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Value-at-Risk of carbon constraints – an input oriented approach of resource scarcity

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Abstract

An increasing number of publications about theoretical approaches and new findings illustrate the relevance of the topic environmental risk assessment. The actual discussion about high oil prices is not incorporated under this headline; 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.

In this discussion one of the most obvious topics are risks related to climate change. According to the findings of surveys evaluated in this paper climate change starts to affect economic development and companies' performance in various ways. Over the next decade, economic losses due to climate change are estimated by US$ 150 billion per year. As result world's business leaders have described climate change as the biggest challenge of the 21st century. Hence, the incorporation of climate change as a risk factor is essential, but risks related to climate change feature a severe issue of complex structure and uncertainty; traditional risk assessment tools appear in the light of not being able to either reflect the multifaceted system nor provide sufficient outcomes.

Environmental risk assessments in general so far have mainly emphasized – if at all – on actual and possible impacts of the release of materials or emissions (external effects). But an overall sustainable risk assessment has also to take into account the risks related to the inflow of materials. The main reason for neglecting the inflow risks from an environmental perspective can be seen in the fact that these risks seem to be less tangible and more uncertain. Nevertheless, in a world where economic development and the use of natural resources is not uncoupled yet, a steadily increasing economic power will result in a continually rising extraction of resources. As all resources are limited, the risk of scarcity will rise; and the example of water illustrates that it already exists. Indeed, scarcity is not tangible for all kind of resources from a present point of view. Hence, a specified analysis is needed considering different market and supply conditions. A comprehensive analysis of environmental risks needs to encompass risks affecting the output as well as the input side of a value chain. This paper enlarges the discussion on environmental risk assessments upon the input dimension using the example of carbon risks.

Firstly, carbon risks are defined as risks related to climate change at the corporate level with a focus on the input as well as the output dimension. Secondly, an analysis of the current discussion on the topic of carbon risk evaluates the status quo of scientific work in this field. Thirdly, in terms of developing a practically oriented tool, the Value-at-Risk approach and it's application to measure input oriented carbon risks are scrutinized. The results discuss how future volatility and market prices can be utilized to describe the uncertainty resulting from markets acknowledging and pricing oil scarcity as a risk factor. Finally recommendations with a focus on strategic management decisions and financial performance analysis are given and further research opportunities are drawn.

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 US$ 15.5 in the short term and even US$ 17.2 in the long term.

The scope of this paper is neither intended to predict one likely development nor to demonstrate how this tool can actually work in terms of forecasting single companies' performance. But in order to point the way ahead, this paper provides scenarios for potential future developments and sets a frame for risk assessments due to oil scarcity.

Contents

1 Introduction

According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) human activities have led to an exceptional intense increase in earth's temperature in the 20th century. The accumulation of carbon dioxide and other greenhouse gases in the atmosphere is the main driver of climate change. But not only the increase of temperature provides evidence for climate change, also the number of reports and statistical results about natural catastrophes, aridity or floats indicate the apparent change.

Due to these facts climate change is one of the most discussed environmental issues in public. Furthermore, climate change has also started to affect economic development and companies' performance in various ways. And this was the trigger that prompted world's business leaders to declare climate change as the biggest challenge of the 21st century.[1] This reaction is reasonable, in light of the estimated economic losses due to climate change of US$ 150 billion per year over the next decade.[2] Hence, the incorporation of climate change as a factor of risk is essential, but related risks have a complex structure; traditional risk assessments, defined as "the calculation of probabilities of specific harm from particular activities, natural or manmade,"[3] do neither reflect the multifaceted system nor provide sufficient outcomes.

Environmental risk assessments so far in general have emphasized on 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.

In terms of assessing environmental input oriented risks, different systematic factors and specific correlations have to be contemplated and evaluated. As all resources are naturally limited, scarcity emerges as one crucial risk factor. Resource scarcity depends on several aspects such as availability, natural stocks, technical development, supply policies etc. The example of water illustrates that resource scarcity is already a serious issue: In many developing countries the problem of water scarcity exists and is presently a tangible risk factor. For other materials 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.

As a first step this paper enlarges the discussion on the topic resource scarcity by considering environmental related risks upon the input dimension. Therefore, carbon risks are defined in this paper as risks derived from (1) indirect and direct impacts of climate change on human

1 Compare WEF 2000
2 Compare UNEP Finance Initiative 2003
3 See Jäger 2000, p. 7

beings, nature and economy, and (2) the use and the limitations of carbon emitting input factors. The assessment of carbon risks at the corporate level demands a preceding analysis of the origins and influences of these risks. Therefore, one possible way of assessing carbon risks on the macro-level is briefly presented in the following section. As this paper is focused on carbon risk assessment at the micro level, the ensuing examination deals with derived impacts on corporations.

1.1 Assessing environmental risks at a macro-level

A tool for assessing global environmental risks, such as climate change, has to consider all causal functions, relations and connections of the object of investigation. This can be seen as a *causal chain* with different elements determining and influencing the overall risk exposure. The first element of this chain is the demand for a good or service. Goods and services demanded are able to affect the choice of the technologies and practices used to meet this demand. The choice in technology can lead to a change in the fluxes of materials, for example recycled materials vs. raw materials. This element should not solely be considered in terms of the output dimension (e.g. emissions), notably the choice of technology does also affect the inward flow of materials, the input. By including this variable into the causal chain, it is no longer an assessment of external effects along the causal chain. In this concept input related factors (e.g. quality and availability of input materials) are scrutinized simultaneously. The ensuing element comprises of the valued environmental component. The last two links in the causal chain describe the exposure and consequences for human beings and property.

Figure 1.1 Causal chain for global environmental risk assessment

Demand for goods and services	Choice of technologies and practices	Flux of material *outputs and inputs*	Valued environmental properties	Exposure of people and things	Consequences to people and the things they value

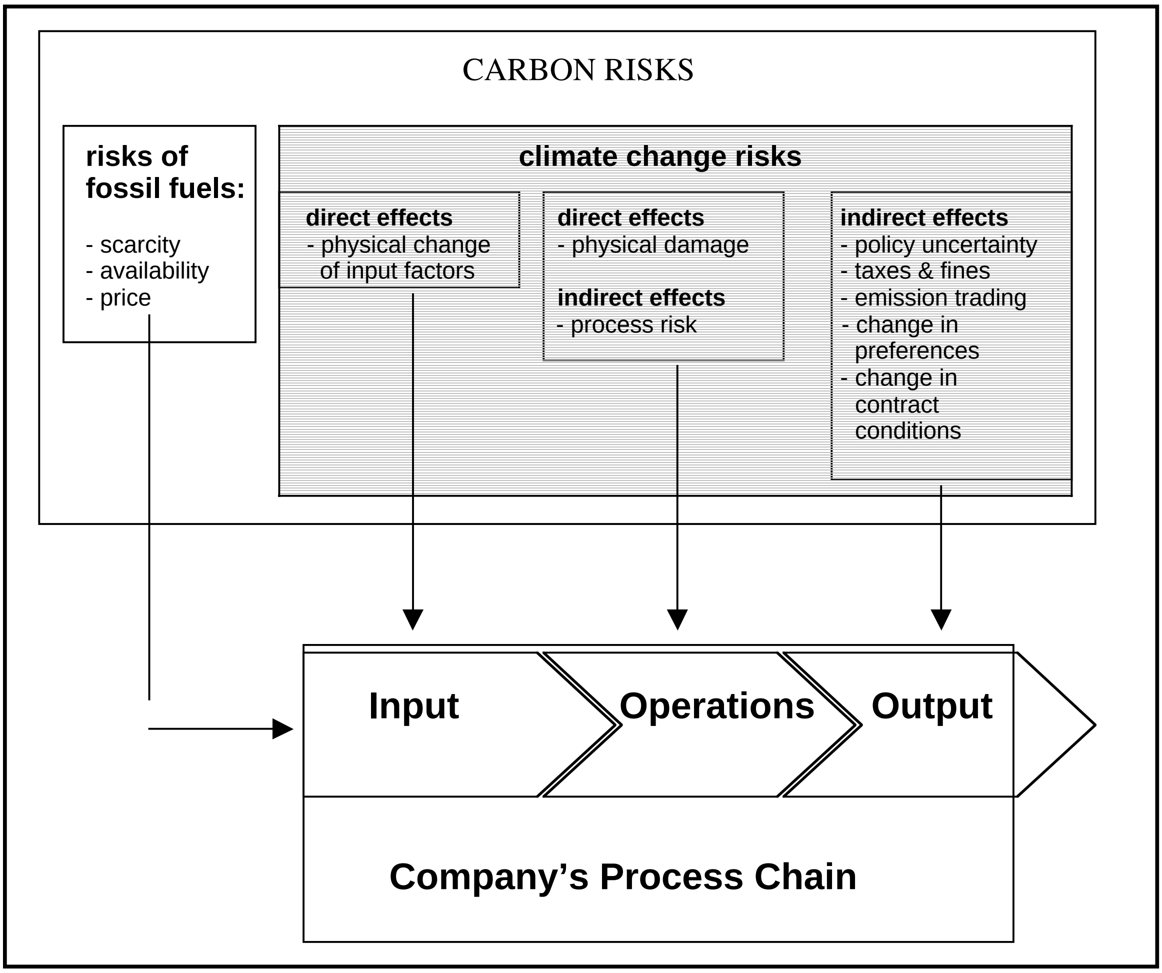
Source: Derived from Jäger (2000)

1.2 Definition of carbon risks at a micro-level

To investigate the effects of environmental risks at the micro level, the causal chain approach is now structured and applied at the corporate level. Thus, the methodology of the causal chain approach can be projected on company’s chain of value-added processes (in the following: process chain); a corporation can be viewed as a process chain with different physical inputs (materials, energy), specific operations (production process) and one or several outputs (products or services).

To distinguish the potential impacts of carbon risks on the output side, the risks can be divided into direct and indirect risks. The former describes direct physical impacts on a company’s assets. The latter encompasses impacts such as political consequences, consumer boycotts, and regulative measures (emission taxes, emission trading). Direct and indirect climate change risks have an impact on the process chain at different levels mainly depending on the industry, the location, and the asset mix of the company.[4] Furthermore, an overall risk assessment based on the idea of the process chain has to include carbon risks derived from the input-side of a company. In terms of climate change these are all risks related with the supply fossil fuels.

Figure 1.2 Carbon risks at the corporate level



1.3 Scope of the study and methodology

Climate change risks and their correlation to different economic indicators have been evaluated, both in qualitative and quantitative ways. The focus of chapter two is to review the literature and to give an overview on the different studies done so far in the field of assessing and evaluating climate change risk. It is shown that the focus so far has been on the assessment of carbon risks from an output perspective.

Chapter three extends the view on carbon risks and introduces an input perspective into the risk analysis. Input oriented carbon risks consist of all carbon dioxide (CO_2) emitting input factors; other greenhouse gases (GHGs) are not considered. Nevertheless, a main source of climate change causing factors is incorporated by this definition due to the fact that carbon dioxide is estimated to be responsible for 60 % of global warming. In addition to that this

4 See Garz/Volk 2003, p. 51

paper does not include the discussion of carbon sinks and sequestration.[5] Although it might be an interesting aspect to scrutinize, if and how emitted carbon dioxides could be (re)utilized to reduce input scarcity.

As the analysis of all fossil fuels and other carbon inputs would break the limits of this paper, this paper could just focus on the conditions of oil as one main carbon input factor and the specific risk exposure. However, "considering that cheap oil based energy has been the lifeblood of the world's economy over the best part of this century"[6] and the actual discussion on economic effects of high oil prices, one core issue of future risk assessment challenges is covered by this survey. In chapter four the Value-at-Risk (VaR) concept is presented as a tool for assessing oil scarcity.

The price and the volatility are the main variables of the VaR function. These variables are explained for crude oil in chapter five and linked with the VaR approach. In chapter six, different scenarios are developed based on existing forecasts and calculations. These scenarios cover different oil price estimations and show how the VaR of oil could develop.

Finally, chapter seven sums up the main findings, presents possible ways of integrating the developed tool into corporate and financial market risk management, and gives suggestions for further research.

5 Compare Körner 2002
6 See Campbell 1997, p. 5

2 Carbon risks from an output perspective – climate change

The contemporary literature discusses innumerable links in terms of climate change and it's causes and effects. Furthermore, a number of approaches and studies try to identify, determine or evaluate related risks from a financial perspective. This chapter presents the current state-of-the-art of this discussion. Part one presents regression studies illustrating how the risks of climate change have been priced on financial markets in the past. Furthermore, it includes quantitative studies, which have examined the correlation between emission costs and financial performance. The second section reviews qualitative studies and surveys including theoretical analysis of climate risk at a corporate level and possible future impacts of climate change on economic development derived from estimations and scenarios. The third section reflects on how markets or the business community perceive and evaluate climate change risks and how they deal with this issue. The enquiries and polls provide a summary of the present expectations on climate change risk. The different methodologies and findings are not commented; a finale part summarizes the key findings and provides concluding remarks.

2.1 Quantitative and regression studies

GARZ, H./VOLK, C. (2003), "Von Economics zu Carbonomics – Value at Risk durch Klimawandel"

Methodology: The study analyses climate change from a macro-economic point of view and describes different models of assessment for climate change (top-down and bottom-up). To calculate the Market-Value-at-Risk (MVaR) Garz and Volk use scenarios and the DICE-Model[7] developed by Nordhaus (1994). Furthermore, the authors use a cross-sectional regression-model based on data taken from 49 industries to examine the correlation between climate change and shareholder value.

Key findings: Based on calculations the worldwide MVaR is between US$ 192 and 915 billion. Neither climate exposure nor management quality has had a significant influence on the post-Rio-return. Thus, climate change is not a priced factor of risk yet; companies with a high climate-exposure have to face a potential valuation discount. There is a significant correlation between the climate-exposure and the G.A.R.P. value and growth scores (special score developed by the WestLB[8]). At the sector level, a high climate change exposure is positive correlated to the management quality: a high management quality decreases the Beta-risk[9] and increases the chances of growth.

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[7] This model is used to identify a global representative consumer/producer. The agent can choose between consumption, investment and the reduction of GHG, while his aim is to maximize his net profits.

[8] For more information see Garz et al. 2001

[9] The Beta-risk is the central risk-measurement of the Capital Asset Pricing Model (CAPM).

RUTH, M./ DAVIDSDOTTIR, B./LAITNER S. (2000), " Impacts of market-based climate change policies on the US pulp and paper industry"

Methodology: This study assesses the potential impacts of climate change policies on energy consumption and emissions in the US pulp and paper industry. A model consisting of four interrelated modules is developed to estimate (a) future technological potentials and (b) energy and policy induced expenditures. The data is used to examine the industry's response to increased cost of carbon for the years 1995 to 2020.[10] Furthermore, the impacts of investment incentives on the diffusion of energy efficient technology are analyzed.

Key findings: The conclusion is that industry responses to cost increases are time delayed due to the adoption procedures. In all scenarios the increase in world energy demand outpaces the development of energy saving technologies in the short and medium run. Energy expenditures range from US$ 37.99 to 42.47 for each ton of output. An investment led climate policy is the only way to overcome the 3 to 4 year time lag following implementation of climate change policy.

KING, A./LENOX, M. (2001), "Does It Really Pay to Be Green? An Empirical Study of Firm Environmental and Financial Performance"

Methodology: King and Lenox analyze the market valuation of 652 manufacturing firms in the U.S. related to their total emissions from 1987 to 1996. Beyond an overview of empirical studies done so far, the empirical part uses a fixed effect regression including dummy variables to eliminate possible differences between companies. Tobin's q[11] and data from Compustat database[12] are applied to measure the financial performance. To determine the environmental performance three different emission variables[13] are developed and figures on emission are taken from the TRI[14] database.

Key Findings: Lower total emissions are correlated with better financial performance. As a significant result companies with relatively lower emissions tend to have superior financial results than other companies in the same industry. On the other hand it is not significant that companies with cleaner industries have a better financial performance.

RUSSO, M./FOUTS, P. (1997), "A Resource-Based Perspective on Corporate Environmental Performance and Profitability"

Methodology: Russo and Fouts try to prove two hypotheses in their study: (1) High levels of environmental performance are associated with enhanced profitability. (2) The level of an industry's growth determines the relationship between environmental performance and profitability. The authors analyze 243 U.S. firms and apply a least squares regression method

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[10] See Ruth et al. 2000

[11] Tobin's q measures the market value of a firm relative to the replacement costs of tangible assets, see Lindenberg/Ross 1981 or Lewellen/Badrinath 1997.

[12] http://www.compustat.com/www/db/me_lev3_01_db.html

[13] These are: (1) Total emissions, the log of total facility emissions; (2) Relative emissions, compare the company's environmental performance within the industry; (3) Industry emissions, the tendency to operate in a clean or dirty industry sector.

[14] Toxic Release Inventory, for more information see http://www.epa.gov/tri/chemical/chemlist2001.pdf

to examine the correlation between a company's environmental performance and it's return on assets over a two year period (1991 to 1992).

Key findings: Both hypotheses were confirmed by the regression analyses. Returns on assets are positively correlated to higher environmental performance at a very significant level. An increase in environmental performance had a positive effect on a firm's ROA in a growing industry.

STANWICK, P./STANWICK, S. (1998), "The Relationship between Corporate Social Performance and Organizational Size, Financial Performance, and Environmental Performance: An Empirical Examination"

Methodology: Stanwick and Stanwick examine the effects of low emission levels on a company's profitability based on the yearly profits as well as their level of corporate social responsibility based on the ranking in the Fortune Corporate Reputation Index (CRI). The basis for the investigation is data of the years 1987 to 1992.

Key findings: In general a high level of variation in profitability and the level of emissions is observed. There is a significant correlation between CRI, low emission levels and profitability in two out of six years and a significant positive relationship between the level of emissions and profitability in five out of six years. The authors point out that the level of emissions as a measurement for environmental performance disadvantages firms in relatively low polluting industries, thus there is a bias towards "heavy manufacturing firms".

2.2 Qualitative studies and surveys

FIGGE, F. (1998), "Systematisierung ökonomischer Risiken durch globale Umwelt-probleme – Gefahr für Finanzmärkte?"

Methodology: Figge states that the portfolio management is confronted with conventional risk as well as risks related to ecology. He differentiates risks by the time of decision-making (pre-decisional and post-decisional) and by dependency (horizontal and vertical division). In his paper he discusses the problem of risk perception on financial markets in general and draws conclusion for the advanced risk management. As an example for global environmental risks he refers to climate change.

Key findings: From an ecological point of view, all risks belong to both the horizontal and vertical division. The risk for financial markets related to ecological sources is caused by the lack of information about ecological induced risks. Global environmental problems and related risks become more and more systematic, as there is a growing dependency between single risks. As the potential for elimination through diversification decreases, he defines a systematical increase of ecological induced economical risks.[15]

[15] See Markowitz 1959 for more information about diversification.

INNOVEST STRATEGIC VALUE ADVISORS (2002), "Climate Change & The Financial Services Industry. Module 1 – Threats and Opportunities"

Methodology: The authors commence with an ex ante analysis of financial impacts of climate change on the economy so far. Section four compares opportunities and threats for both insurance and finance industry. This qualitative analysis assessed financial figures and estimations from different scientific and institutional sources and outlines possible impacts on institutional investors. The report concludes with recommendations for the different sectors.

Key findings: Based on future outlooks and scenarios[16] the authors argue that abatement of GHG is economically feasible. There is an increase in economic losses due to natural disasters, which are doubling every ten years, and have reached almost US$ 1 trillion over the past 15 years. Even small changes (< 10%) in the severity of weather events related to climate change can generate multiple increases. The study draws conclusions in different areas, e.g. foreign direct investment or project finance. As a result it is stated that insurance companies and asset management companies are challenged to ensure viability of their business and investments.

INNOVEST STRATEGIC VALUE ADVISORS (2002a), "Value at Risk: Climate Change and the Future of Governance"

Methodology: Innovest puts emphasis on the importance of the topic climate change for investors as "universal owner". The study conducts the role of institutional investors as they have to face (a) economic risks from damages due to climate change and (b) exposures to the costs of GHG-abatement. A sector specific analysis and implications for CEOs as well as institutional investors conclude the study.

Key findings: Estimations about the size of GHG emissions trading market range from US$ 10 billion by 2005 to US$ 60 billion and even US$ 1 trillion in an unspecified timeframe.[17] Five main risks and potential impacts on shareholder value are identified for all sectors: Balance sheet risk, market and "reputational" risk, capital cost risk, operating risk and business sustainability risk. Based on results of another Innovest study[18] about the U.S. electric utilities' GHG emissions and climate risk exposures, the firm specific climate risk expressed in terms of percentage of share price "at risk" can vary by a factor of nearly 60 times within the same industry.

MANSLEY, M./DLUGOLECKI, A. (2001), "Climate Change – A Risk Management Challenge for Institutional Investors"

Methodology: The study focuses on institutional investors and their long-term view. It is stated that institutional investors can have a huge impact on economic activity related to climate change. The findings are based on data of the Intergovernmental Panel on Climate Change. Mansley and Dlugolecki develop ten action points how to better manage climate change risks.

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16 Compare IPCC 2001
17 See Innovest 2002a, p. 30
18 See Innovest 2002b

Key findings: The authors argue that institutional investors should adopt a more strategic approach to climate change risk. Recognizing climate change as a risk factor for long-term investment is crucial for successful investment. Both significant costs as well as net benefits result due to potential economic impacts of emissions reductions. The paper points out that brokers have the greatest capacity among financial institutions to carry out detailed research.

MANSLEY, M. (2003), "Sleeping Tiger, Hidden Liabilities: Amid growing risk and industry movement on climate change, ExxonMobil falls farther behind"

Methodology: The report investigates the action ExxonMobil has undertaken concerning the impacts of climate risk over a one-year period.[19] Furthermore, Mansley compared ExxonMobil with other companies like BP, Shell and ChevronTexaco in terms of strategies and actions on the topic of climate change. Then he analyzed the different steps taken so far by ExxonMobil responding to climate change risks.

Key findings: Mansley points out increasing pressure from evolving climate change policy as one major risk. Furthermore, he identifies growing reputation risks and risks from litigation as he states that the company refuses to take concrete steps into consideration. He concludes that the company has internal problems.

2.3 Enquiries and Polls

MAIER, B. (2002), "Klimaänderungen und betriebswirtschaftliches Risikomanagement. Am Beispiel der Wintersturmaktivitäten in Nordrhein-Westfahlen", empirical part

Methodology: Mayer examines in his book the consequences of climate change related risks and the economical impacts on business entities. The enclosed questionnaire encompasses questions about a company's expected impacts of ecological and climate risks, the company's actions related to winter storms, and the risk management tools applied in the company. The poll comprises of 260 firms.

Key findings: One striking outcome of the study is that two thirds of the questioned companies only had a planning horizon for climate change events of less than five years; 30 % are even planning just two years or less. This confirms results of other empirical studies[20] that economic agents tend to ignore events with a low probability occurrence like natural catastrophes. Companies that have already been affected by damages from storms are going to include climate change risks in their overall risk management. Companies with a longer planning horizon or more than 200 employees are more likely to incorporate climate change risk in their management strategies. Furthermore, the relevance of climate risk for the risk management is correlated to the company's location.

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19 See also Mansley 2002
20 See Kunreuther 1978

COGAN, D. G. (2003), “Corporate Governance and Climate Change: Making the Connection”, CERES Sustainable Governance Project Report

Methodology: The study examines the business strategies and governance practices related to the topic of climate change of 20 of the world’s biggest corporate emitters of greenhouse gases. A 14-point "Climate Change Governance Checklist" is used to identify each company’s action related to climate change risks. The checklist is divided into the categories: board structure and environmental oversight, management accountability and environmental auditing, disclosure on climate change, and Inventories of GHG emissions.

Key findings: The results show that 17 companies have environmental committees at the corporate board level. The level of engagement differs: mainly European oil and gas companies are investing at least small portions in renewable energy sources, whereas American oil corporations are mainly concentrating in traditional fossil fuels. The worst ranking was received by the American utilities sector, which has only reached seven action points on average.

INNOVEST STRATEGIC VALUE ADVISORS (2003 and 2004), “Climate Change and Shareholder Value In 2004”; “Carbon Finance and the Global Equity Markets”

Methodology: In 2003 the Carbon Disclosure Project (CDP) published the first results of the FT500 Global Index companies’ request. This was followed by the follow up version in 2004. In 2003 35 institutional investors representing assets in excess of US$ 4.5 trillion were involved, in 2004 it were 95 institutional investors representing US$10 trillion. The investors request the disclosure of investment relevant information relating to the risks and opportunities presented by climate change.

Key findings: The 2004 report states that the mainstream investment community has realized the financial implications of climate change; financial markets are starting to see that risks and opportunities take shape. Thus, companies are likely to face increased pressure from financial markets in dealing with climate risk factors. Climate change and shareholder interest are becoming more closely intertwined: 59% of firms responded to CDP2 (47% in CDP1). 45% of the FT500 believe climate change represents risk and/or opportunity. 65% of companies in high-impact sectors are now measuring and reporting emissions versus 51% in CDP1. Significant differences of opinion remain within same sectors on the importance of climate change to company business and competitiveness. Many companies still remain firmly ‘behind the curve’.

2.4 Conclusion – climate change risk

Quantitative and regression studies analyzed companies from different industries as well as different regions and tested a wide variety of environmental indicators and their effects on the financial performance. The results point out the consensus that financial markets have recognized a correlation between environmental performance and corporate profitability. These results are confirmed by a more comprehensive compilation published by Murphy

(2002) and a study focused on European stock companies conducted by the Centre for European Economic Research.[21]

But climate change is not an explicitly priced risk factor: On the one hand regression studies using total emissions of a company as a measurement for climate change risk found that lower emissions have an positive impact on shareholder value. On the other hand authors stated that financial markets do not incorporate the risks in determining risk premium rates so far.

According to the enquiries, climate change risks and related abatement costs differ between industries and regions; and the approaches towards risk management vary within sectors. These outcomes are similar to a more general study about sustainability and shareholder value, conducted by Deutsches Aktieninstitut/European Business School (2003). The sector analyzing studies illustrate that oil & gas, automobile, transport, energy, tourism, and utilities industry are likely to be the most vulnerable for climate risks. According to Mansley and Dlugolecki (2001) different types of climate change risks can be defined:

- Direct physical impacts of climate change,
- Potential catastrophes due to climate change,
- International political consequences of climate change, and
- Business and economic risks of policy failures.

Garz and Volk (2003) are structuring the risks into *first order effects*, which are similar to Mansely's first two points, and *second order effects*, which are similar to Mansley's last two points. The considered literature identified first order risks such as:

- Potential destruction of infrastructure through extreme weather events,
- Potential water scarcity in the agrarian sector,
- Potential impacts on the tourism industry, and
- Potential spreading of tropical diseases.

Risks of second order derive from:

- Potential climate change policies,
- Additional adaptation costs related to changes in production processes,
- Changes in consumption behavior, and
- Short term adjustments of contract conditions.

Although there is increasing scientific evidence about climate change[22] and confirmations of world business leaders that climate change is the greatest challenge facing the world at the beginning of the 21st Century, it can be stated that there is no significant reaction: the business community and the financial markets do not counteract this development in a sufficient manner. This is a crucial outcome, especially as indirect risks from climate change are becoming a reality:

[21] Compare Ziegler et al. 2002
[22] Compare IPCC 2001 and WMO 2003

- European emission trading scheme is going to start 2005.[23]
- It is likely that more carbon taxes emerge in the near future.[24]
- The lowering of stock ratings by equity analysts.[25]

Companies might have to face this issue not only as a strategic factor for success and competitiveness but also due to legal reasons. For example the German Corporate Governance Codex already requests corporate boards of publicly listed companies to disclose any issues that are relevant or could have impact on the financial situation of the corporation.[26] Thus, climate change as a business case will be a viable topic in future annual general meetings.

Furthermore, reactions on markets are naturally not only based on hard facts. Especially on stock and derivative markets, decisions usually include expectations and anticipations. In terms of carbon risks, these rather soft facts already have negative effects on companies' performance, as it is illustrated by Xstrata (FTSE 100 listed company): In 2002 the Japanese government announced that they were considering a coal levy, which would be put into effect in Oct 2003. The shares of Xstrata – as one large coal exporter to Japan – fell approximately 10% in a few days due to the likely impact of such a move.[27] Furthermore, Standard & Poor has already warned of the effects of emissions trading on cost structure and profitability of European utility corporations. Inevitably this is going to be monitored by the rating results.[28]

Thus, the conclusion of the status quo analysis is: climate change is not only a matter of fact; it is also going to be a crucial business topic. For comprehensive and reliable risk perception, corresponding assessments should already be the business case. And this is applicable to all companies, whereby the individual intensity is in dependency of the specific industrial sector and size of the company. According to Figge (1998), global environmental risks such as climate change show a different structure than conventional risks; they are becoming more systematic as there is an increasing dependency between the risk factors over time periods.[29] But current assessment tools obviously have a lack of embedding these risks in an adequate manner. This might be due to the complexity of the risks. In this context Chichilnisky and Heal (1993) state that the concern climate change has two elements: the global nature of possible changes and the fact that they are driven by human activity. They conclude that the risks posed by climate change are endogenous and so (still) outside of the classical economic framework for analyzing risk allocation. However, as this type of risk gains more and more systematic features, there is a growing necessity to consider this issue, for both managers and financial analysts. Shareholders and investors should reinforce their claim for disclosure of climate change risks and how companies are intending to manage this issue.

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23 In order to fulfil the obligation to contribute to the Kyoto reduction aims, the European Union (EU) laid down the regulations for the European emission trading (ET) system in 2002. Plants above a defined size are going to receive a fixed amount of allowances, whereby the amount will decrease due to tightening emission targets over the time. In the case that the allocated amount is not sufficient, it is up to them to decide whether to improve efficiency by modernizing their production facilities or to purchase further allowances to allow excess emissions over permits.

24 Compare for example "Swiss put climate tax options on table" in Environment Daily 1467 (2003) or the ensuing Xstrata illustration.

25 On 17/12/2002 Lehman Brother downgraded their rating on Canadian Natural from 1-Overwight to 2-Equal weight because of uncertainty surrounding the requirements of the Kyoto Protocol, see Lehman Brothers Equity Research 2002.

26 Compare the chapter "transparency" on http://www.corporate-governance-code.de/eng/kodex/6.html

27 Compare UNEP Finance Initiative 2003, p. 12 and Kiernan 2002

28 See Lund 2003

29 See Markowitz 1959 for a definition and detailed explanation of the term "diversification".

3 Carbon Risks from an input perspective – the resource oil

From the current perspective on the process chain, carbon risks seem mainly be affected in the output dimension. Discussions therefore focus on methods of risk reduction by mitigation, adaptation, and end-of-pipe approaches. Input oriented risks seem to be not relevant yet.

But 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. 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.[30]

In economic terms a resource is scarce when the quantity supplied is not sufficient to satisfy demand. Normally this would result in an upward pressure in price. But even before a resource is ultimately exhausted, the risk due to scarcity will emerge; and capital markets will price this as a matter of fact. The crucial question is whether this risk will emerge slightly or suddenly and prices will increase slowly or exponentially? The dilemma is how to forecast the potential developments, especially when the expected effects rely on market's acknowledgment of occurred scarcity. This chapter considers oil as a risk factor in general; chapter five is focused on the market and price reactions.

3.1 Risks of oil as an input factor

Oil can be defined as a "private exhaustible natural resource"[31] 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.[32] Since the birth of the oil industry in the middle of the 18th century the economy's demand for oil steadily increased as it became vital for transport and agriculture.[33] World oil production increased to 78.6 million barrels a day in July 2003.[34] Up to now, world oil consumption has increased by 11.6 % since 1992 and is likely to increase further.[35] The consumption in Asia (including China and Japan) even increased by 26.9 % over the same

30 See WRI 2002, p. 26
31 See Stiglitz 1979, p. 55
32 See Stiglitz 1979, p. 37
33 See Campbell 1997, p. 5
34 See BP 2003
35 IEA 2003

period. Worldwide consumption of oil exceeds US$ 500 billion and oil is the world's most actively traded commodity, accounting for about 10 % of total world trade.[36]

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.[37]

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 means scarcity and higher prices."[38]

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.[39] Obviously, for many companies unstable oil prices already present a severe risk.[40] 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)[41] crude oil future contracts. The annual trading volumes of No. 2 heating oil future contracts[42] grew from 25,910 in 1978 to 9.6 million in 2000.[43] And this development seems to continue due to oil prices become more sensitive to rumors and misinformation.[44] 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 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

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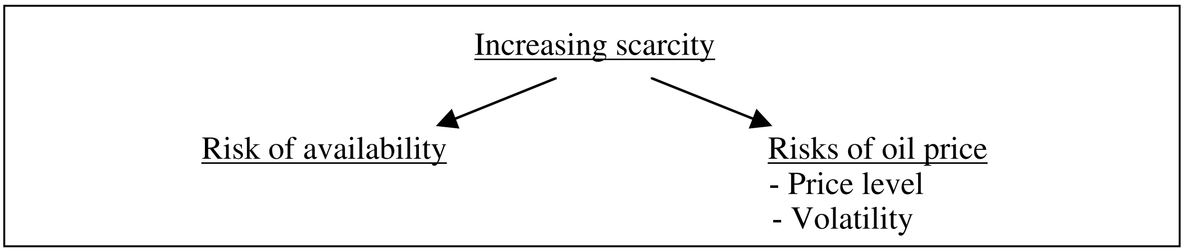
36 See Sharma 2002, p. 3
37 See Rettberg 2004a and Rettberg 2004b
38 See Campbell 1997, p.81
39 Compare WIR 2003 and Shell 2001
40 See Fishhaut 2003
41 See http//www.nymex.com
42 Heating oil futures are commodity futures, which are used in order to hedge price risks.
43 See EIA 2002, pp. 23-24
44 See Stevens 1996, p. 400

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.

Figure 3.1 Structure of oil scarcity risks



Risks of oil availability encompass all sources that could possibly irritate or prevent the needed – i.e. demanded – oil supply.[45] This paper primary 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[46]
- Change of consumer preferences
- Political developments, especially in oil delivering countries

3.2 Resource scarcity in theory

As one option for assessing the overall significance of resource scarcity the focus can be laid on physical indicators: Based on reliable sources of information physical measures such as reserve-to-use ratios enable assessments over time and direct comparison with other resources. But corresponding figures do not provide tangible information about the significance and actuality of current scarcity perceptions reflected by market behaviors and trends. Beyond physical approaches, economic indicators can obtain this type of information. According to economic theory scarcity is usually combined with rising prices; under the assumption of constant or increasing demand, the price tends to be negatively related to the size of the stock.[47] This entails the smaller the stock, the higher the price and vice versa.

Hotelling (1931) wrote one of the most famous contributions to the theory of exhaustible resources and resource prices. In the neo-classical tradition he assumes profit maximization behavior by the resource owner and efficient markets for resources and future resources contracts. Furthermore, all agents are subject to perfect information. Different resources are used in order of their specific extraction costs. Extraction costs can vary due to the geographical accessibility, related transportation costs or the geological differences. According to the Hotelling-principle, under certainty about future prices and perfect competition among

[45] See e.g. Ströbele 1996, p. 347

[46] It might be interesting to investigate further the options and effects of input-taxes (e.g. German levy on gas/petrol) in the scarcity context; for details on environmental taxation compare HM Treasury 2002.

[47] See Fisher 1977, p. 247

producers, the unit price of an exhaustible resource less the marginal cost of extracting should rise over time at a rate of interest equal to the risk less return. The extraction costs are likely to increase over time, as companies will always try to extract low cost resources first. Thus, prices are likely to increase over time with greater scarcity and as a market effect demand eventually decreases over time. Barnett and Morse (1963) showed that none of these theoretical ideas became reality. They proved that resource prices did not provide any significant evidence for scarcity, except for forest products. They argue that extraction costs have decreased over time, while extracted quantities of natural resources have increased. The interpretation is that technological improvement and substitutes are a type of mitigating factors and seem to eliminate all evidence of scarcity.[48]

A rather new approach considers uncertainty about resource endowments and market failures as standard. Reynolds (1999) suggests that an adequate measure for scarcity is provided by exploration costs. These costs are influenced by the information effect (the more information about resource location exist, the cheaper the exploration) and the depletion effect (the fewer resources available, the costlier the exploration). Reynolds' model assumes that the true scarcity will be only revealed towards the end of the exhaustion. This could cause a sudden and sharp increase in resource prices, even after decades of declining prices.

Supporters of new institutional economics suggest that one possible explanation for certain inefficiencies on resource markets is path-dependency. Antonelli (1997) defines path-dependency as "the set of dynamic processes where small events have long-lasting cones-quences that economic action at each moment can modify yet only to a limited extent."[49] In the context of scarcity, this means that agents in resource markets stick to old consumption patterns and have difficulties or obstacles for changing their behavior. This might be due to switching costs when facing new technological opportunities and sunk costs of assets. Switching to a new – e.g. more resource efficient – technology is combined to certain costs, such as the purchasing price or installation costs. Although it is obvious that resources are used in a non-efficient way, the decision is to stick to an existing investment project due to sunk costs. Thus, the actors' behavior on markets is often biased or non-rational. As an effect, path-dependencies can be the reason for less commitment in the development of large technological innovations.[50] In this context also the game theory approach can be utilized to analyze the interactions between different suppliers and their bargaining strategies.

After this short review on the economic explanation for resource scarcity in theory, the focus is now on the exhaustible resource oil. Discrepancies between the Hotelling-principle and the actual scarcity patterns are described by Reynolds' model and path-dependencies.

3.3 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

[48] See Tietenberg 2004 and Tietenberg 2003
[49] See Antonelli 1997, p. 643
[50] Compare Walker 2000

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.[51] 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.[52]

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 3.1 gives an overview about recent estimations on world's reserves, resources and ultimate recovery of oil.

Table 3.1 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

Every forecast uses its own methodology in determining the ultimate recovery and its own model to estimate undiscovered resources. The divergence of the estimations is mainly due to the different estimation techniques. In general it can be stated that the Hubbert Centre produces a rather pessimistic view, while the United States Geological Survey delivers an optimistic view on world's endowment of oil. In general it can be stated that recent figures on ultimate recovery show a trend towards a value of approximately 2000 billion barrels.[53] This could indicate an increasing consensus on the world's endowment of oil; at least recent discussions prevail a common opinion about scarcity in a rather short-term future.[54]

3.4 Future oil supply

Hubbert explained oil discovery and production both form a bell-shaped curve over time, known as the Hubbert-curve.[55] 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

51 See Schanz 1976
52 See Campbell 1997, p. 70
53 Compare BGR 2000
54 Compare Meacher 2004 and Roberts 2004
55 Using this model, in 1956 he correctly predicted that U.S. oil production would peak around 1970, see Lagesse 2003, p. 62

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 depletion 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 3.2 summarizes different estimations on the depletion mid-point.

Table 3.2 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)

In this context it is important to note that the depletion mid-point is reached before peak production. From this point of view it is assumed that consumption will still increase while natural endowment will accelerate the path to its final depletion point. Future supply might not just be limited by the natural endowment of world oil resources, but also determined by access to reserves. As the World Resources Institute (2002) puts it: "As traditional oil producing regions mature and yield progressively less oil, the industry is increasingly exploring and producing in new areas, where environmental and social controversies may be significant." However, "if economic growth remains technologically dependent on growth in conventional oil supply until global conventional oil production peaks, then the development following the peak is unpredictable."[56]

3.5 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

[56] See The Danish Board of Technology 2003, p. 64

Theses factors have to be considered for investigating the question how oil prizes are stimulated by the demand site. Table 3.3 presents scenarios by the International Energy Agency on the possible development of per capita world oil demand.

Table 3.3 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

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.[57] 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.

3.6 Conclusion – oil scarcity

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.[58] Furthermore, it is not easy – or almost impossible – to foresee the aforementioned restrictions in a precise manner.

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.[59] This could indicate that the downgrading already has 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."[60] In order to grasp this topic from a risk management perspective, the further focus is on the Value-at-Risk model.

57 See The Danish Board of Technology 2003, p. 73
58 Compare Fisher 1977
59 See L-B-Systemtechnik GmbH 2000
60 See Fisher 1977

4 Value-at-Risk

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.[61] This single number provides a standardized risk measure; it generates "a common language with respect to risk"[62] for investors and management.

4.1 Definition of VaR

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."

Several regulatory institutions support VaR methods for quantifying risks. For example the Basel Committee on Banking Supervision suggests VaR for a bank's risk assessment in capital allocation and the Group of Thirty (an international group of derivative dealers) proposed that dealers should calculate a VaR as a routine business practice for managing risk.[63] There is an increasing number of VaR–tools employed in companies' risk management operations. JP Morgan developed the VaR estimation system RiskMetrics™, Credit Swiss First Boston released Primerisk and PrimeClear in 1997, Chase Manhattan employs Charisma and Deutsche Bank is using the dbAnalyst.[64]

Nevertheless, the VaR model has three critical points:[65] (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 never can 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 is advantages in quantifying risks as well as disadvantages of statistical errors.

61 See Cabedo/Moya 2003, p. 2.
62 See Marshal/Siegel 1996, p. 3
63 See Fallon 1996, p. 3
64 See Khindanova/Rachev 2000, pp. 2-3
65 Compare The Economist 2004, p. 11

4.2 Calculation of VaR

In general VaR consists of a measurement for volatility, the distribution of the underlying yield and an evaluation model.[66] Based on that, Fallon (1996) derived

$$\text{Prob}[\Delta P(\Delta t, \Delta x) > -VAR] = 1 - \alpha \qquad \textit{Equation 4.1}$$

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%.[67] The choice of the confidence level is discretionary and differs across institutions.[68] From Equation 4.1 the VaR formula is derived

$$VaR = S_0 \, Z(\alpha) \, \sigma_s \qquad \textit{Equation 4.2}$$

Where

S_0	is the underlying,
$Z(\alpha)$	is the z-value of the normal distribution,
σ_s	is the volatility of the underlying.

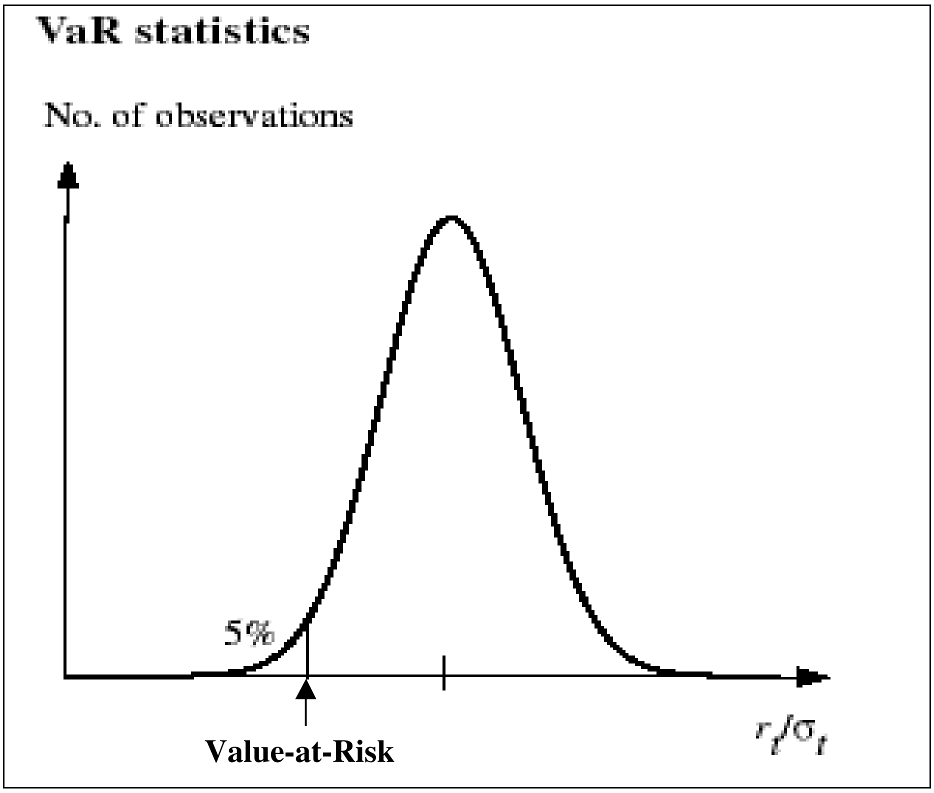
VaR can be calculated for different time periods; this depends on the volatility intervals. For example to calculate the one-month VaR of an underlying, the average monthly volatility needs to be determined. Under the assumption that the return of the underlying S is normally distributed and the confidence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

$$VaR = S_0 \, 1{,}65 \, \sigma_s \qquad \textit{Equation 4.3}$$

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.

66 See Dockner/Harold 1997, p. 1
67 See Fallon 1996, p. 2
68 See JP Morgan/Reuters 1996, p. 6

Figure 4.1 Value-at-Risk graphic



Source: JP Morgan/Reuters (1996)

<u>Example:</u> An investor has a 10 million Euro position of share A in his portfolio and intends to calculate the VaR of this position over a 1-day horizon with a 5 % probability. Share A's daily volatility is assumed to be 1.5 % (derived from the daily average standard deviation). Under the assumption of normal distribution, the VaR with a confidence level of 0.95 is located at the z-value of 1.65. Thus the VaR is calculated by multiplying the volatility with the z-value: 1.65*1.5 % = 2.475 %. The monetary VaR of this position is derived from the market value:

EUR 10 million * 2.475 % = EUR 247.500

This means that with a 95 % probability share A's value is not likely to decrease for more than EUR 247.500 over the next day.

5 Value-at-Risk and Oil

This chapter is focused 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. In chapter four the VaR was 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**.

5.1 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.[69] According to Adelmann (1993) there are three assumptions about the oil price:

1. The current price is the long-run competitive price, plus an error in estimation.
2. Due to inevitable scarcity the long-run competitive price must rise.
3. 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 theses 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.

5.1.1 Past oil prices

In the long-term view the average crude oil price adjusted for inflation has been 18.63 US$/barrel since 1869.[70] During the period from 1947 to 1997 the average oil price was 19.27 US$/barrel.[71] 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.

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[69] See Sharma 1998, p. 2
[70] See http://www.wtrg.com
[71] See Sharma 1998, p. 2

Beside 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 this uncertainty, the OPEC introduced a price band mechanism in 2000. This so-called target zone model[72] intends to keep the price of a barrel of crude oil within a US$ 22 to US$ 28 band. Figure 5.1 illustrates the Brent Crude oil price development since the introduction of the target zone and illustrates its general effectiveness.

Figure 5.1 Brent Crude oil price development 01/03/2000 – 30/06/2003 & plotted price band

Data: Europe Brent Spot Price FOB (US$/barrel), http://www.eia.doe.gov

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.[73] 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.

5.1.2 Future oil price

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.[74] 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.

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72 This target zone model is similar to target zone models for foreign exchange markets, for more detailed information see Krugman 1991.

73 Compare Tang/Hammoudeh 2002, pp. 579-582

74 See Adelman 1992, p. 269

Table 5.1 Overview of nominal[75] oil price estimations (in US$/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 US$ 30 and 70.[76] These numbers are based on the oil price jumps in 1974 and 1979 in real terms.[77]

5.1.3 Determination of oil prices

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 US$ 19.07 and 43.3 in 2020. This is roughly in the range of OPEC's target zone model of US$ 22 to 28. However, none of the aforementioned approaches considers the aspect of a scarcity shock and the corresponding reactions on markets.

5.2 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.[78] "Volatility generates uncertainty and uncertainty inhibits or confuses the investor."[79] Volatile input prices make it difficult to plan accurately future investments, for both companies and investors. The oil market is characterized be 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.

75 The prices are not adjusted to inflation.
76 See Massarrat 2000, p. 6
77 See Massarrat 2000, p. 4
78 Speculators or day traders care about price movements within minutes, whereas investment funds or policy makers are more concerned about volatility in a long-term perspective.
79 See Mabro 2001

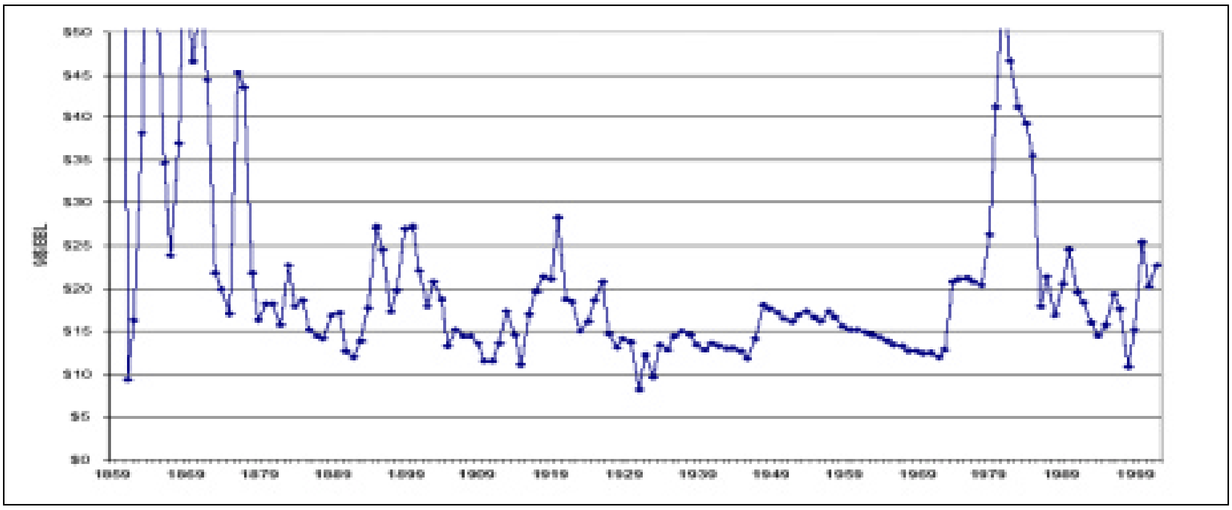
5.2.1 Statistical analysis of oil price volatility

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.[80] Two main statistical features of the oil price result in a time-invariant structure:[81] heteroscedasticity[82] and autocorrelation.[83] Thus, the calculation of the simple standard deviation (as the square root of variance)[84] 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.[85] 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.

5.2.2 Oil price volatility in the past

Between 1860 and 1900 oil prices were very volatile due to the small size of the industry and related uncertainties.[86] With the foundation of the *Seven Sisters*[87] 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 at 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.[88]

Figure 5.2 Crude oil price volatility



Source: Lynch (2002)

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80 See Kuper 2002

81 See Granger/Machina 2002

82 *Heteroscedasticity* indicates increasing variance across residuals. It violates the classical assumption that error terms have constant variance (homoscedasticity). The presence of heteroscedasticity can be tested with the Lagrange Multiplier test and the Cook-Weisberg Test.

83 *Autocorrelation* is specific condition describing the perseverance of oil price volatility. It refers to the correlation of two different values of the same variable at two different points in time. To test autocorrelation in variance the Ljung-Box test and the Durbin Watson Test are mainly applied.

84 See Fahrmeier et al. 1999, pp. 246-250

85 See Dockner/Harold 1997, p.6

86 See Lynch 2002, p. 5

87 The Seven Sisters was a cartel of seven oil companies consisting of EXXON, MOBIL, SOCAL, Texaco, Shell, BP, and Gulf.

88 Compare Lynch 2002 and Stevens 1996

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:[89] (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.

5.2.3 Correlation of oil price volatility and natural scarcity

The VaR model describes future related risks by incorporating implied volatilities, i.e. historical incidents and developments of the same underlying are utilized for the predicting future trends. Thus, the objective is to identify natural scarcity indicators that explain an adequate past oil price volatility. Table 5.2 illustrates several correlation tests that have been done.

Table 5.2 Tested variables

Production/Demand EIA	A "Scarcity coefficient" Ratio between oil production and demand on EIA figures.
Yearly Volume Future	The yearly trading volume of crude oil future contracts based on NYMEX figures
Log Change Futures Volume	The Log change in yearly Futures trading volume based on NYMEX figures
Yearly Volume Options	The yearly trading volume of crude oil option contracts based on NYMEX figures.

Standard linear regression analyses[90] have been used to test these variables on their correlation with the average yearly oil price volatility. Table 5.3 gives an overview of the results.

Table 5.3 Summary statistics for different oil volatility indicators

	R^2	Std. Err.	Pearson Corr.	Significance*	Auto-correlation	Hetero-scedasticity
					*Durbin Watson-Test***	*Cook-Weisberg-Test χ^2* ***
Production/Demand EIA	0,011	0,325	0,103	0,739	0,919	3,575
Yearly Volume Future	0,133	7,54E-10	0,365	0,22	1,126	0
Log Change Futures Vol.	0,03	0,1229	0,173	0,572	1,077	0,15
Yearly Volume Options	0,022	3,31E-09	0,149	0,6	1,07	0,1

* Significant at 0,005 or less
** No autocorrelation if 1 > x < 3
*** At n=1, x < 3,5415

89 See Lynch 2002
90 Compare Griffiths et al. 1993 for detailed information on regression analysis.

The results point out that past oil price volatility cannot be explained by the chosen scarcity variables. The poor significance results of the oil price future and option contract volumes are also confirmed by the results of Fleming and Ostdiek (1999) who found no clear evidence that an increase in derivative trading results in higher oil price volatility. Thus, the further challenge is to generate an adequate but significant implied volatility that describes the future oil price volatility by historical scarcity indicators.

5.3 Conclusion – 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.[91] 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 inefficiency 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 manmade scarcity has emerged. The scenarios in the next chapter assume future oil markets to react on increasing *natural* scarcity in a similar way as they did on *artificial* scarcity in the past.

91 See Massarat 2000, p. 2

6 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 chapter illustrate potential developments of the VaR of one barrel crude oil due to natural scarcity.

6.1 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.[92]

[92] See The Danish Board of Technology (2003)

Table 6.1 Construction of the basic scenarios

Scenario	*Characteristic features*	*Possible explanation within the 21-month period*
S_1	• High uncertainty • Overreactions in the short term • After a couples of month moderate increases of prices	• Panic sells and purchases • Path-dependence remains to a certain extent • Unreliable information about oil endowment and actual production quantities
S_2	• Lower uncertainty • Constant increase of market prices within the time period	• Market participants realize and accept slowly fostering scarcity • Demand increases steady, reinforced due to development in emerging markets • Oil supply is reliable, no unexpected alterations of delivery

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 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 US/$barrel. This corresponds to the oil price leap in real terms, after OPEC cut the oil supply in 1979.[93] 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.

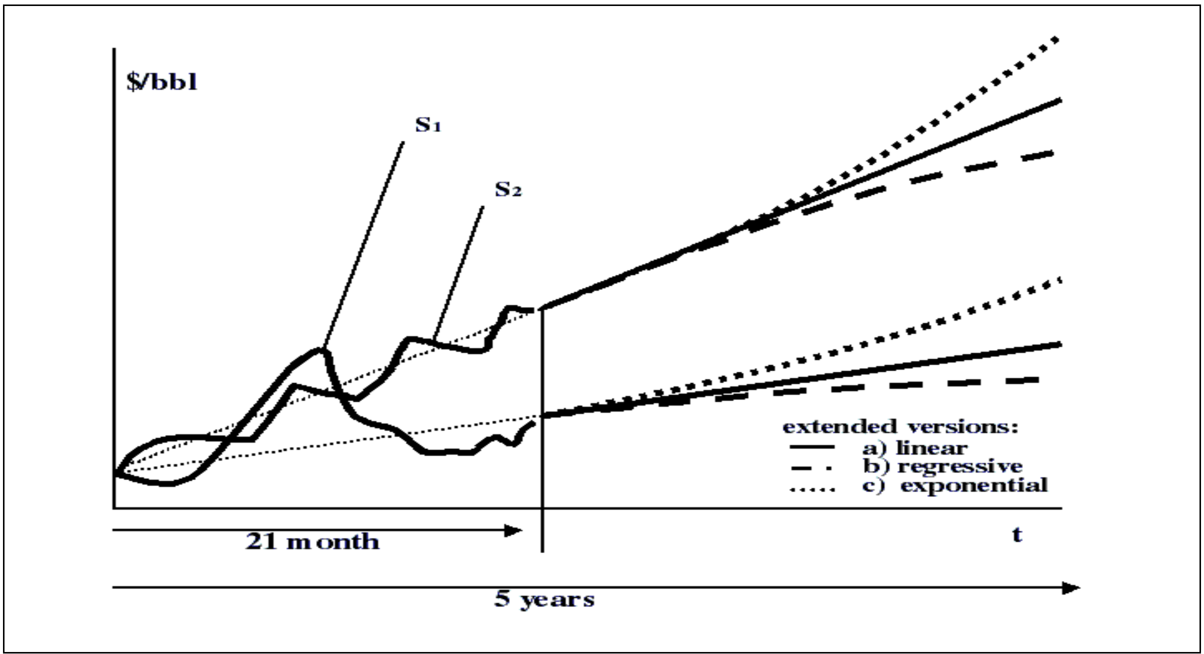
93 See Massarat 2000, p. 4

Table 6.2 Construction of the extended scenarios

Scenario	*Characteristic features*	*Possible explanation within the 5-year time frame*
$S_{1\text{-}a}$	• High uncertainty • High price level • Linear increase of prices in a moderate way	• Ad-hoc information on markets • Alternatives and substitutes are available, but sufficient implementation takes time; newly explored are not able to meet increasing demand • Long term market trend is constant • Demand cannot be met
$S_{1\text{-}b}$	• High uncertainty • High price level • In the long run regressive increase of prices in a negligible manner	• Participants are still unsettled but opinions and strategies due to market trend match in many areas in the long term • Options for alternatives and substitutes are used more and more; newly explored fields are able to damp the price increase due to it's high level • Strong evidence for path-dependency, until a new shock reaction occurs • Gap between demand and supply increases slowly and in a downward trend
$S_{1\text{-}c}$	• High uncertainty • High price level • In the long run exponential increase of prices in a significant way	• Unreliable information and short-term speculation on markets • Alternatives and substitutes are not marketable in sufficient manner; new areas turn out not to be economically viable • Increasing supply shortages causing steady and steep price increases up to the backstop-level • Gap between demand and supply increases dramatically
$S_{2\text{-}a}$	• Lower uncertainty and price level • Linear increases of prices with a high rate of price increase	• Stocks and markets are relatively transparent and reliable; common opinion and strategy due to long term market trend • Alternatives and substitutes are not sufficiently implemented at the beginning; newly explored fields can only marginally dampen the price increase • Long term market trend is constant • Gap between demand and supply increases steadily
$S_{2\text{-}b}$	• Lower uncertainty and price level • In the long run regressive increase of prices in a rather negligible manner	• Stocks and markets are transparent and reliable; opinions and strategies due to market trend match • Options for alternatives, substitutes, and new explorations are available; they are used more and more with increasing market pressure • Path-dependency resumes, although prices rise slightly; the scarcity shock is considered as temporary • Supply seems to meet demand
$S_{2\text{-}c}$	• Lower uncertainty and price level • In the long run exponential increase of prices with a accelerated rate of price increase	• Stocks and markets seem to be transparent to a certain extent; reliable information about ultimate oil endowment • Increasing supply shortages causing significant price increases • Alternatives and substitutes are not marketable at all, even under increasing market pressure; no fundamental new explorations • Gap between demand and supply increases constantly

Figure 6.1 illustrates the methodology. Within the 21-month period the two basis scenarios S_1 and S_2 are applied, based on empirical data. The there follow up scenarios for the ensuing 39 month are based on the three assumed trends a, b, and c.

Figure 6.1 Modeling the basic and extended scenarios



6.2 Determining the basic scenarios' variables

Based on the World Oil Market and Oil Price Chronologies: 1971 – 2002 published by the Energy Information Administration (2003) 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.

<u>Period 1: January 1990 – September 1991 – historical base for scenario S1; Features:</u>

- Iraq's invasion in Kuwait causes rise in oil prices
- U.S. refinery problems indicate a loss in daily capacity
- January – February 1991: very volatile oil prices due to inconsistent news about the Gulf war
- OPEC production cuts by 22.3 million barrel/day
- Announcement of Soviet Union oil export cuts by nearly half
- High level of monthly volatility

<u>Period 2: January 1999 – September 2000 – historical base for scenario S2; Features:</u>

- Several OPEC and Non-OPEC production cuts
- High world oil demand
- Low crude oil stock levels in the United States
- Trend of a high rate of monthly price increases

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).

Table 6.3 Price scenarios EIA

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

As the EIA-estimations assume that the OPEC is not completely exhausting it's scope of prices,[94] 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.[95]

Table 6.4 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

$$R_t = LOG(P_t / P_{t-1}) \qquad \textit{Equation 6.1}$$

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,[96] the volatility is described by the standard deviation.[97] As the tests in Table 6.5 indicate, there are no signs of heteroscedasticity and autocorrelation in the standard deviation of the so defined volatility.

Table 6.5 Summary statistics for monthly oil price returns

	Heteroscedasticity *Cook Weisberg* χ^2*	Autocorrelation *Durbin-Watson-Test***
Log return	0,65	2,023

* No heteroscedasticity at n=1 if $\chi^2 < 3{,}5415$
** No autocorrelation if 1 > x < 3

Other studies use daily returns of oil prices as basis for their volatility calculation and apply different models, such as (G)ARCH[98] or historical simulation with ARMA.[99] In this paper implied volatilities are utilized to generate scenarios in a distant future. Thus, the average yearly volatilities and log-normal changes in the oil price have been calculated on a monthly basis.

94 See Horn 2002, p. 108
95 In differentiation to the symmetric Hubbert-curve, the Gompertz-curve has an asymmetric shape.
96 $Var(R_t) = \sigma^2 = E(R_t - \mu)^2$, where μ is the mean.
97 $Var(R_t)^{0,5}$
98 See Bollerslev 1986
99 See Engle 1982

Figure 6.2 Oil price development in period one

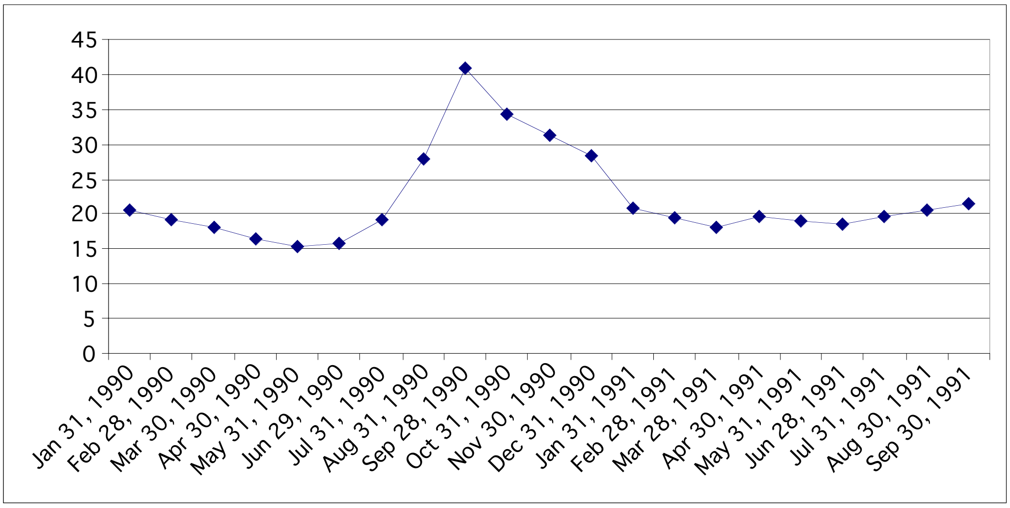
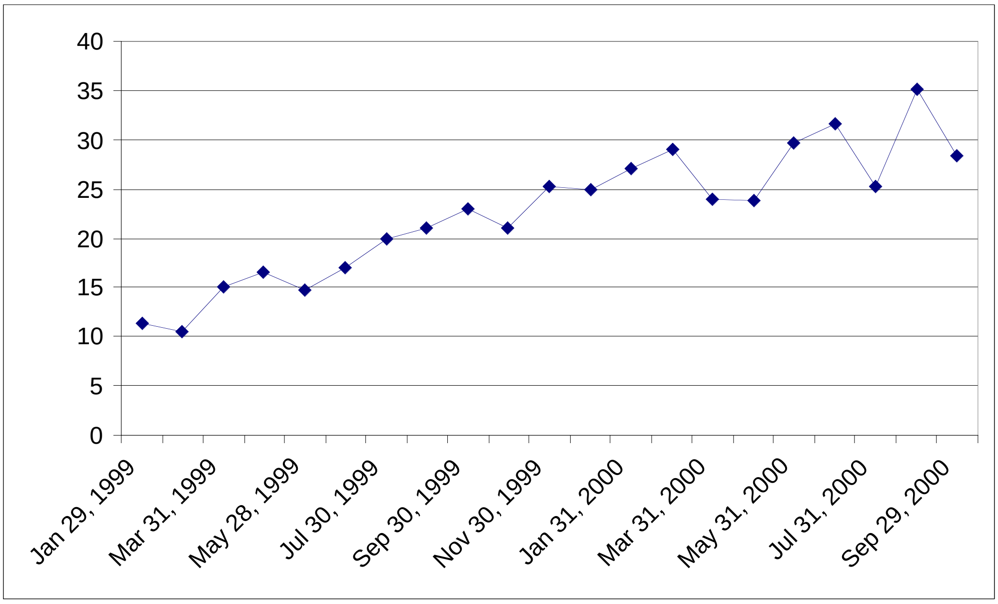


Figure 6.3 Oil price development in period two



Both periods are utilized to describe the variables of the two basic scenarios S_1 and S_2. Over the 21-months time frame, period one features a higher level of volatility, but lower rate of monthly price increases. In comparison the average monthly volatility of period two is lower, but the oil price increases with higher pace.

Table 6.6 Average volatility and price changes for 21-month period

Scenario	Average monthly volatility	Average monthly price increase
S_1	18,02 %	0,037 %
S_2	6,88 %	2,05 %

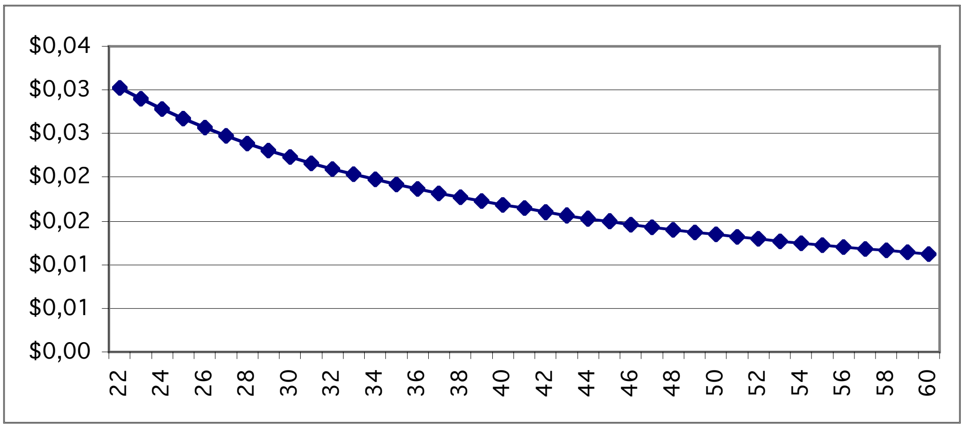
6.3 Determining the extended scenarios' variables

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";[100] 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 month; 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 applying a linear trend formula $p = c_{a-1} + (c_{a-2} * t)$, where p is the price in US$, 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}.

Figure 6.4 Monthly rate of log-normal price change for the regressive price trend



The price development in sub-scenario "c" is exponential. The underlying formula is $p = c_{c-1} * e\ (c_{c-2} * t)$.

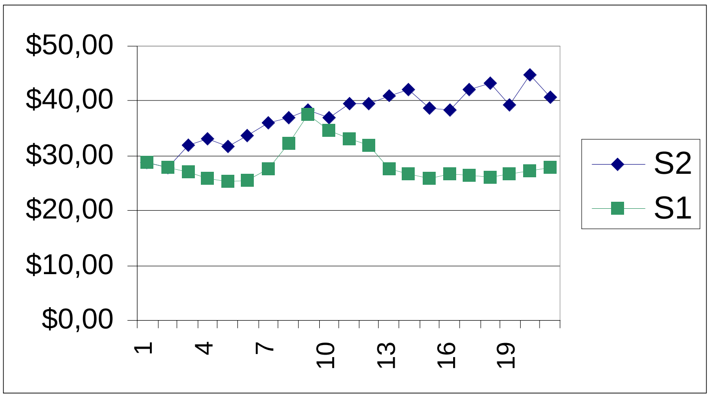
In the case of a price development in the extended scenario hits the backstop price of 70 US$/barrel, it is assumed that the price does not increase further and stops at this level for the rest of the considered time frame. As the implied volatility is hold constant in the extended scenarios, the VaR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

[100] See Stiglitz 1992

6.4 Results

The statistical results of the two 21-month periods were applied to the four price estimations and an assumed depletion mid-point in 2005. As an example, figure 6.5 illustrates the two possible scenarios on the basis of the EIA high price estimation.

Figure 6.5 Depletion mid-point scenario 2005, prices in US$/barrel, first 21 months



In scenario S_2 (blue graph) the market reacts immediately after there is a common agreement regarding the occurrence of the depletion mid-point. Within the first 21 months the price reaches a level of US$/barrel 40.64. In scenario S_1 (green graph) the information needs certain time to hit the market. After the first seven months the oil price is skyrocketing and reflects an over-reaction of the market. At a peak of US$/barrel 37.56 the price normalizes, but uncertainty remains, hence a high level of volatility.

Table 6.7 and 6.8 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 6.7 Results of VaR – basic scenarios – in US$/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 6.8 Results of VaR – basic scenarios – in US$/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 US$ 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 US$ 2.42 within the next 21 month. On the other hand the VaR can increase to a maximum level of US$ 11.16 applying the EIA estimations and even US$ 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.

Table 6.9 and 6.10 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 6.9 Results of VaR – 5-year horizon – in US$/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 6.10 Results of VaR – 5-year horizon – in US$/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 US$ 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 US$ 13.24; applying the Horn-Gompertz forecast the possible VaR reaches even US$ 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.

7 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."[101] 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 carbon risks.

An examination of literature on the assessment of carbon risks reveals that the output dimension – climate change – is one of the biggest issues the world faces in the 21st century. Finally, this seems to have attracted the attention of the business community; but financial markets still do not price corresponding risks. Furthermore, confirmations pertaining to risks in the input dimension are lacking despite the importance of carbon resources in today's economy. Therefore, the purpose of this study is to broaden the discussion on corporate environmental risk exposure by integrating an oil scarcity factor. This broader approach can be utilized as a means of instigating a discussion on carbon risks beyond output oriented adaptation and mitigation strategies. 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;[102] 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 US$ 2.4 up to 15.5 within the first 21 months.
- The follow up scenarios result in a VaR between US$ 4.1 and 17.2 for the end of the five-year time frame.

[101] See Innovest 2002b, p. 25
[102] See Rettberg 2004a and Rettberg 2004b

- 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 the VaR is going to be; volatile oil prices as a result of uncertainty will foster this.

7.1 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.[103] 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.

[103] See Meacher 2004, Roberts 2004, Campbell 1997

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: as discussed in chapter four 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.

7.2 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,
- It's position in the value chain, and
- The location of its operational activities and sales.

In accordance to 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.[104] 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.

[104] Roberts 2004

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 easy substituted or technical altered and which have to rely on oil. The results help to evaluate different strategies and options.

For example, a company works in the chemical industry and uses oil as an input factor, both within a specific production process and for the energy production. Assuming the case that a sudden and permanent shortage in oil occurs, the company has to adapt current strategies; two options are possible: (1) A specific production system could be replaced by a new one with less oil consumption. This alternative is combined with high investment costs. Furthermore, the process is still relying on oil. Assets like this are very inflexible concerning the substitution of oil. (2) On the other hand, single assets for energy production can be considered to be more flexible in terms of adaptation strategies: An oil based combustor can be replaced by a new one using an alternative energy source; or at least the option of outsourcing exists.

Incorporation of 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.[105] 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.

[105] Compare Faff/Brailsford 1999

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).

Development of 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.

7.3 Suggestions for further research

In general further research is advised to put emphasis on more concrete calculation of VaR of resource inputs and volatility forecast. With the focus on oil scarcity, the development of further highly significant variables for oil can increase the describing and forecasting value of this VaR model.

Future studies could develop an integrated evaluation model including the VaR of oil as an input factor and VaR of climate change. Garz and Volk (2003) calculated the worldwide market VaR of climate change at the macro-level. It is a challenging task to answer the question of how these results can be transferred to the micro-level. Given precise outcomes result, the combination with input oriented VaR figures could generate an overall carbon risk assessment.

Beyond the limitations of this model, a certain level of consensus about this topic will settle sooner or later as a matter of fact. Then management models and analysis instruments are needed to incorporate derived threats and risk. Thus, adequate tools such as the suggested benchmark system should be developed by then. It has to be scrutinized to what extent single companies and sectors are affected by oil scarcity; empirical simulations and correlation studies are needed to reveal the actual coherence between carbon risks and companies' success.

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