cabedo and Moya (2003), who suggest that the VaR approach is directly applicable to oil prices. The VaR can be defined as the product of the underlying's spot price, it's volatility, and the z-value. The z-value is a discretionary variable, hence the two missing variables to calculate the VaR of oil, are the *future oil price* and its *volatility*.

3.1. The VaR Model

Value-at-Risk measures the maximum potential loss in the value of a portfolio of financial instruments with a given probability. A typical VaR model will put a figure on the chances of losing no more than a certain amount of money over a defined time period. From a statistical point of view, VaR can be defined as a biased confidence interval. Jorion (2000) refers to the VaR as "the maximum amount one can expect to lose of a given position during a given period (the potential close out period) with a predefined probability."

In general VaR consists of a measurement for volatility, the distribution of the underlying yield and an evaluation model[4]. Based on that, Fallon (1996) derived

$$\mathrm{Prob}[\Delta P(\Delta t, \Delta x) > -\mathrm{VaR}] = 1 - \alpha \tag{3.1}$$

for the VaR as a one-sided confidence interval. Within a given period the value of a portfolio ΔP depends on the forecast horizon Δt and the vector Δx changes in risk factors. The confidence variable α has to be determined and depends on the risk tolerance of the portfolio manager. Normally the value ranges between 1% and 10%[5]. The choice of the confidence level is discretionary and differs across institutions[6]. The VaR formula is derived as

$$VaR = S_0\, Z(\alpha)\, \sigma_s, \tag{3.2}$$

where

S_0 is the underlying,

$Z(\alpha)$ is the z-value of the normal distribution,

σ_s is the volatility of the underlying.

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[1] L-B-Systemtechnik GmbH (2000).

[2] Fisher (1977).

[3] Cabedo/Moya (2003, p. 2).

[4] Dockner/Harold (1997, p. 1).

[5] Fallon (1996, p. 2).

[6] JP Morgan/Reuters (1996, p. 6).

VaR can be calculated for different time periods; this depends on the volatility intervals. For example to calculate the one-month VaR of an underlying, the average monthly volatility needs to be determined. Under the assumption that the return of the underlying S is normally distributed and the confidence level is 95% Dockner and Harold define the VaR as

$$VaR = S_0\, 1{,}65\, \sigma_{s,}, \tag{3.3}$$

where σ_s describes the volatility and the z-value of 1,65 the quartile of the standard distribution. Figure 4.1 shows the distribution curve of different returns r_t/σ_t. Under the assumption that r_t/σ_t are normally distributed and the confidence level is determined at 95%, there is a 5% chance that within the forecast horizon Δt the loss of the portfolio value ΔP will be higher than the VaR.

However, the VaR model has three critical points[1]: (1) Assessments assume that the returns conform to a particular pattern. Risk managers define their confidence in a certain outcome, but the patterns of financial markets can never be considered as certain. (2) There is always the possibility of “fat tails”. Even so a likely risk is predicted, there is always the option that this chance suddenly increases (e.g. by new or not encompassed factors). (3) Furthermore, the model relies on ex post data and assumes that markets will continue to develop similarly in future. But as covariances are mostly not stable, markets are likely to adhere to this role as well as to go in the opposite direction. These three points are more crucial on daily assessments on capital markets than in this survey. Although, it has to be kept in mind that VaR is a mathematical model with its advantages in quantifying risks as well as disadvantages of statistical errors.

3.2. The oil price

The world oil market is a capital-intensive environment influenced by multiple interactions deriving from the wide variety of products, transportation/storage issues and environmental regulations[2]. According to Adelmann (1992) there are three assumptions about the oil price:

- The current price is the long-run competitive price, plus an error in estimation.
- Due to inevitable scarcity the long-run competitive price must rise.
- The price does not mirror oil scarcity and is determined by cartels (e.g. OPEC).

Applying the Hotelling-rule, oil fields are exploited in order of their extraction costs. Under the assumptions of efficient markets, increasing prices would reflect oil scarcity and eventually determine supply and demand. Reynolds (1999) and Antonelli (1997) suggest that resource markets do not work efficiently due to uncertainty and market failures. Based on these assumptions and economic theories, the question rises whether a rule or common pattern can be identified, which is able to explain the actual development of the oil price.

In the long-term view the average crude oil price adjusted for inflation has been 18.63 USD/barrel since 1869[3]. During the period of 1947-1997 the average oil price was 19.27 USD/barrel[4]. These figures indicate a general increase; this is mainly caused due to three oil price shocks that took place in the latter period:

- The oil embargo of 1973, where several Arab states proclaimed an embargo on oil exports.
- The events surrounding the Iranian Revolution and the overthrow of the Shah-regime in 1979, followed by the beginning of the Iran-Iraq war in 1980.
- The invasion of Kuwait by Iraq and the resulting second Gulf war in 1990.

Besides political crisis, the oil price was also influenced by events such as natural disasters, strikes, boycotts or accidents. A further important factor is OPEC, which was founded in 1960. The purpose was to stabilize prices by setting production quotas. The interactions between all these factors create a complex and often uncertain situation on the oil market. In order to reduce

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[1] The Economist (2004, p. 11).

[2] Sharma (1998, p. 2).

[3] http://www.wtrg.com.

[4] Sharma (1998, p. 2).

this uncertainty, the OPEC introduced a price band mechanism in 2000. This so-called target zone model[1] intends to keep the price of a barrel of crude oil within a USD 22 to USD 28 band.

In theory, the oil price is a function of the sum of: OPEC members' assigned quotas, the cumulative inventory shock at a given time, and the speed the market adjusts to output changes[2]. In practice, two main factors determine the oil price, in the case of the price approaches the upper or lower limit of the price band: an actual intervention of OPEC or the expectations of speculators that OPEC is going to intervene. As long as markets consider OPEC as reliable, this instrument seems to work. But one disadvantage remains; the chance of higher volatility increases, once the price approaches the price band.

Future oil price scenarios apply different depletion theories and diverse estimations on ultimate recovery. Referring to Adelman, in the long term the price must rise in any case because oil is a non-renewable resource[3]. This is in accordance with the majority of the considered forecasts. In the context of this survey, it was neither intended to generate an own estimation nor to comment existing results.

Table 3.1

Overview of nominal oil price estimations (in USD/barrel)

Author	2005	2010	2015	2020	2025
EIA (Energy Information Agency), 2003 – Reference	23,27	23,99	24,72	25,48	26,57
EIA (Energy Information Agency), 2003 – High Price	28,65	32,51	32,95	33,02	33,05
EIA (Energy Information Agency), 2003 – Low Price	22,04	19,04	19,04	19,04	19,04
Altos Partners, World Oil model (2002)	22,64	23,4	25,58	27,9	31,61
IEA, International Energy Agency (2003)	21,47	21,47	23,52	25,56	27,61
DBAB, Deutsche Bank Alex Brown Inc. (2003)	19,04	18,94	19,34	19,07	19,18
OPEC, Oil outlook 2002, Reference	20,6	19,7	19,7	19,7	
OPEC, Oil outlook 2002, High Price	31,3	31,3	31,3	31,3	
OPEC, Oil outlook 2002, Low Price	11,8	11,8	11,8	11,8	
Horn, (2002) EIA-oil production, Reference case	27,7	28,5	29,3	30,1	
Horn, (2002) Gompertz-oil production, Reference case	39,9	41,1	42,2	43,3	

The wide range of price estimations indicates the uncertainty about this issue. Massarrat extends this even further; he argues that the real scarcity price should range between USD 30 and 70[4]. These figures are based on the oil price jumps in 1974 and 1979 in real terms[5].

A huge pool of factors influences the oil price creating a high complex system. Different theories attempt to describe and explain this complexity, but at the present moment there is no approach that can accurately determinate the development of the oil price. Ströbele (1996) suggests that the development of oil markets from the 1950's to 1973 and the rapid increase in the oil price in 1973-1974 can be described by the Hotelling-rule; and the development after 1974 is better described by game theory approaches.

The forecasts on future oil prices show a diverse picture: According to the different estimations, the price for one barrel of crude oil could be in the range of USD 19.07 and 43.3 in 2020. This is roughly in the range of OPEC's target zone model of USD 22 to 28. However, none of the aforementioned approaches considers the aspect of a scarcity shock and the corresponding reactions on markets.

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[1] Krugman (1991).

[2] Tang/Hammoudeh (2002, pp. 579-582).

[3] Adelman (1992, p. 269).

[4] Massarrat (2000, p. 6).

[5] Massarrat (2000, p. 4).

3.3. Oil price volatility

Volatility summarizes price changes over time in a single number, whereby the individual definition of volatility mainly depends on the user's time span. Volatile input prices make it difficult to plan accurately future investments, for both companies and investors. The oil market is characterized by a high level of volatility. According to an empirical study by Sadorsky (1999), that scrutinizes oil price volatility and economic impacts, volatility shocks have asymmetric effects on the activity of the economy.

Under closer examination, the volatility of oil price shows the specific statistical feature of *volatility clustering*. The volatility clustering implies current volatility shocks influence expectation of future volatility[1]. Two main statistical features of the oil price result in a time-invariant structure[2]: heteroscedasticity and autocorrelation. Thus, the calculation of the simple standard deviation (as the square root of variance)[3] does not provide accurate results Engle (1982) introduced the autoregressive conditional heteroscedastic (ARCH) model. In this model the conditional variance is to be a determinant of the mean and the weightings are estimated from historical data[4]. The model has been extended by Bollerslev (1986) to the generalized ARCH (GARCH) models, which implies that volatility persistence is infinite and past volatility is significant in predicting future volatility.

Between 1860 and 1900 oil prices were very volatile due to the small size of the industry and related uncertainties[5]. With the foundation of the *Seven Sisters*[6] in 1928 the oil price became more stable. After 1973 OPEC stabilized the price (except for the oil price shocks in 1973/1974 and 1978/1979). After 1981 the price freely fluctuated on the market. During the early 1990s huge increases and decreases could be observed due to the first Gulf war. In general, oil prices have become more volatile since 1986[7].

The main reasons for oil price volatility are information uncertainty about markets and unexpected events from endogenous and exogenous drivers. According to Lynch (2002) endogenous reasons for increasing volatility can be divided in: (1) a decline in the surplus capacity of the petroleum industry, (2) product regulations and price microbursts, and (3) behavioral changes in demanded inventories and industries' inventory levels. Exogenous reasons for increasing volatility can be[8]: (1) Data uncertainty and unpredictability: there is uncertainty about short-term forecast in variables affecting the oil price such as consumption or economic growth. Further the oil price is affected by a number of unpredictable variables (weather, wars). Both uncertainty and unpredictability create a false perception about future market development; and corrections of these errors cause price swings. (2) Speculations: speculators try to profit from the volatile prices by exploiting arbitrage opportunities and hence distorting the market. (3) Transparency: although there is an increase in information flow of data, data on oil consumption or production are hard to obtain and unreliable.

3.4. Pricing of scarcity and implied volatility

So far, oil markets have priced man-made scarcity; significant price movements have been determined by *artificial scarcity* due to political conflicts, economic interventions, or supply restrictions. The market has not acknowledged *natural scarcity* yet; prices do not reflect this risk factor[9]. Even so new information about exhaustion has been published; actors in markets still react in the same manner as usual. However, the seriousness of oil scarcity exists and is scientifically proven. The actual market development obviously draws an incorrect picture due to ongoing path-dependencies. According to Reynolds' model this type of market failure and information ineffi-

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[1] Kuper (2002).

[2] Granger/Machina (2002).

[3] Fahrmeier et al. (1999, pp. 246-250).

[4] Dockner/Harold (1997, p. 6).

[5] Lynch (2002, p. 5).

[6] Cartel of seven oil companies consisting of EXXON, MOBIL, SOCAL, Texaco, Shell, BP, and Gulf.

[7] Lynch (2002).

[8] Lynch (2002).

[9] Massarat (2000, p. 2).

ciency can result in a sudden price increase, unpredicted shortages, and high market uncertainty. The economic and financial risks resulting from such an abrupt allocation problem are enormous, for both single companies as well as the world economy.

Therefore, existing management systems and risk assessments need to be extended, especially in order to reflect risks in a long-term horizon. But it is not able to identify ex post significant relations between increasing natural scarcity and market behavior, neither in terms of oil prices nor volatility. A lack of empirical data exists for simulating possible future scenarios. Therefore, the further focus is on generating implied volatilities that consider single events in the past, where man-made scarcity has emerged. The scenarios in the next section assume future oil markets to react on increasing *natural* scarcity in a similar way as they did on *artificial* scarcity in the past.

4. Scenarios

A broad spectrum of different socio-economic, political as well as ecological factors has an impact on the supply, the demand, and the derived price and volatility of oil. Precise forecasts seem to be almost impossible due to the resulting complexity. Scenarios can produce a number of possible futures within a given horizon, by focusing on distinct factors and generating a spectrum of plausible outcomes. The scenarios in this section illustrate potential developments of the VaR of one barrel crude oil due to natural scarcity.

4.1. Modeling the Scenarios

The scenarios are applied under the assumption of markets acknowledging the depletion mid-point in 2005. Therefore it is presumed, that once it is statistically and scientifically proven that the depletion mid-point is reached, markets will realize this and participants will adjust their decision making processes similar to past incidents when scarcities occurred. Estimations on other possible depletion mid-points do not reveal any considerable new insights, as based on the assumptions of the model only the pertaining four price forecasts would vary negligibly. In the end the calculation results do not differ significantly, only the date of occurrence is postponed.

Two basic scenarios are designed on empirical data in order to reflect the period after the occurrence of the depletion mid-point. The scarcity scenarios are based on two 21-month periods on the oil market taken from historical market developments. These periods are characterized by a sudden shortage in oil due to political events, increasing uncertainty, and panic reactions. The developments of the oil price and its volatility during these periods are applied to reflect market reactions for a possible mid depletion situation. By taking a 21-month period not only the short-term reactions of the market but also the following “normalization” process of the price can be observed. In the scenarios, the depletion mid-point occurs at a fixed point in time, without any distinct preceding warning. This assumption corresponds to Reynolds (1999) who states that a severe increase in prices is possible even after decades of falling prices. Furthermore, according to scenarios presented at the Copenhagen Conference on “Oil Demand, Production and Cost – Prospects for the Future” in 2003, a sudden steep drop in oil supply combined with a growing demand is considered to be a realistic option for future developments[1].

With the follow up scenarios the basic versions are extended to three additional price developments. Per definition these additional developments include the following 39 months, in the end this results in a five-year scenario. To extend the scenarios beyond this time frame does not seem to provide realistic and useful results. Furthermore, the purpose is to describe potential market reactions in a rather short term, after natural scarcity is acknowledged.

These extended scenarios are based neither on historical data nor on official estimations. It is assumed that after markets accept the existence of the depletion mid-point they will act and counteract as described in the basic scenarios S_1 and S_2. In this relatively short time range, actors on markets have different short-term options and strategies for matching demand and supply. After this period the latitude of markets decreases and more exogenous long-term factors have to be

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[1] The Danish Board of Technology (2003).

taken into consideration for determining prices. Hence, the follow-up scenarios are trends representing certain constant price developments. The implied volatility is assumed to be constant for the 39 months of the follow up scenarios.

A backstop price has to be defined, where alternative technologies, substitute fuels, or new exploration areas and methods become economically viable. Per definition the maximum price shall not exceed 70 USD/barrel. This corresponds to the oil price leap in real terms, after OPEC cut the oil supply in 1979[1]. The extended scenarios define a linear, regressive and an exponential course of prices towards the backstop price, whereby:

a) The linear trend assumes the same monthly price-increase remains as calculated in the basic scenarios.
b) The regressive trend assumes a diminishing monthly price increase. After the first 21 month the scarcity shock is received as being less and less relevant. Markets slide into a new kind of path-dependency: a high price level remains and the price increases in a diminishing trend.
c) The exponential trend assumes that the effects of scarcity accelerate over time. The market price increases exponentially.

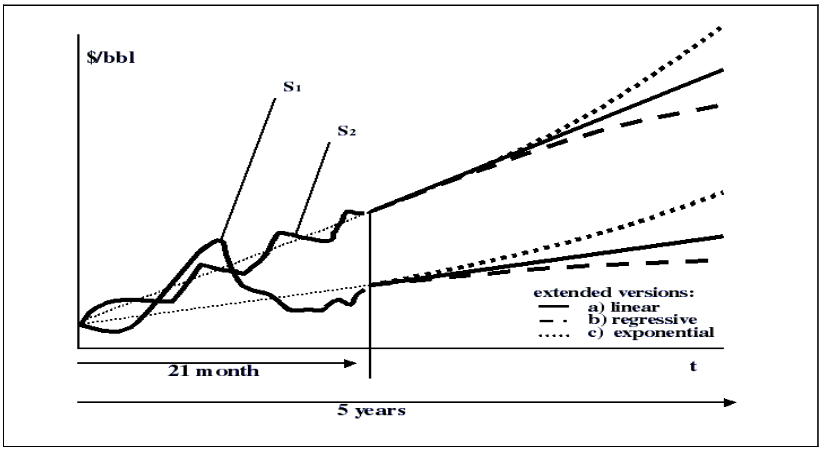

Fig. 4.1. Modeling the basic and extended scenarios

4.2. Determining the basic scenarios' variables

Based on the World Oil Market and Oil Price Chronologies 1971-2002 historical oil price movements have been scanned for incidents, where scarcity occurred for different reasons, such as oil productions cut backs or political crisis. Two 21-month periods are chosen to reflect potential oil price movements in the scenarios:

- Period 1: January 1990 – September 1991 – historical base for scenario S1
- Period 2: January 1999 – September 2000 – historical base for scenario S2

The underlying prices for the scenarios are taken from two estimations by the Energy Information Agency (2002). These scenarios are chosen due to the similarity of the results of the OPEC oil outlook (2002).

As the EIA-estimations assume that the OPEC is not completely exhausting its scope of prices[2], Horn's scenarios are based on the assumption of profit maximization by OPEC. Horn's reference case scenario represents an optimistic view of world's oil endowment, while the second scenario estimates world's ultimate recovery with the Gompertz-curve[3].

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[1] Massarat (2000, p. 4).
[2] Horn (2002, p. 108).
[3] In differentiation to the symmetric Hubbert-curve, the Gompertz-curve has an asymmetric shape.

Table 4.1

Price scenarios EIA

Author	2005
EIA (Energy Information Agency), 2003 – High Price	28,65
EIA (Energy Information Agency), 2003 – Low Price	22,04

Table 4.2

Price scenarios Horn

Author	2005
Horn, (2002) EIA-oil production, Reference case	27,7
Horn, (2002) Gompertz-oil production	39,9

The average volatility observed in the historical periods is adopted to generate implied volatilities. The log returns R_t of prices of the last trading day of the month are taken to calculate the average volatility on a monthly basis. Under the assumption of normal distribution of the log-normal returns and a constant variance, the volatility is described by the standard deviation. As tests have indicated, there is no sign of heteroscedasticity or autocorrelation in the standard deviation of the so defined volatility.

Table 4.3

Average volatility and price changes for 21-month period

Scenario	Average monthly volatility	Average monthly price increase
S1	18,02 %	0,037 %
S2	6,88 %	2,05 %

4.3. Determining the extended scenarios' variables

The two basic scenarios reflect the market's reaction in a temporary scarcity situation, where supply shocks are dampened to a certain extent by so called "buffers"[1]; national oil stocks of the industrialized countries are able to ease the effects of natural supply cuts. In the case of natural scarcity, these stocks are likely to dampen the supply shock for only a short time. For the scenarios it is assumed that this is the case within the first 21 months; afterwards, national oil stocks are not able to influence the market any longer. The supply is solely determined by other factors; the resulting market developments are described by the extended scenarios. The curves of the extended sub-scenarios are derived from the basic scenarios and combined with three different options for further development:

- The price in sub-scenario "a" increases linearly. After the first 21 months the trend has been calculated by applying a linear trend formula $p = c_{a-1} + (c_{a-2} * t)$, where p is the price in USD, c_{a-1} and c_{a-2} are coefficients and t reflects the time. The coefficients are derived from characteristic features and trends of the basic scenarios.
- Sub-scenario "b" applies a regressive trend based on a logarithmic trend formula $p = c_{b-1} + (c_{b-2} * LN\ t)$. Figure 6.4 illustrates the log-normal oil price changes from on a month-to-month level for scenario S_{1-b}.
- The price development in sub-scenario "c" is exponential. The underlying formula is $p = c_{c-1} * e\ (c_{c-2} * t)$.

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[1] Stiglitz (1992).

In the case of a price development in the extended scenario hits the backstop price of 70 USD/barrel, it is assumed that the price does not increase further and stops at this level for the rest of the considered time frame. As the implied volatility is hold constant in the extended scenarios, the VaR is then also constant.

4.4. Results

Tables 4.4 and 4.5 summarize the VaR simulation results for the 21-month period. The third column describes the VaR for the first month when markets have acknowledged the depletion mid-point. The ensuing two columns illustrated the minimum and the maximum VaR within the underlying 21-month period.

Table 4.4

Results of VaR – basic scenarios – in USD/barrel – EIA estimations

Scenario	EIA-estimation	VaR first month	Min. VaR within 21 months	Max. VaR within 21 months
S_1	Low	6,55	5,76	8,60
	high	8,51	7,49	11,16
S_2	Low	2,50	2,42	3,91
	high	3,25	3,15	5,08

Table 4.5

Results of VaR – basic scenarios – in USD/barrel – Horn estimations

Scenario	Horn-estimation	VaR first month	Min. VaR within 21 months	Max. VaR within 21 months
S_1	reference	8,23	7,23	10,79
	gompertz	11,86	10,43	15,55
S_2	reference	3,14	3,05	4,91
	gompertz	4,53	4,39	7,07

Example: Under the assumption that the depletion mid-point is reached in 2005, the possible VaR of one barrel crude oil can range between USD 2.5 and 11.86 once markets face the scarcity shock. If markets recover and path-dependency resumes, the VaR can afterwards drop back to a minimum level of USD 2.42 within the next 21 months. On the other hand the VaR can increase to a maximum level of USD 11.16 applying the EIA estimations and even USD 15.55 applying the Horn estimations.

The conclusions out of the simulations are, (1) the VaR is likely to increase steadily over time, once the depletion mid-point is acknowledged by the markets, (2) this is independent of the underlying price forecasts and market behavior, (3) the significant higher differences between the minimum and maximum VaR for all price assumptions in period two can be explained by the higher monthly growth rate of the oil price, (4) the relatively higher VaR for all scenarios of period one is linked to the underlying higher implied volatility.

Tables 4.6 and 4.7 summarize the VaR simulation results of the extended scenarios. In the columns the VaR of different time segments are calculated. A differentiated consideration of the minimum and maximum VaR is not appropriate for this diagram as constant developments are assumed over this time frame.

Table 4.6

Results of VaR – 5-year horizon – in USD/barrel – EIA estimations

Scenario	EIA-estimation	VaR after 30 months	VaR after 40 months	VaR after 50 months	VaR after 60 months
$S_{1\text{-}a}$	low	7,88	8,52	9,04	9,67
	high	9,15	9,75	10,26	10,77
$S_{1\text{-}b}$	low	6,65	6,71	6,75	6,79
	high	8,64	8,72	8,77	8,83
$S_{1\text{-}c}$	low	8,45	9,7	11,14	12,79
	high	9,63	10,6	11,76	13,24
$S_{2\text{-}a}$	low	4,38	4,98	5,57	6,16
	high	5,25	5,90	6,56	7,21
$S_{2\text{-}b}$	low	3,84	3,97	4,07	4,15
	high	5,22	5,40	5,54	5,62
$S_{2\text{-}c}$	low	4,62	5,58	6,73	7,95
	high	5,41	6,35	7,45	7,95

Table 4.7

Results of VaR – 5-year horizon – in USD/barrel – Horn estimations

Scenario	Horn-estimation	VaR after 30 months	Var after 40 months	VaR after 50 months	VaR after 60 months
$S_{1\text{-}a}$	reference	8,94	9,43	9,92	10,41
	gompertz	12,40	12,94	13,48	14,03
$S_{1\text{-}b}$	reference	8,35	8,43	8,49	8,53
	gompertz	12,04	12,14	12,23	12,29
$S_{1\text{-}c}$	reference	9,26	10,14	11,10	12,14
	gompertz	13,20	14,43	15,78	17,24
$S_{2\text{-}a}$	reference	5,18	5,82	6,47	7,12
	gompertz	7,40	7,95	7,95	7,95
$S_{2\text{-}b}$	reference	4,86	4,99	5,12	5,22
	gompertz	6,94	7,18	7,37	7,52
$S_{2\text{-}c}$	reference	5,3	6,19	7,23	7,95
	gompertz	7,62	7,95	7,95	7,95

Example: The most conservative scenario results in a VaR of USD 4.15, five years after markets have acknowledged the depletion mid-point. This value is based on the EIA low price estimations, the rather non-volatile market behavior, and an assumed return to path-dependency in the follow up scenario. On the other hand, the highest VaR result applying the exponential price developments in the follow up scenarios and the higher volatility of S_1. After five years, for the EIA high price estimation the VaR is then as high as USD 13.24; applying the Horn-Gompertz forecast the possible VaR reaches even USD 17.24.

The conclusions out of these extended simulations are, (1) based on the characteristic features and derived trends of the two scenarios S_1 and S_2 the VaR is likely to increase further for all underlying price forecasts within the considered five-year time frame, (2) for the development of the VaR over the time it is not important which initial price estimation the scenario is based on, (3) significant differences of VaR result mainly from the underlying price development and the implied volatility.

5. Summary and final conclusions

"Financial analysts and investors are recognizing that there is a strong, positive, and growing correlation between industrial companies' 'sustainability' performance and their competitiveness and financial performance"[1]. But for integrating sustainability factors into the measurement of return on investment or return on equity, quantitative data is needed. The Value-at-Risk approach is able to provide concise information in this matter. This paper illustrates how the VaR method can be applied in the context of risks derived from oil scarcity.

Even though the outcomes might not seem to be relevant for current economic activities, the recent discussion about oil prices affecting the global economy illustrates the future relevance of this topic[2]; it is just a matter of time before risks related to future oil supply and endowment will emerge. The scenarios show the potential risk exposure of crude oil; i.e. the VaR results give insight on the extension and quantity of the risk once markets have started to realize actuality of this new type of risk dimension. The VaR model illustrates how volatile input prices bare immense risks by increasing uncertainty. Thus, the scarcity risk is not defined and scrutinized as a single risk of increasing prices but also as a risk of uncertainty and volatile markets.

Empirical data are taken from two historical periods, when *artificial* scarcity occurred. The periods are harnessed to generate two different implied volatilities. In two basic scenarios the implied volatilities are used to anticipate possible future market behavior, when markets will acknowledge and therefore price *natural* scarcity. On the basis of four different price estimations two basic scenarios are generated for 21 months. The follow up scenarios describe a five-year time frame. They are based on the characteristic features of the two basic scenarios and assume three different market developments. The overall results present a spectrum of potential VaR that can be summed up as:

- The basic scenarios illustrate that the VaR might be as high as USD 2.4 up to 15.5 within the first 21 months.
- The follow up scenarios result in a VaR between USD 4.1 and 17.2 for the end of the five-year time frame.
- The scenarios are based on the assumption that the depletion mid-point will occur in 2005; presuming depletion mid-points at a later point in time do not alter the results in a significant way, only the date of occurrence is postponed.
- The results show that the VaR is likely to increase steadily over the time, once the depletion mid-point is reached and acknowledged by the markets. This is independent of the underlying price forecasts and market behavior.
- The different price estimations of the scenarios are not the crucial factor for the VaR development in the course of time. Significant differences in the development of the VaR result mainly from the actual price development and its volatility.

The final conclusion is, that once the depletion mid-point has been acknowledged by markets, natural oil scarcity will result in a higher VaR. This is the result of all scenarios, irregardless whether the underlying estimations are conservative or not. The outcomes illustrate possible developments under the assumption that markets will react similar to the two underlying historical periods. The definite course of the VaR cannot be predicted. But it can be stated that once markets have realized oil scarcity and react in a similar way, the market behavior will determine the level of VaR: As the actual prices will increase, the higher VaR is going to be; volatile oil prices as a result of uncertainty will foster this.

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[1] Innovest (2002, p. 25).

[2] Rettberg (2004a) and Rettberg (2004b).

5.1. Discussion of the results

The spectrum of oil depletion forecasts is huge and the results differ immensely; however, it is certain that sooner or later the world's oil-resources are going to be exhausted[1]. From an economic point of view, it is crucial to focus on the peak production rather than on the overall depletion. However, defining exactly when this peak is reached and forecasting market behavior are two different things. Even so statistics might be able to prove that oil reserves are situated at the downward part of the curve, specific industries, governments, or other influential actors will affirm their opinion and insist that there is no oil scarcity. This might influence the attitude and behavior of market's participants in a way that none of the forecasts turn out to be real for a next two decades and strong path-dependency remains. Furthermore, the amount of stored oil and the effects of buffers can steer the entire development in a totally different way, as they play a crucial role in the determination of market behavior. On the other hand, the current development in emerging markets points out that the world oil demand is going to increase significantly; therefore, future effects of path-dependency or buffers have to be questioned in general.

Nevertheless, focusing on the economic implications and impacts of oil scarcity, the imminent effects after the peak have to be considered. Possible outcomes are described by the basic scenarios (21-month period) and the extended scenarios (five years). Three main factors emerge: the price, its volatility, and the actual availability. In this paper the price and the volatility are considered in terms of market's reactions due to restrictions by nature. Change of technology, the option of alternative fuels and other substitutes are not considered in an explicit way; three different developments are assumed whereby single triggers are not discussed in detail. Other possible restrictions like taxes or political interventions and their effects are not contemplated.

According to Cabedo and Moya (2003) a volatile oil price environment requires an adequate risk assessment and quantification. The results of the scenarios illustrate that under the assumption of increasing scarcity the VaR of oil increases significantly. This entails rising uncertainty on markets and increasing potential financial losses related to investments in oil sensitive sectors. In this context it has to be questioned whether the VaR approach provides adequate assessments and concise quantifications. Although there is a relatively high significance of the developed scarcity variables, the weaknesses of the approach need to be considered: drawbacks emerge due to the assumption of fixed patterns on markets, the existence of fat tails, and the reliance on ex post data. Furthermore, forecasts of future oil prices and its' volatility depend on a wide range of variables and factors that have not been considered explicitly. Admittedly, all these factors make an accurate and precise forecast almost impossible. Thus, the scenarios describe a spectrum of potential outcomes. However, the actual VaR is likely to be within this forecast frame. The uncertainty of the estimations in this paper are correlated to the uncertainty level in the quoted predictions on world's ultimate resources of oil and the future oil price. The implied volatilities are based on historical reactions on markets and assume a similar behavior in future. For utilizing the results in concrete assessments the user has to choose and define the preferred variables first.

To sum up, the outcomes of this survey present a new view on evaluating risks related to scarcity of oil. Especially in the light of the discussed uncertainty and reliability of underlying data, the purpose of this paper was not to give a concise prediction. The scenarios and estimated figures rather intend to illustrate a possible frame for the actual development and to initiate and stimulate further discussions and research on this topic.

5.2. Integrating the results in corporate and financial risk management

Companies and sectors have different exposure to carbon risk. Similar to the company's general risk profile, the risk profile in the context of increasing oil scarcity is determined by:

- The company's asset mix,
- The necessity on oil as an input factor,
- The possibility for substitution and technical alternatives,
- Its position in the value chain, and

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[1] Meacher (2004), Roberts (2004), Campbell (1997).

- The location of its operational activities and sales.

In accordance with the quoted studies, the output dimension of carbon risks illustrates that specific sectors are more concerned than other sectors. In the input dimension the most vulnerable sectors are: the entire oil industry, the automobile industry, transport and energy industries. The risk exposure becomes obvious as oil currently provides 40% of all energy and nearly 90% of all transportation fuel[1]. But beyond that every industry has to consider this issue when crude oil is used as an input factor within the production process or the supply chain. And from this point of view not only the internal activities have to be evaluated; also suppliers and customers can have a higher risk exposure and therefore affect the bottom line.

In the next step it is discussed how the input oriented VaR approach could be integrated into the strategic planning of companies and financial performance analysis. Potential ways of considering oil scarcity as a risk factor could be:

- Include the oil VaR in strategic planning at a company level: Company's management can derive their individual risk exposure to oil scarcity by examining the percentage of assets and products linked to oil as an input factor and multiplying these assets with a VaR figure. A substitution factor can be added showing which assets can be easily substituted or technically altered and which have to rely on oil. The results help to evaluate different strategies and options.
- Incorporate the oil VaR in the evaluation of stocks: Volatile input prices affect companies' cost structure; in the end this can be interpreted as a factor for determining shareholder value. There have already been attempts to add an oil price factor to the CAPM-framework[2]. By including the discussed VaR considerations into the fundamental analysis of stocks, related risks can be analyzed and assessed more accurately.
- Include the oil VaR calculations in credit ratings of companies: Rating agencies and banks analyze companies' cost structure, (risk-)management activities, and competitiveness on current and future markets. Especially long-term risks are relevant for calculating risk premiums. Thus, oil scarcity should be a crucial factor as it determines future options and constrains on markets. In the context of company ratings Standard & Poor has already pointed out the potential negative effects in the output dimension. Therefore it seems to be just a matter of time, when the analysis will be enlarged by a scarcity factor.
- Include the oil VaR considerations in credit ratings of countries and bonds: For private and institutional investors holding large bond positions in their long-term investment portfolio it is interesting to obtain detailed information about a countries predicted GDP development and composition. New risks and options can be revealed in this matter by analyzing the dependency of GDP on oil (e.g. by analyzing a country's income related to oil imports or exports).
- Develope a sustainable benchmark system: In a further step the VaR of oil could be compared with the VaR of potential alternatives. This benchmark system could facilitate strategic decision making related to future investment opportunities. Areas where oil can be substituted by alternative input factors, the VaR of all alternatives could provide another indicator for the economic feasibility of future investments.

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[1] Roberts (2004).

[2] Faff/Brailsford (1999).

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