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A critical review of the peak oil phenomenon

by

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"This thesis was written as a part of the Master of Science in Economics and Business Administration at NHH. Neither the institution, the advisor, nor the sensors are - through the approval of this thesis - responsible for neither the theories and methods used, nor results and conclusions drawn in this work."

Executive summary

Through this master thesis I have done a critical review of the peak oil phenomenon. My analysis indicates that the production profiles for several countries seem to follow the Hubbert curve, but at the same time the methodology does not give reliable predictions. That means that the Hubbert curve seems better suited to explain the past, rather than predict the future.

My further discussion revealed large uncertainties regarding the size of the ultimate resource base, and how long we can expect it to last. It is also an open question whether or not peak oil will occur as a result of geological factors, or if it will arise as a result of other above ground factors. In this context, the thesis found that lack of investments, politics and lapse of demand can all, or in combinations, cause peak oil.

Contents

Preface

I have looked forward to write my master thesis for a long time. It is a unique opportunity to use a semester to look into something which interests me. I developed my interest for future energy supply during my bachelor at the Norwegian School of Economics and Business Administration (NHH). During my master degree this interest increased, something which made the choice of theme for my thesis simple. In this master thesis I will look into to the phenomenon of peak oil, using acknowledged literature trying to contribute to the understanding of the future energy situation.

The work has given me a unique possibility to learn more about the future of oil production. It has periodically been challenging, but also very interesting. There is no doubt that I have had steep learning curve. When this process started, I was convinced that there is nothing in the peak oil arguments. But through this work, I have realized that the problem is much more complex then what I first thought. Today, my understanding is much broader, and it is clear that multiple factors are affecting the outcome of the future supply of energy. I now look at the peak oil debate with brand new glasses.

It has been a challenge to identify relevant literature. In my view the debate is partly dominated by people and groups that cannot be assumed to be serious contributors to the debate. Instead they are using peak oil as an argument to promote and support other statements and interests, often political. Therefore, I have decided to build my thesis on books and articles written by authors renowned for their opinions in both the peak oil- and the non peak oil community.

I would like to thank my supervisor, Professor Rögnvaldur Hannesson. The collaboration has been excellent. He has given me enthralling guidance in addition to quick and constructive response to all my questions. This has undoubtedly contributed to both my thesis and my personal interest for the theme. Professor Hannesson has also been helpful recommending relevant literature. I would also like to thank Øyvind Våge Nilsen in The Ministry of Petroleum and Energy for help to find further relevant literature. Last but not least, I would like to thank my cohabitant, Inger Anne Halrynjo. She has been a good supporter and has through many intense debates tested the strength of my arguments. Such discussions have obviously been valuable. Although contributions from others, I am in the opinion that I have worked independently with the thesis, and that I have worked my way towards the finished product myself.

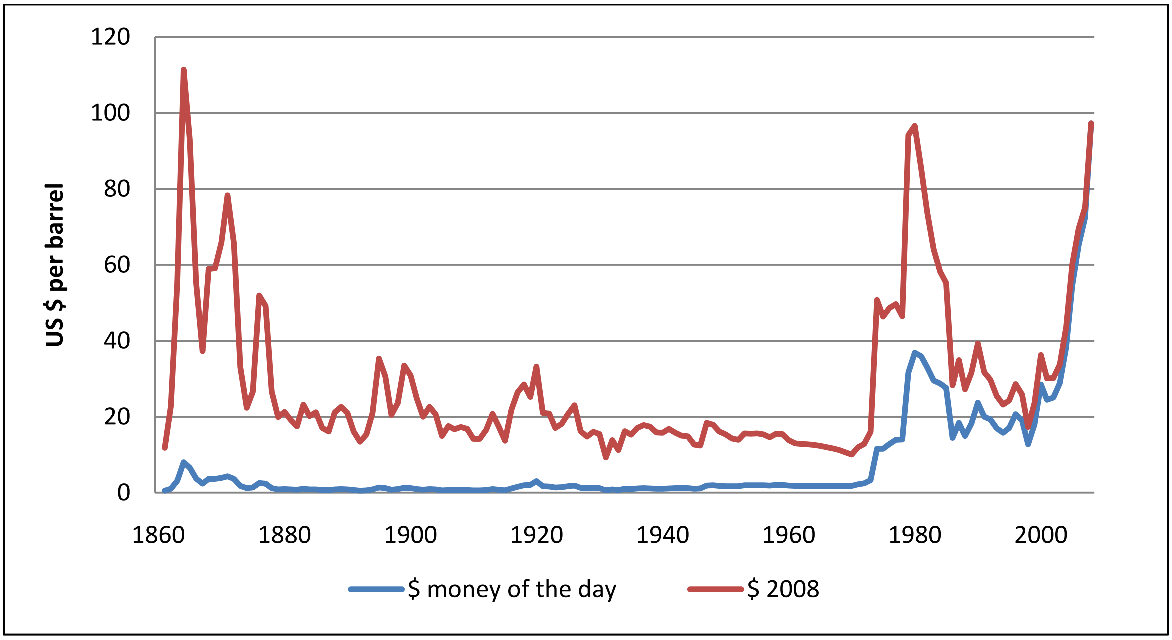
Nils Petter Fosse Bere

Oslo, June 2010

1.0 Introduction

Based on the text, *"A critical review of the peak oil phenomenon"*, I will like to take a closer look behind the peak oil debate. The recent high oil prices have again brought life to the peak oil debate, putting emphasis on how important oil is in the modern economy. There is no doubt that oil has contributed to develop the world we know today, and one can argue that cheap oil has been a very important driver to the enormous economical growth we have seen the last hundred years. Since oil is a non-renewable resource, it gives rise to a concern about what happens when all the conventional oil has been spent. A fast increasing oil price is not a new phenomenon. The historical price level of crude oil is illustrated in figure 1. The crude prices are reproduced in appendix E.

Figure 1: Historical crude oil prices 1861-2008

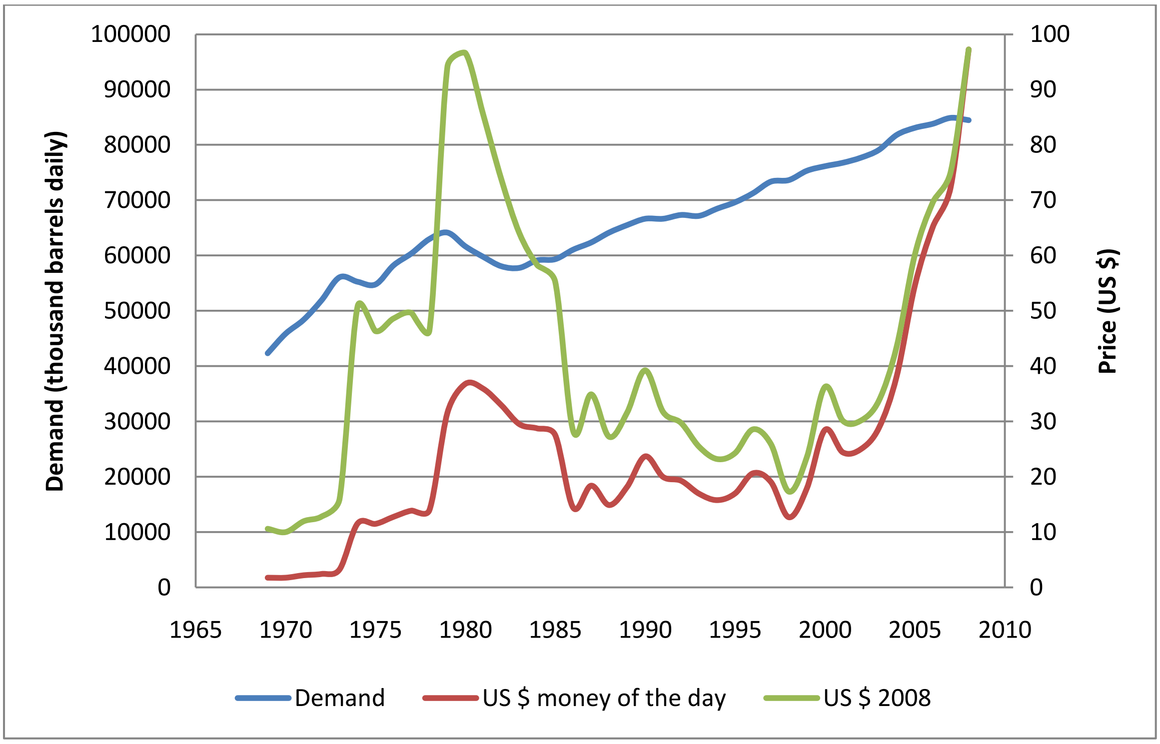


Source: Illustration based on data from BP Statistical Review (2009).

As the figure illustrates, the real price of oil had falling trend throughout the first century of production. It was not until the price shocks in the 1970s that the oil price started to increase. The 1970s is a good case study when trying to understand the world's dependence on oil. The collocation in price and demand is illustrated in figure 2.

Figure 2: Collocation in price and demand 1969-2008

1969 - 1983: Price is calculated using average Arabian Light posted at Ras Tanura.
1984 - 2008: Price is calculated using yearly average nominal Brent Dated.



Source: BP Statistical Review of Energy (2009)

The 1970s showed that even if there was a rapid increase in the oil price, the world demand continued to grow. In 1969, the last year of relatively cheap oil, the price of oil was about 1.80 US dollars per barrel and the world demand was about 42 million barrels a day (BP Statistical Review, 2009). According to Simmons (2005), many experts at the time argued that the price was excessive. But still, the oil price rose steadily from 1969 until 1973. From October 1973, there was a rapid increase in oil price due to the oil embargo carried out by OPEC as a result of the Yom Kippur war. The embargo made the oil price stabilize at a price level of 10 to 15 US dollars per barrel. In 1978 the oil price was 14 US dollars. Within the same timeframe (1969 – 1978), the global oil demand increased from 42 to 63 million barrels per day. Even if the price increased almost 8 times, the demand for oil increased with 50 percent. These data illustrates how important the oil is, and how little a change in price level influence demand. It indicates that the demand is inelastic on short term basis.

It was not until the Iranian revolution started in 1979, and the oil price increased to 31 US dollars per barrel, that the demand stared to decline. The collocation between price and demand is illustrated in figure 2. The oil price stayed relatively high from 1979 to 1985, and demand was falling throughout that period. Looking at the period from 1974 to 1985, we see that the demand almost stagnated. This illustrates how the demand is affected by changing price level on longer terms. In other words, it indicates that the demand is more elastic over time.

The oil price stabilized in the 1980s and 1990s, but during the last few years the oil price have multiplied reaching an average price of 97 US dollars in 2008. In July 2008, the crude price almost reached 150 dollars per barrel. The demand has increased gradually since 1985.

Using this example on today's energy situation, the recent high oil price may be a result of inelastic demand, meaning that a huge change in price does not influence the demand to a great extent. In a future situation with restricted supply, the price may reach very high levels. Both Fattouh (2010) and Maass (2005) stress how the combination between the inelastic demand for oil and the lately narrowed gap between demand and supply gives little possibility to act when it comes to stabilize shocks in the market. If the recent high oil price is due to lack of spare capacity, it may indicate that the suppliers are struggling getting enough oil to the market, something which can be interpreted as a warning of peak oil being close in time.

Today's situation is quite different from the situation in the 1970s and 1980s. When OPEC reduced their production in the 1970s, new oil provinces like the North Sea and the Gulf of Mexico was ready to compensate for the reduced OPEC production. At the same time, the developed world faced an economic stagnation, something which reduced the demand for oil. Today, the situation is different. Firstly, there are no obvious new provinces ready to compensate for falling oil production in other provinces. Secondly, there is a very high economic growth in some large developing countries which require oil. I will take a closer look at this in chapter 5.

When it comes to my thesis main topic, peak oil, it is general agreement to the fact that oil as a non-renewable resource one day will be exhausted, at least in an economic sense. But just saying that an exhaustible resource will be exhausted does not add anything to the debate. It is rather the deduction of a self-evident truth. It is worthless to predict the future by saying that an exhaustible resource will eventually be exhausted and its production will decline until extinction after reaching a peak. Such statements are under certain conditions just a tautology. In my view, the interesting debate includes the questions of what happens when the peak is reached, what will cause the peak, and when will it happen. At that time the production capacity has reached its maximum, and cannot continue to grow, something which implies that either or both the demand and supply has to adjust to a new reality. With a world that demands more and more energy, this may be a serious challenge for future generations.

Based on the above text, I will like to divide the task of this thesis into three different subtasks, which can be summarized as:

- Do production paths follow the Hubbert curve?
- How large is the world's ultimate resource base?
- Can other factors, not related the Hubbert methodology, cause peak oil?

To answer these three subtasks, I have chosen to split the rest of the thesis into four chapters. In the first part, chapter 2 and 3, I will present the phenomenon of peak oil, and give a theoretical approach towards it. In chapter 3 I will analyze the Hubbert methodology in two different ways. Firstly, I will analyze how the Hubbert curve correlates with historical production data. Secondly, I will test the reliability of the Hubbert predictions. In the second part, chapter 4, I will look deeper into the most fundamental assumption behind the peak oil theory, which is the total amount of oil in the world, referred to as the ultimate resource base. Further, I will use the third part, chapter 5, to go closer into other factors influencing the future of oil, and discuss how non-geological factors may be of vital importance when it comes to the presence of a production peak.

2.0 The phenomenon of peak oil

As mentioned before, this chapter will introduce the phenomenon of peak oil, which is the time when the global rate of crude oil extraction reaches its maximum rate, and then starts to decline. The chapter will also give a theoretical approach towards it.

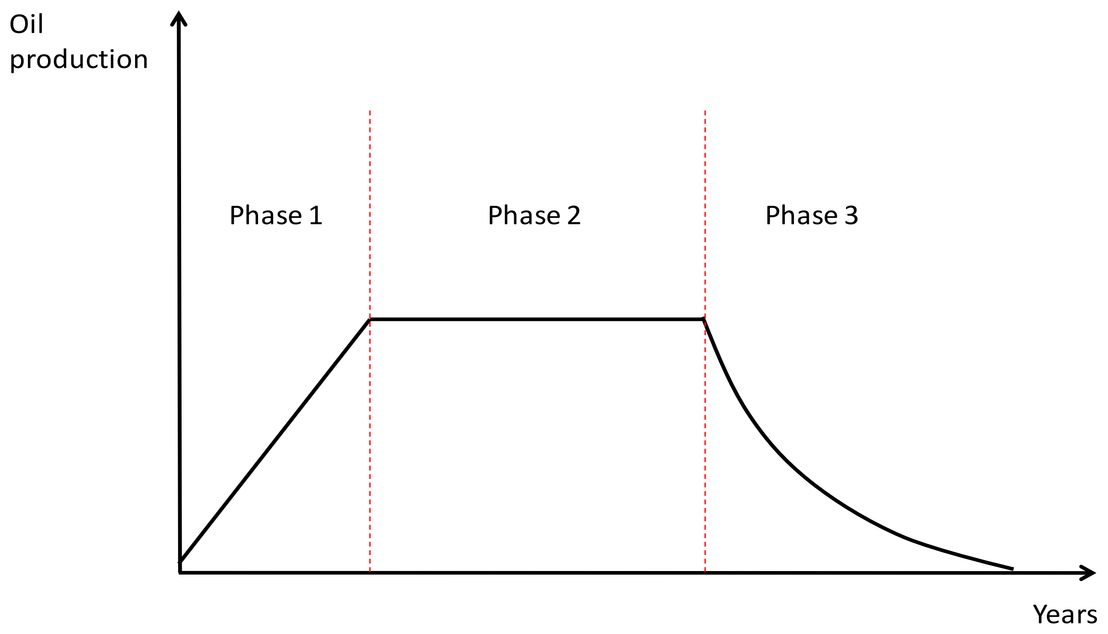
2.1 Introduction to peak oil

There is a fundamental concept surrounding the debate of peak oil production which is often misunderstood. This is the use of the word *peaking,* which does not mean that the world is running out of oil, but is rather a concept of reaching a maximum production level.

According to the NPC Global Oil & Gas Study (2007), the essence in the peak oil debate is simple. There is a finite amount of oil in the world, something which implies that an everlasting growth in production and consumption is not sustainable. The idea is that geological scarcity at some point will make it impossible for global petroleum production to avoid falling, heralding the end of the oil age.

The world’s oil resources can be divided into reservoirs and wells. There are only so many wells required to efficiently extract oil from each reservoir. The production profile is given by the sum of many individual wells or reservoirs, added together to one production profile (Hannesson, 1998). An individual reservoir typically follows the specific path, illustrated in figure 3.

Figure 3: Typical production phases for a petroleum reservoir.

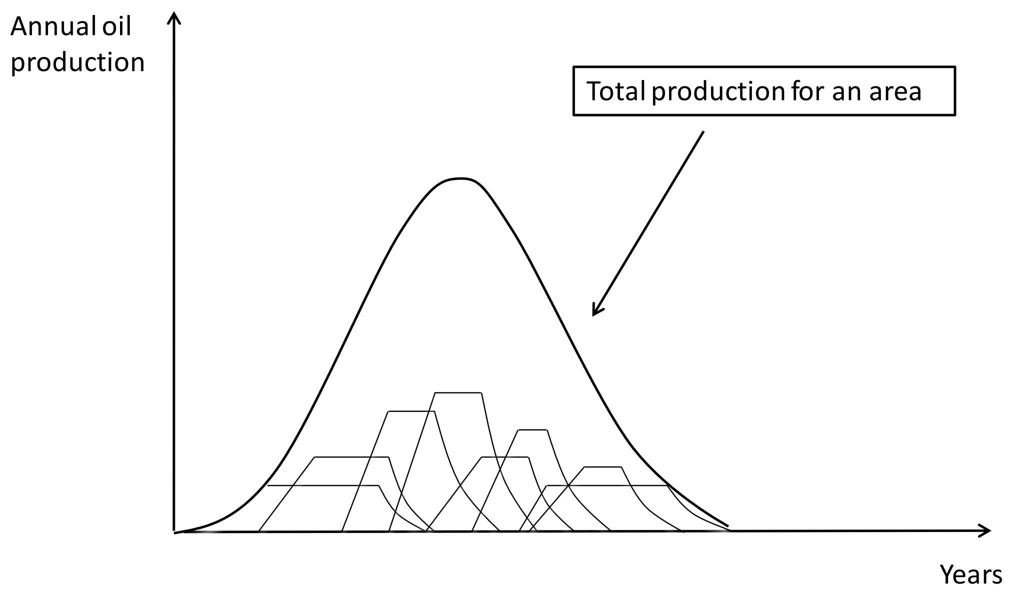


Source: Replication of Hannesson (1998), page 63.

The typical production path in figure 3 can be divided in three different phases. The first phase consists of a period with increased production rate. The increasing production rate comes from a growing number of production wells being drilled. When the optimal numbers of production wells have been drilled, the reservoir will reach its maximum production and eventually maintain at a production plateau in phase 2. When extracting oil, the pressure within the well starts to decline as more and more oil is extracted. Several methods can be used to maintain a certain level of production, but sooner or later, the production from the well will reach phase 3 and start to decline. In phase 3 the declining production will continue until the cost of extraction exceeds the value of the product sold. Thus, no reservoir has ever been pumped dry.

Since reservoirs will be exhausted at different times, the sum of them will not shape a production path equal to each individual path. As the industry in the area or country develops, more and more reservoirs are producing at the same time, something which gives an increasing total production. But since oil is a non-renewable resource, the resource is getting exhausted, making it more and more difficult to find new and economically feasible projects. At a given point, the production within the area will start to decline. The sum of many different individual wells gives us a bell-shaped production path, which is illustrated in the following figure:

Figure 4: The relationship between individual reservoirs and total production.



Source: Replication of Hannesson (2008).

It is difficult to determine the global production profile. Firstly, there is a lack of reliable data, including both known and unknown resources. Secondly, other factors have to be taken into consideration, for instance economic, political and technological factors. Since the production relies on multiple factors the predictions are hard to estimate. I will discuss the most important factors closely in chapter 4 and 5.

Since most economic models of exhaustible resources do not explicitly generate a peak in production, they do not give additional insight into the peak oil phenomenon. One example is the classic Hotelling framework, which predicts the net prices to grow at a rate equal to the interest rate. According to Holland (2006), even if extensions are done on the classic Hotelling model, including uncertainty, limited capacity, set-up cost, increasing cost with cumulative extraction, and different grades of ore, the model does not predict a peak in production. This raises the question whether an observed peak ever could have been predicted by using an economic model, or if production peak is an example of a market failure or disequilibrium.

2.1.1 Two different views on peak oil

The debate of peak oil is dominated by two different polarized groups. One side consists of the *peak oil community*, or *peakist*. This group of people argues that geological scarcity will make it impossible for global petroleum production to avoid falling, and that it will start happening in the near future, heralding the end of the oil age. They predict that the production rate will drop rapidly after the peak is reach, something which will cause a potential economic catastrophe. Thus, they emphasis an urgent need of developing both foreign and domestic policies to address economic implications associated with post-peak decline in global oil production.

The other side is the *non-peak oil community*. This group consists of people who do believe that the oil production will continue to grow for many decades to come. They acknowledge the fact that oil is a nonrenewable resource, something which implies that the consumption of oil cannot grow forever. Thus, there has to be some kind of a future peak in oil production. But, they also believe that the resource base is sufficient to sustain an increasing rate of production for many years to come. Further, this group also differs from the peak oil community regarding their expectations of what will cause the peak, and in their expectations regarding what will happen when the peak is reached. In contrast to the peak oil community, the non-peak oil community argues that the production rate will not drop rapidly after the peak is reach. Instead, they argue that the production will stabilize at a plateau, or at least fall more slowly than the peak oil community predicts. As this thesis will illustrate, the outcome of the prospects depends heavily on the assumptions made.

2.1.2 Definitions

Before I present some of the theoretical framework behind the idea of peak oil, I would like to stress the importance of definitions and how they influence the outcome of the debate. The definitions mentioned in this chapter are summarized in table 1.

The debate depends heavily on the definitions of the resource base. By this I mean what to include in the base, since there are several categories of oil. Each of the categories has different costs, depletion profiles and characteristics. While some of the categories are easy, fast and cheap to produce, others are the opposite. In this context, terms like c*onventional* and *unconventional* are widely used. According to World Energy Council (WEC, 2007), there are no standard definitions of the terms, something which leads to confusion. In this thesis, I will define the term *conventional* to include oil extracted by the use of traditional well method. The term u*nconventional* is defined as oil extracted by the use of non-traditional methods, including extra-heavy oil, bitumen, shale-oil and oil from coal.

There is also confusion connected to the use of the terms *reserves* and *resources*. While *reserves* are the amount of oil which are currently economically and technologically recoverable, *resources* are the quantities that cannot be recovered economically and technologically today, but may be so in the future. According to Odell (2004), to be classified as a resource, two basic conditions need to be satisfied. Firstly, there has to exist knowledge and skills to allow for both extraction and use. Secondly, there has to be a demand for the resource. We cannot talk about a resource if not both of these conditions are satisfied.

Table 1: Summary of definitions

Term	Explanation
Reserves	The amount of oil which is currently economically and technologically recoverable.
Resources	The quantities that cannot be recovered economically and technologically today, but may be so in the future.
Conventional	Oil extracted by the use of traditional well method.
Unconventional	Oil extracted by the use of non-traditional methods, including extra-heavy oil, bitumen, shale-oil and oil from coal.

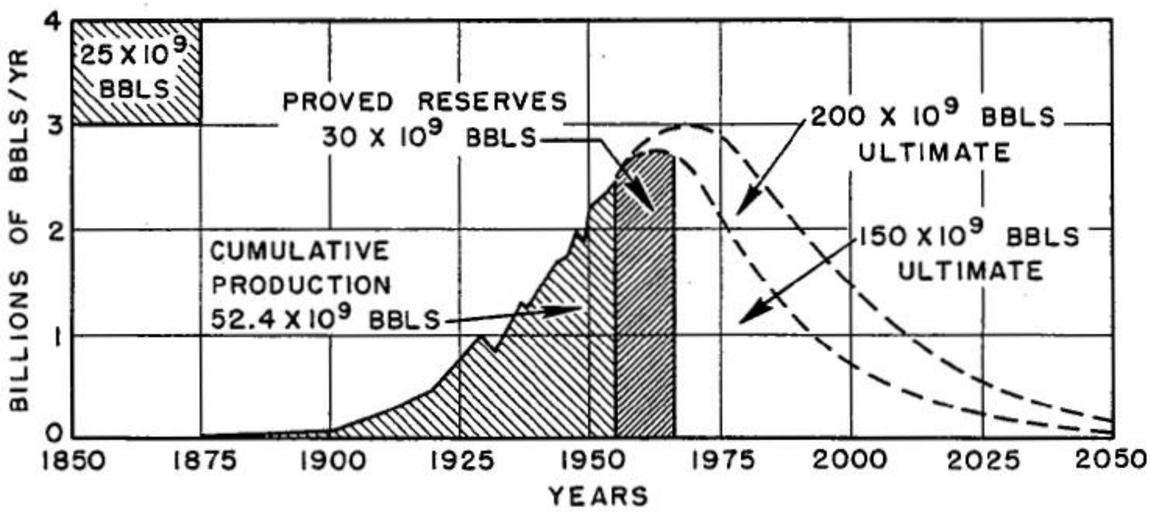
2.2 The Hubbert curve – geometrical approach

In this thesis I will present two different theoretical approaches towards the Hubbert curve. In this chapter, I will present *Hubbert's geometrical approach*, while I will present *Hubbert's mathematical approach* in chapter 2.3.

People have predicted a near-future peak in the global oil supply for more than half a century, without being able to hit the bull's eye with their prospects. What has given fuel to the debate of peak oil is the phenomenon of the Hubbert curve, or Hubbert's Peak, named after the US geologist Marion King Hubbert. He used the relationship between current production and accumulated production to estimate that the US oil production would start to fall early in the 1970s (Hubbert, 1956). At the time, Hubbert's predictions were controversial, but when they turned out to be true, Hubbert became a legend.

Today, Hubbert's way of thinking and the phenomenon of peak oil are used as an argument in the debate of future energy sources. The idea is that if the oil production within a specific area does follow the Hubbert curve, then it should also be applicable on a global scale. Hubbert's estimate from 1956 for the US crude oil production is shown in figure 5.

Figure 5: Hubbert's prediction for US crude oil production.
The ultimate production is based on assumed initial reserves of 150 and 200 billion barrels.



Source: Hubbert (1956), page 22.

Hubbert's prediction, which is presented in figure 5, was built upon the geometrical approach. He extrapolated the curve in the figure by making two basic considerations. Firstly, for any production curve for a finite resource, two points of the outset are known. This is when time equals zero (t=0) and when time equals infinity (t=∞). This means that we know for sure the production rate is zero when the time reference is zero, and the production rate will be zero when the resource is exhausted. Secondly, the ultimate cumulative production equals the shaded area in figure 6. This consideration arises from the fundamental theorem of integral calculus. If it exists a function

(1) $y = f(x)$,

then the

(2) $\int_0^{X1} y dx = A$,

where *A* is the area between $y = f(x)$ and the x-axis from *0* to *X1*. If the production curve is plotted against an arithmetical scale, we can write the ordinate as

(3) $P = dQ/dt$,

where *dQ* is the quantity of the resource produced over the interval *dt*. It is this logic Hubbert uses when he says that the area under the curve up to any time *t* is given by

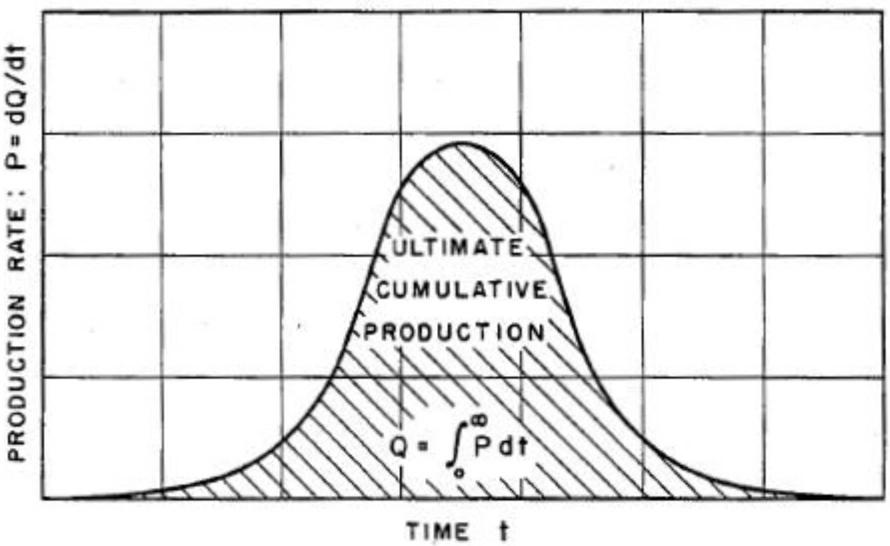
(4) $A = \int_0^t Pdt = \int_0^t (dQ/dt)\, dt = Q,$

where Q is the accumulated production up to time *t*. The ultimate production is given by

(5) $Q_{max} = \int_0^\infty Pdt$

These basic mathematical relationships are illustrated in figure 6.

Figure 6: Mathematical relation between production rate and cumulative production.



Source: Hubbert (1956), page 10.

Based on Hubbert's two basic considerations, he argues that the only a priori information needed is the magnitude of the ultimate cumulative production (Hubbert, 1956). This production will be less, or at most equal to, the quantity of the initial resource. If we know the quantity of the initial resource, we are able to draw possible production curves. The curves will all begin and end with a production equal to zero, and encompassing an area equal to the ultimate cumulative production. But, even if the geometric approach derives the logic behind the bell-shaped curve, it does not give any mathematical formulas on how to fit and use a Hubbert curve. The curve is fitted using cumulative production and requires educated guesses about the global ultimate reserves.

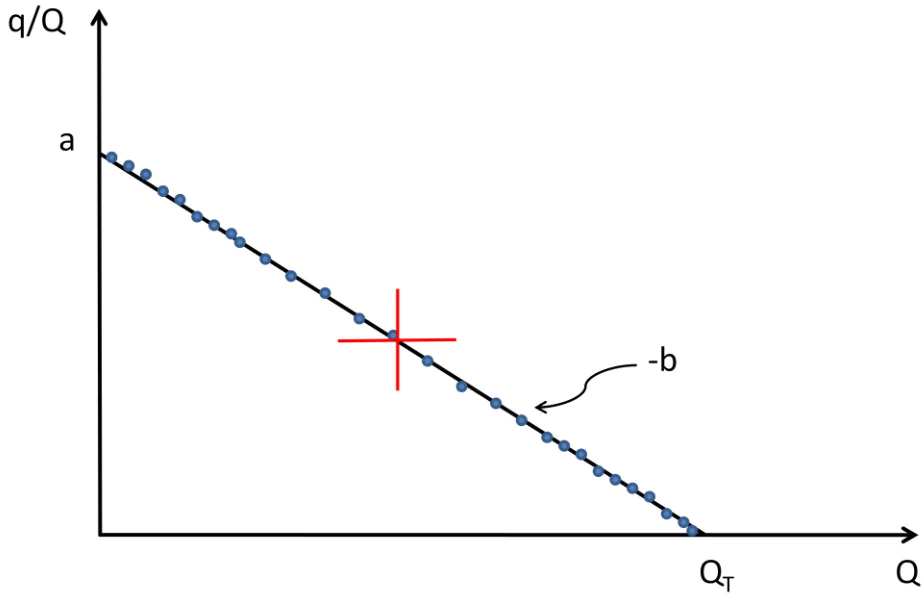
2.3 The Hubbert curve - mathematical approach

In addition to the geometrically fitted Hubbert curve, which was presented in chapter 2.2, the Hubbert curve does also have a mathematical approach. Hubbert presented this approach in his 1982 paper (Deffeyes, 2009). The mathematical approach gives an approximation towards the production profile without the use of educated guesses regarding the size of the global ultimate reserves. As Deffeyes argues, there are reasons to believe that Hubbert probably reached his conclusion first, and then searched for raw data and methods to support his conclusion afterwards. If these assertions are right, it means that the mathematical method should be seen as a mathematical approximation towards the original method, which consisted of educated guesses regarding the size of the ultimate global reserves.

Hubbert's mathematical approach is built upon a logistic curve. This means that the production actually has to follow a logistic shaped curve. Otherwise, the methodology is useless. Hubbert could have used several bell-shaped curves, such as the Gaussian, Lorentz and the logistic curve. All these curves are quite similar, and could all have been used for a mathematical approach towards the peak oil phenomenon. It is an open question why Hubbert used a logistic model, especially since the use of a Gaussian curve actually fits the US production outcome best (Deffeyes, 2009).

In Hubbert's 1982 paper, he presented a way of making a graph which turns a logistic curve into a straight line. This technique is referred to as Hubbert's linearization. An idealized graph is illustrated in figure 7.

Figure 7: Hubbert's linearization – idealized graph.



Source: Replication of illustration Deffeyes (2009), page 153.

The horizontal axis is the cumulative amount of oil produced, and the vertical axis is the oil production per year as a percentage of the cumulative production up to that year. As the figure shows, the dots fall closer together at the beginning, and at the end, when only small amounts of oil are produced. If the historical production data are approximately a straight line on the graph, then the history is well described by a logistic curve. The cross in the center marks the peak year of annual production. The intersection between the straight line and the horizontal axis gives the accumulated production when the region is finally exhausted.

The logic behind Hubbert's linearization can be explained by using the following simple linear equation:

(6) $$Y = a + bX,$$

where *Y* and *X* is respectively the vertical axis and the horizontal axis of the graph (Deffeyes, 2005). The symbol *a* is a constant which gives the value of *Y* when *X* is zero. The symbol *b* is the slope of the line. When linking this simple equation (6) to Hubbert's linearization, we have to make the following translation, using the symbols from figure 7. Symbol Y becomes the oil production per year as a percentage of the cumulative production up to that year $\left(\frac{q}{Q}\right)$, symbol *X* becomes the cumulative amount of oil produced (*Q*), and symbol a keeps the same meaning. Symbol b can be calculated using the ratio $\frac{a}{Q_T}$. The negative sign is due to the negative slope of the curve. By doing the translation, we get equation (7).

(7) $\frac{q}{Q} = a - bQ$

Rewriting equation (7) gives equation (8).

(8) $q = aQ - bQ^2$

Based on the above derivation, the annual production will evolve over time as stated by equation (9), which gives the relationship between the current production (g_t) and accumulated production(Q_t), where *a* and *b* are constants. To be able to estimate a logistic curve, like Hubbert did, one has to estimate the parameter values *a* and *b* in the logistic curve (Hannesson, 2008). To do so, one needs several years of production data. The estimation can be done by minimizing the sum of squares of the misfits between the historical observations and equation (9), or by the use of Hubbert's linearization.

(9) $q_t = aQ_t - bQ_t^2,$

where:

(10) $q_t = \frac{dQ}{dt}$

Equation (9) and (10) gives us the equation behind the Hubbert curve, presented as a first-order non-linear differential equation (11).

(11) $\frac{dQ}{dt} = aQ_t - bQ_t^2$

(12) $\frac{dQ}{dt} = aQ_t\left(1 - \frac{bQ_t}{a}\right)$

(13) $\frac{dQ}{Q_t\left(1 - \frac{bQ_t}{a}\right)} = adt$

(14) $\frac{dQ}{Q} + \frac{dQ}{\frac{a}{b} - Q} = adt$

(15) $\int \frac{dQ}{Q} + \int \frac{dQ}{a/b-Q} = \int a dt$

By rewriting the equation (11) through equation (12) to (14), I can more easily solve the differential equation. By solving the equation, I find the Hubbert curve on a logarithmic form. The solution is presented in equation (16):

(16) $\ln Q_t - ln(a/b - Q_t) = at + k$

(17) $Q_t - \left(\frac{a}{b} - Q_t\right) = e^{at+k}$

(18) $\frac{Q_t}{a/b-Q_t} = e^{at+k}$

By rewriting through equation (16) to (18), I can more easily solve for e^k , something which gives me equation (19). The term e^k is a constant which can be calculated when setting a specific reference year. The choice of reference year is important when fitting the curve towards the historical data:

(19) $e^k = \frac{Q_t}{a/b-Q_t}$

Solving equation (18) for Q_t gives equation (20), which is the usual way of presenting the logarithmic version of the Hubbert curve. By using equation (20), I can trace the yearly cumulated production:

(20) $Q_t = \frac{(a/b)e^{at+k}}{1+e^{at+k}} = \frac{(a/b)e^k}{e^{-at}+e^k}$

The ultimate recoverable resource base is given when time goes to infinity, t → ∞:

(21) $\lim_{t\to\infty}\left(\frac{(a/b)e^k}{e^{-at}+e^k}\right) = \frac{a}{b} = Q_\infty$

Through equation 6 to 21, I have derived Hubbert’s mathematical methodology towards the peak oil phenomenon. By using this mathematical methodology, I will be able to make Hubbert curves, using only historical data as input. This can be used to make predictions about the future, giving us early estimates of the future production path. But, as mentioned earlier in this chapter, it is important to stress that the mathematical methodology is an approximation towards Hubbert's original methodology.

2.4 Critics and strengths by Hubbert's methodology

Cambridge Energy Research Associates (CERA) points out several weaknesses with Hubbert's methodology (Jackson, 2006). Firstly, Hubberts initial estimates were built on a geometrical approach. It was much later that Hubbert developed a mathematical approach. Secondly, Hubberts approach predicts the production to peak when half the resource base of an area is depleted. This means that the production path has to be symmetrical in time, which implies the decline curve to be a mirror image of the of the growth curve. Even Hubbert himself noted that the curve did not need to be symmetrical. Thirdly, the use of Hubbert's methods requires quite accurate knowledge of the size of the ultimate recoverable reserves. Even if Hubbert's mathematical approach does not need data for the ultimate recoverable reserves, the logic behind is built upon the assumption of a known and constant ultimate resource base. Numerous studies have shown the fact that the estimates for most oil fields, as a result of improved technology, often increase over time. An example is the North Sea, where the proven reserves increased by 86 percent from 1985 to 2006. The model does not incorporate technical or economic factors which influence the production capacity. In other words, the model simply ignores some of the major drivers of production. The critics are also supported by Deffeyes (2005), who argues that the Hubbert curve relies on an underlying assumption that the possibility of finding oil is strongly dependent of the fraction of undiscovered oil and that nothing else is of major significance, including the price of oil.

In general, most of the critics regarding Hubbert's method rely on the fact the method is very simple, but the simplicity is also one of the main advantages with the model. Instead of having to take into account multiple factors and enormous amounts of data, the method uses only the historical production to make a very simple approximation to a very complex world.

3.0 Analysis of Hubbert's mathematical methodology

I will now use the mathematical approach, which I presented in chapter 2.3, and analyze how well the model fits actual historical data and how good the predictions historically have been. The Hubbert curves are traced by the use of equation (20).

$$Q_t = \frac{(a/b)e^{at+k}}{1+e^{at+k}} = \frac{(a/b)e^{k}}{e^{-at}+e^{k}} \quad (20)$$

Firstly, chapter 3.1 will test how well the actual production correlates with the Hubbert curve. Secondly, chapter 3.2, will test whether or not the method gives reliable predictions, and try to give rational explanations for my findings making it a qualitative analysis. To limit the scope of the analysis I have chosen to take a closer look at available data for the United States (US), Norway and the United Kingdom (UK).

3.1 The correlation between actual production and the Hubbert curve

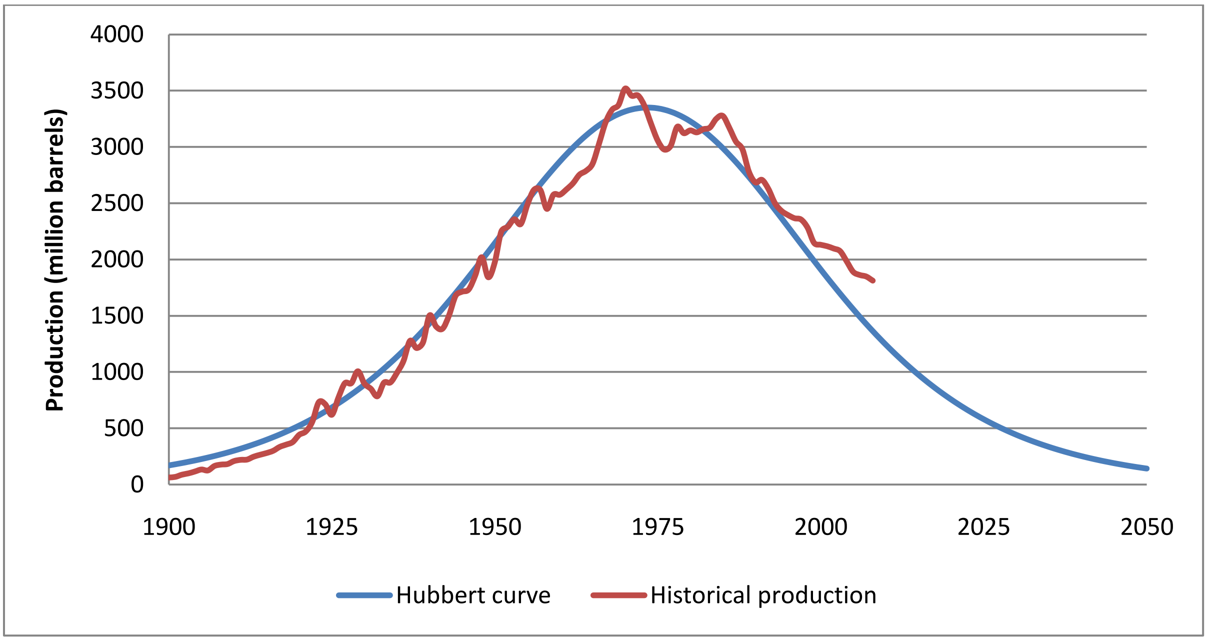
One can argue that some countries have a large enough production to influence the world market. Notwithstanding, I want to assume that each country's supply of oil does not make any significant influence on the world market price. Thus, looking at only a single country, the demand is not of significant interest. The demand is then given by the world market, and nothing else, and I will not consider the change in demand when discussing each single country's production. Looking at each single country, the interesting factors are the ultimate recoverable resource base within each country, and how the resource base tends to grow.

<u>US</u>

The analysis of the historical production and the US Hubbert curve is presented in figure 8. Looking at the figure, there should be no doubt to the fact that the US production is closely correlated with the Hubbert curve. Thus, the US production profile serves as an excellent example of the Hubbert curve. The Hubbert curve is based on data for all 50 states from 1900 to 2008. The reference year is set to 2008, but since the historical production follows the

Hubbert curve closely, the choice of reference is of little importance to the outcome of the analysis. Production data for the US are reproduced in appendix A.

Figure 8: Historical US production and the Hubbert curve
Year of reference is 2008.
Hubbert curve is estimated on dataset from 1900 to 2008.
Dataset includes all 50 states.



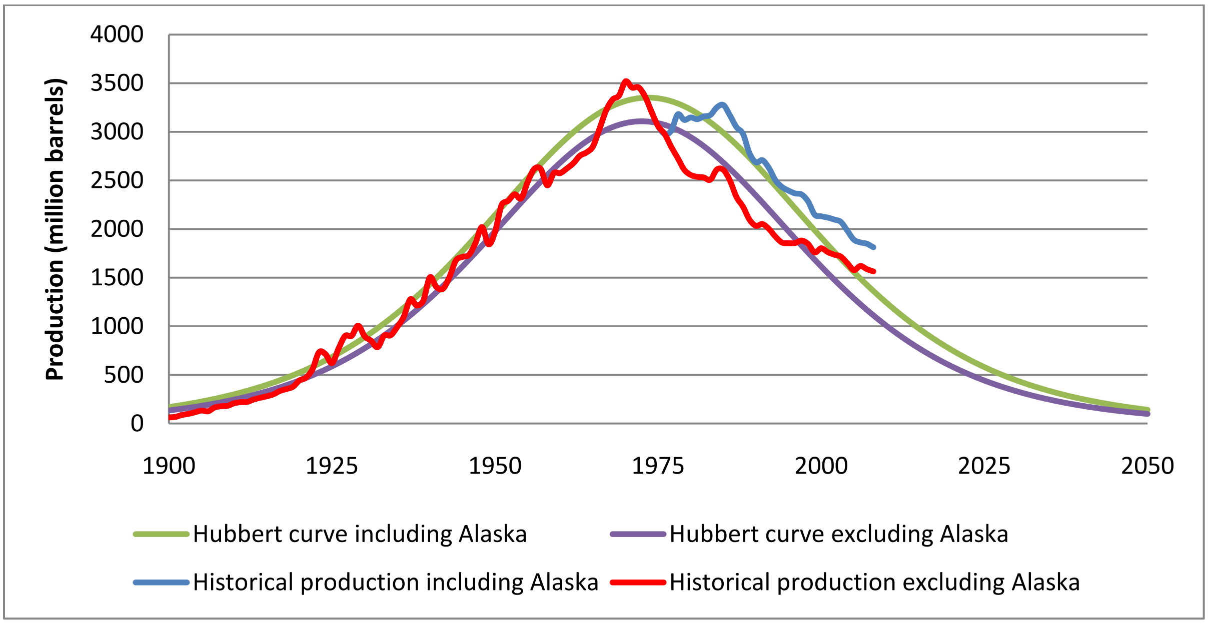
Source: Calculations based on EIA - 1.

Even though the US production profile clearly correlates with the Hubbert curve, it is important to note that the US production have been in decline for a long time, something which implies that there is not too many years' left to predict.

As discussed in chapter 2, Hubbert's methodology is based on the assumption of a fixed resource base. One can then ask if Alaska should be included in the historical US production, or if it is more correct to only include data from the contiguous states, referred to as the lower 48 states. Large oil reserves were discovered in Alaska in the 1970s, something which is a not consistent with the assumption of a fixed resource base. Figure 9 illustrates both Hubbert curves and the US production rate with and without Alaska. The Alaskan data are reproduced in appendix B.

Figure 9: US production and the importance of Alaska

Year of reference is 2008.
Data for Alaskan production from 1977 to 2008.
Data for US production from 1900 to 2008.



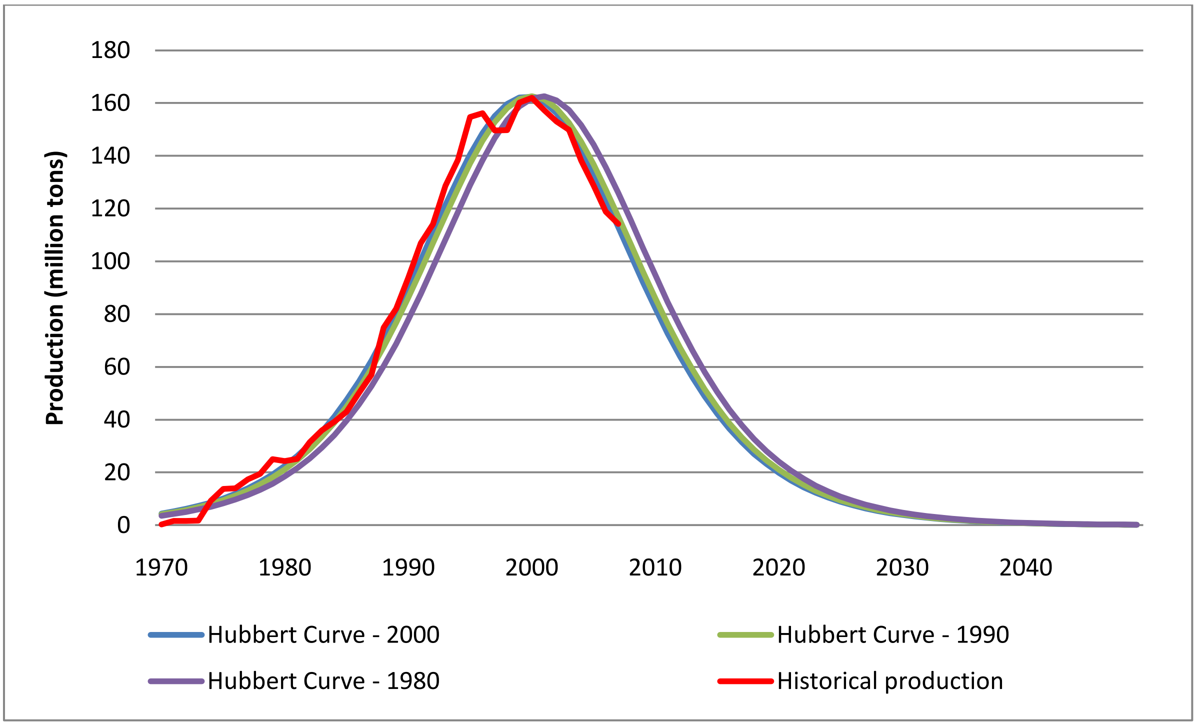
Source: EIA – 1 and EIA – 2.

As figure 8 shows, the oil production from Alaska moves the Hubbert curve outwards. This is not unexpected, since the Alaskan production for several years contributed for more than 20 percent of the total US production. In 1988, the peak year for the Alaskan production, the contribution was over 25 percent. It is also worth mentioning that the peak year is not affected by the choice of dataset, but by including the Alaskan production the Hubbert curve gets a higher peak which is more consist with the actually historical production. But as the figure shows, the question whether or not to include Alaska in the dataset has little influence on the big picture and when the US oil production ends. If the Alaskan production had been relatively larger, then we can expect the influence on the US Hubbert curve to be even larger. One can just imagine how the US Hubbert curve would look like if the oil discoveries in Alaska were equal to the Saudi Arabian reserves.

<u>Norway</u>

The Norwegian oil production is another good example of how the historical production profile follows the Hubbert curve. As figure 10 illustrates, independently of the choice of reference year, the method shows that the Norwegian oil production is in fact following the Hubbert curve very closely. This means that the choice of reference is of little importance for the outcome. The estimation is based on data from 1971 to 2008, using both, 1980, 1990 and 2000 as reference year. The Norwegian data are reproduced in appendix C.

Figure 10: Historical Norwegian production and the Hubbert curve
Year of reference is 1980, 1990 and 2000.
Hubbert curves are estimated on data from 1971 to 2008.



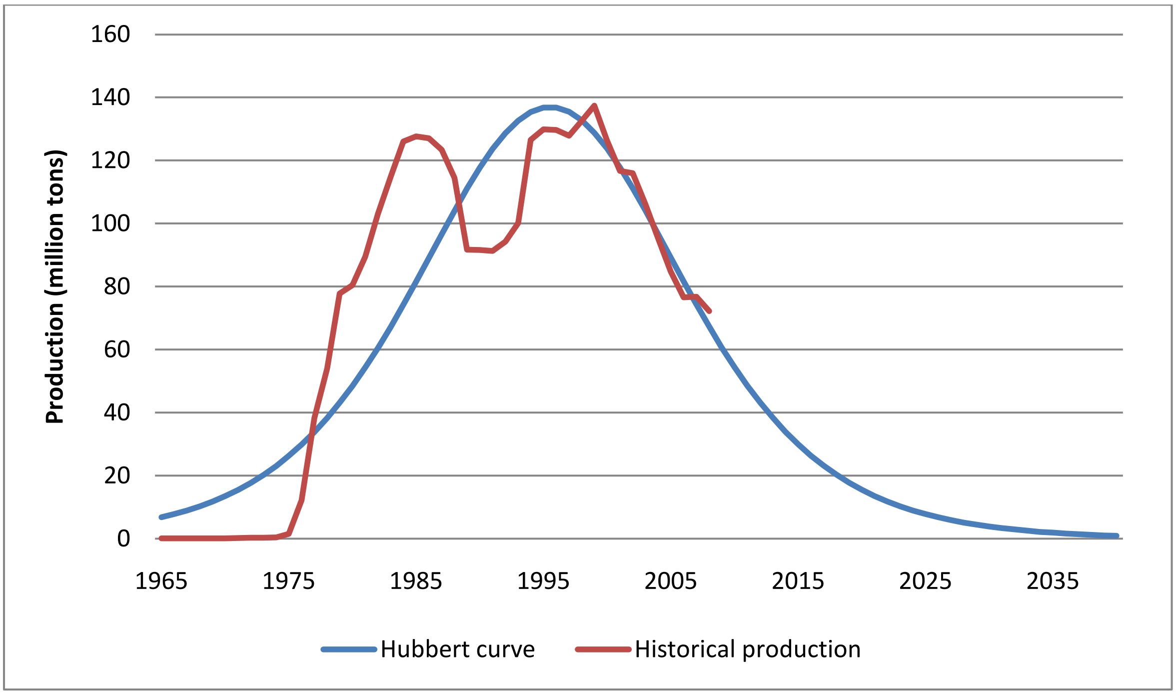
Source: Calculations based on data from BP Statistical Review (2009).

Comparing the actual Norwegian production with the estimated Hubbert curve, the estimates are very close to the actual production. This has mainly two reasons. Firstly, the Norwegian production has been kept within a limited area. This is vital for the methodology of Hubbert, which is based on the fact that the resource base has to be fixed. Most of the resources which have been added to the Norwegian resource base are mainly based on technological improvements and not major findings in new areas. But, we may expect that a possible future opening of the Lofoten and Vesterålen areas will make the Norwegian production profile shift outwards. This will be a breach with the underlying assumption behind the Hubbert curve, namely that the size of the ultimate resource base has to stay constant. Secondly, the Norwegian oil production is already declining. Thus, more than half of the production profile is already known for sure, something which means that there are not many years' lefts to predict.

United Kingdom

When looking at the United Kingdom's profile in figure 11, we see that the production path does not correlate with the bell-shaped Hubbert curve. The model is based on historical data from 1965 to 2008, where 2000 is used as reference year. It is worth mentioning that the UK had oil production from 1965, but the production was low and did not start to increase until 1976. The UK production profile does not follow the Hubbert curve closely, but has a rather rough approximation to the Hubbert curve. Production data for the UK are reproduced in appendix D.

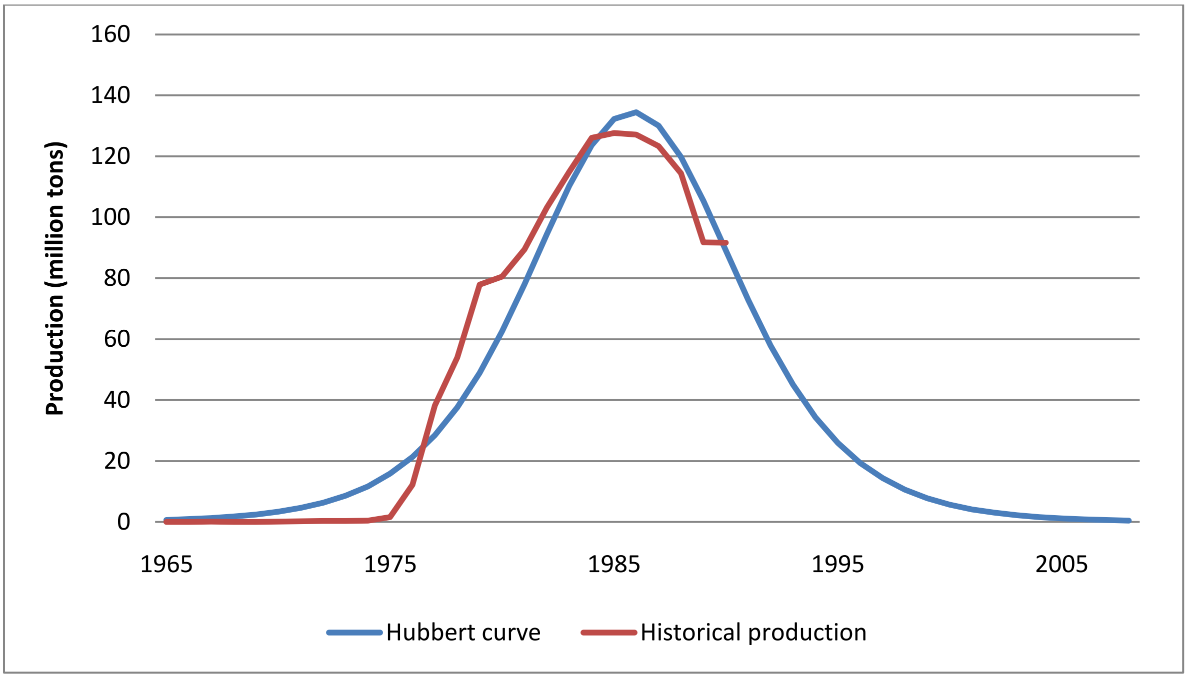
Figure 11: Historical UK production and the Hubbert curve.
Year of reference is 2000.
Hubbert curve is estimated on data from 1965 to 2008.



Source: Calculations based on BP Statistical Review (2009).

The production profile has two separately peaks. This is due to the Piper Alpha accident, which caused a dramatic production decline between 1985 and 1989 (ASPO, 2001). The accident forced the government to introduce new safety standards. But if we isolate the period from 1965 to 1990, we can see that the Hubbert curve roughly fits the historical production. This is illustrated in figure 12.

Figure 12: Historical UK production and the Hubbert curve.
Year of reference is 1990.
The Hubbert curve is estimated on data from 1965 to 1990.



Source: Calculations based on BP Statistical Review (2009).

Even if the Hubbert curve fits the UK production within a limited time frame, figure 11 and 12 does not give much support for the Hubbert curve. The fact that political involvement at such extent can influence the production profile clearly illustrates how non-geological factors do play a vital contribution to the progress of production, shown as the two peak production path in figure 11.

That fact that both Norway and the US seems to have a production profiles which follows the Hubbert curve, adds weight to the peak oil arguments. Even the UK production profile does have a disheveled bell shape. On the other hand, the historical UK production clearly illustrates how political considerations influence the production rate. In addition, the US production illustrates how new major discoveries influence the Hubbert curve.

3.2 The reliability of predictions made by the Hubbert curve

To test the reliability of the predictions made by Hubbert's logistic approach, which was presented in chapter 2.3, I have used the model to predict the countries' production paths based on historical data which should have been available at different points in time. In that way, I will be able to compare the estimates made with Hubbert mathematical approach with the actual production outcome. Just as my analysis in chapter 3.1, the Hubbert curves are traced by the use of equation (20).

$$(20) \qquad Q_t = \frac{(a/b)e^{at+k}}{1+e^{at+k}} = \frac{(a/b)e^{k}}{e^{-at}+e^{k}}$$

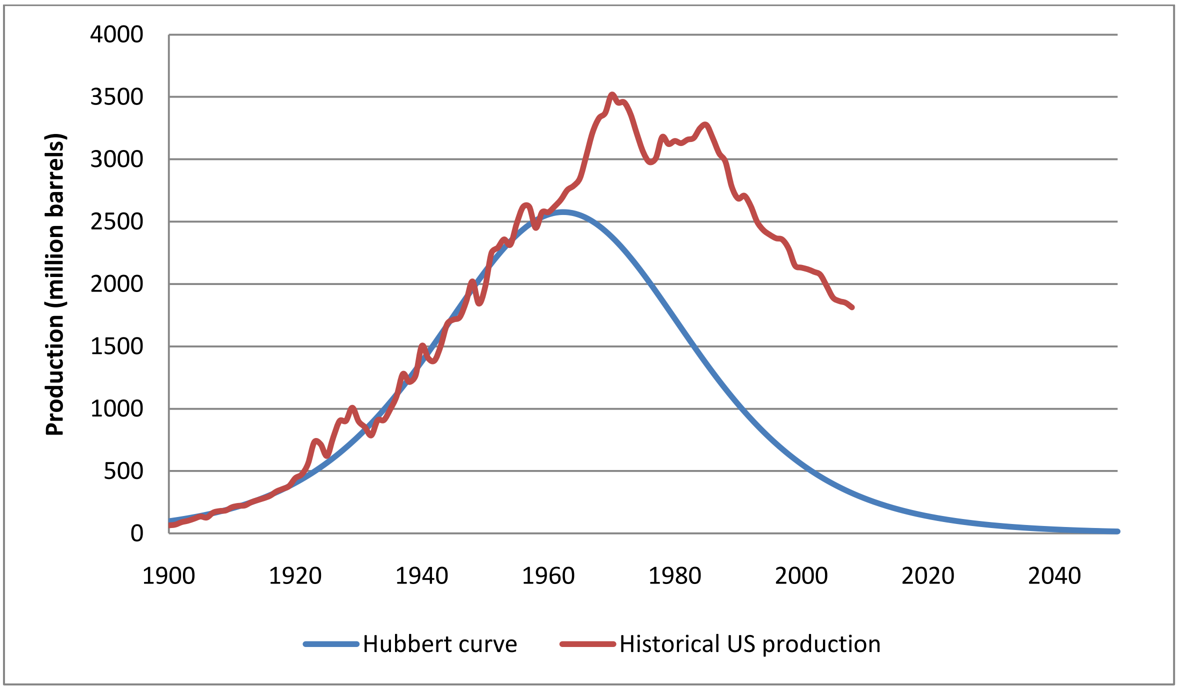
<u>US</u>

By testing how reliable the predictions made by Hubbert's mathematical approach are, I find it interesting trying to replicate the predictions made by Hubbert in 1956, when he predicted that the US oil production would peak in 1970. The calculations are based on the historical data available from 1900 to 1956, using 1956 as reference year. As discussed in chapter 3.1, the historical production follows the Hubbert curve so closely that the choice of reference year does not influence the outcome. The result is presented in figure 13.

Figure 13: Historical US production and a Hubbert curve based on available data in 1956.

Year of reference is 1956.

The Hubbert curve is estimated on data from 1900 to 1956.



Source: Calculations based on EIA – 1.

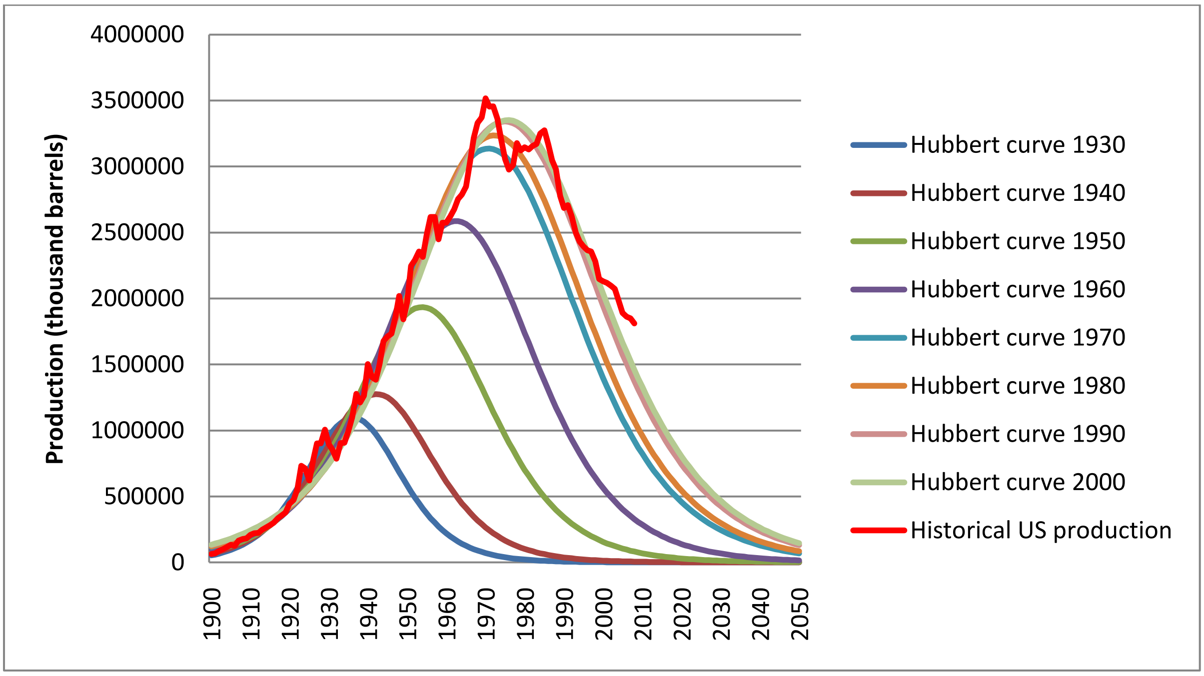
As illustrated in the figure, the use of Hubbert mathematical approach does not fit well with the actual US production profile. Hubbert's mathematical methodology forecasts the peak to be reached in 1962, with a maximum production of 2.58 thousand million barrels. Looking back in history, the US production reached its maximum in 1970, with a production of 3.52 thousand million barrels This is about 36 percent higher than what should have been the maximum production. Taking into consideration that the predictions were done in 1956, which is close to the predicted peak in 1962, the predictions has to be described as poor. On the other hand, Deffeyes (2009) stresses that we have to remember that Hubbert did not develop a mathematical approach until later, and based his predictions in 1956 on a geometrical approach, presented in chapter 2.2. This means that my replication of Hubbert's 1956 prediction is not built upon the same methodology as Hubbert actually used in 1956. This may explain the different results. Thus, an important factor is Hubbert guesses for the size of the ultimate reserves. In the mathematical approach, the size of the ultimate reserves is estimated as the constant *a* divided by the constant *b*, cf. chapter 2.3.

Another important factor influencing the accuracy of Hubbert's predictions relies on the fact that new major oil discoveries were done in Alaska. The super giant oilfield, Prudhoe Bay, was discovered in Alaska in 1968, something which expanded the US's resource base. Even if Prudhoe Bay is a large oilfield, it did not ensure that the US remained the world largest oil producer. The importance of Alaska was discussed on chapter 3.1.

Deffeyes (2005) stresses the question whether or not Hubbert could have predicted the US peak even earlier than 1956, or if Hubbert just had luck with his 1956 prediction. As figure 5 shows, Hubbert gave his readers a choice between two different estimates. It means that even if Hubbert managed to hit the bull's eye with his predictions, it was only one of the prospects that were right. One has to remember that giving more than one guess increase the possibility of hitting the target.

Anyway, the mathematical approach does not predict the peak to come in the same year as Hubbert predicted in 1956. This may not necessary be a coincidence. According to figure 14, it looks like it exist a trend that Hubbert's mathematical approach predicts the peak to come in the near future as long as the peak is not reached. As time goes by, the predictions of the peak is moving into the future.

Figure 14: Evolvement in the Hubbert curve over time – US dataset.
Year of reference is set equal to respectively prediction years.



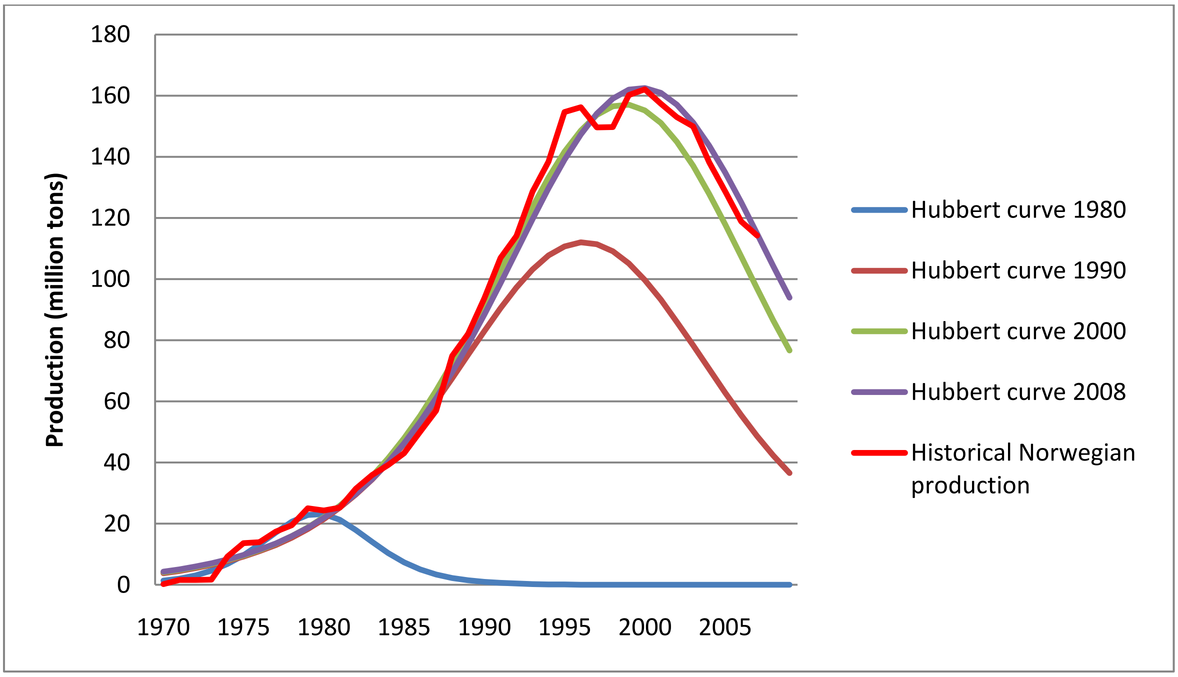
Source: Calculations based on EIA – 1.

Based on my findings in figure 14, it seems like the Hubbert curve does not predict the peak until the peak is almost reached. The predictions of the US oil production show that the peak is predicted to arise about 2-6 years after the year when the predictions were made. The trend seems to exist as long as production is increasing. This indicates that Hubbert's mathematical approach does not give reliable predictions of when a peak is to be reached, as long as the production is increasing. It is not until the peak is near that the Hubbert curve actually makes reliable prospects of the oil production.

Norway

The findings done on the US dataset are supported by similar findings in the Norwegian dataset. By making a Hubbert curve with the historical data available in 1980, 1990, 2000 and 2008, I have compared the predictions made by available data in the specific years with the actual outcome. The results are given in the following figure:

Figure 15: Evolvement in the Hubbert curve over time – Norwegian dataset.
Year of reference is set equal to respectively prediction years.



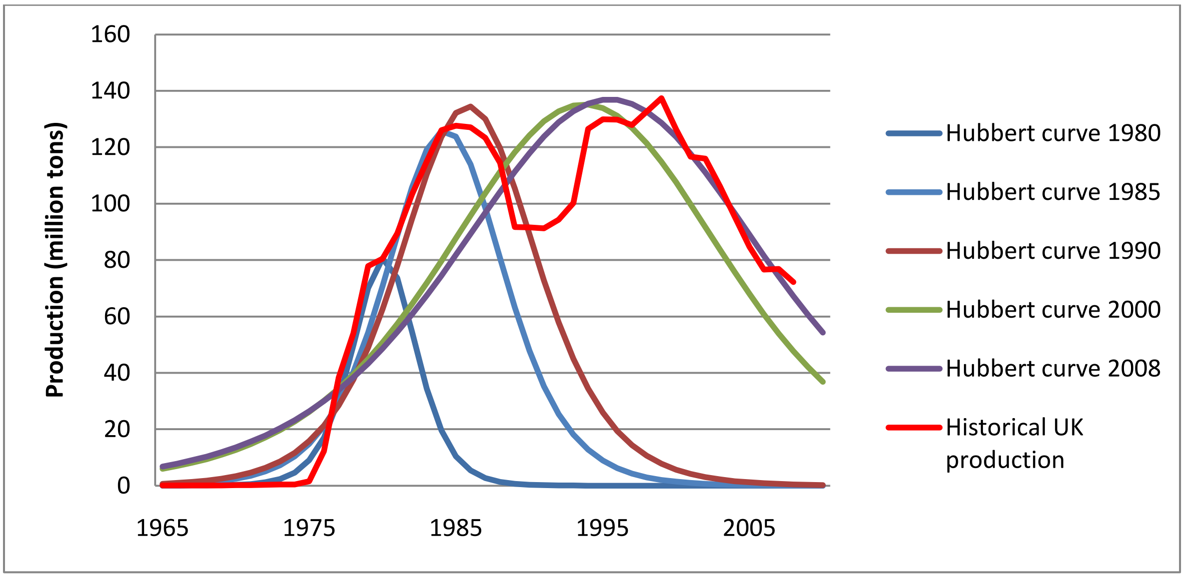
Source: Calculations based on data from BP Statistical Review (2009).

As figure 15 illustrates, the methodology developed by Hubbert does not give accurate predictions in the early phases of production. As seen in the US dataset, also the Norwegian dataset has a trend where the peak is predicted to arise a few years into the future. As we are getting closer to the actual peak, more data are added into the model, and the Hubbert curve adjusts to fit the actual outcome better. It seems like the predictions evolve over time, something which is not that surprising since more and more data is included in the model, making the model more accurate.

<u>UK</u>

In the same way as with the US and Norway, I will illustrate how the UK predictions based on Hubbert's methodology have evolved over time. A graphical illustration of the results is shown in figure 16.

Figure 16: Evolvement in the Hubbert curve over time – UK dataset
Year of reference is set equal to respectively prediction years.



Source: Calculations based data from BP Statistical Review (2009).

As the figure illustrates, the predictions evolve over time to fit the actual production. As discussed in chapter 3.1, the British production profile consists of two separate peaks. Thus, the analysis of how the predictions made by the Hubbert curve have been able to hit the bull's eye is not straight on. But, by taking a closer look at each of the two peaks, I will make the same conclusion as I did with the Norwegian and the US dataset, namely that the model needs so much data that we have almost reached the peak until the model is capable of predicting the peak fairly precisely. The use of Hubbert's methodology does not give reliable predictions, thus it does not have the availability to predict when the oil production will peak.

3.3 Summary

Based on my analysis of the three countries in chapter 3.1, which have had declining production for years, I will conclude that the production rates seems to follow the Hubbert curve. Thus, there may be something to the theory of Hubbert. Over time, one can therefore expect a production path for a defined area to follow a bell-shaped curve like the Hubbert curve.

My analysis in chapter 3.2 clearly reveals a weakness with the use of Hubbert's methodology, since the methodology always predicts the peak to arise in near future as long as the peak is not reached. This may work as a reasonable explanation why the peak oil community has failed in predicting the peak for more than half a century, and why they always predict the peak to be reached with a few years. My analysis of the production, clearly illustrates my point that Hubbert's method does not give reliable predictions regarding future oil productions.

The various estimations evolve over time to fit the actual outcome, and its ability to predict when the peak is reached looks rather incidental. In many ways, as long as the peak is not reached, it seems like Hubbert's method always predicts the peak to come a few years into the future. A reasonable explanation may be the fact that cumulative additions to the declared proven reserves have virtually kept pace with cumulative oil production, making the methodology very inaccurate since one does not know the future appreciation of the reservoirs. The question is whether this is a result of the continuous extensions of the resource base, or if it is in the logistic curve's nature to behave in such a way. I will take a closer look into the prospects of reserves in chapter 4.

On the other hand, it is important to be aware of the limitation of the analysis. Most important is the fact that even if the selected countries all had a significant oil production, the decline in production from these countries has not resulted in a global decline. This means that even if such case studies are valuable, they do not include what will happen when the global production peaks and eventually starts to decline. When the global production reaches the peak and starts to decline, it is rational to expect the world market price to increase, something which will influence both the supply- and the demand side in the market.

4.0 The size of the ultimate reserve base

As discussed in chapter 2.4, the Hubbert theory can be criticised in several ways. The most important criticism is connected Hubbert's main assumtion of a constant ultimate global reserve base.The lack of reliable data regarding the size of the world reserves are the major problem in the prospects of oil. The definistion of what to include in the reserve base brings clouds to the debate of peak oil, and are the main difference between the peak oil community and the non-peak oil community.

According to Jackson (2006), the current peak oil debate is characterized by the following: Firstly, peakist arguments are built upon the Hubbert curve, a model which is highly questionable. As discussed in chapter 2, the curve is estimated using historical production to predict the future. This means that the model does not incorporate future factors like major new discoveries, revolutionary new technology and political influence. Secondly, the peakist arguments are not grounded in a credible systematic evaluation of available data. This leads to the debate of the size of the ultimate resource base, which is the total amount of oil in the world, including both known and unknow sources. A very important factor regarding the future of oil is the geological factors and limitations of oil production. This is in fact the most important argument used by the peak oil community.

The forecasts of peak oil are controversial, because no one really knows how much oil remains underground and how close we are to the halfway point. Geologists have tried to forecast the peak for half a century, without being able to predict when the peak will arise. As we have seen in chapter 2, the Hubbert methodology gives an approximation to the size of the world oil reserves. Therefore, I want to take a closer look at this assumption, and examnine how the oil reserves have evolved historically, and are likely to evolve in the future. This chapter will try to throw some light on the size of the reserves, and how we can expect the reserve base to evolve over time. In this context I will discuss conventional reserves in chapter 4.1 and unconventional resources in chapter 4.2.

4.1 Conventional reserves

As mentioned in chapter 2, *conventional reserves* are defined as oil which is economically and technologically extractable by using a traditional well method. In the discussion of peak oil, the numbers which the reasoning are based upon are essential to the outcome of the debate. In this context it is important to emphasis that it is possible to select data to suit a desired argument. The peak oil community tends to pick low estimates, arguing that only proven reserves of conventional oil is to be considered. According to Jackson (2006), the peak oil community estimates the remaining oil reserves to be approximately 1.2 trillion barrels. Consequently, they use approximately the same numbers as the size of the world proven reserves (IEO 2009). By only using 1.2 trillion barrels as an estimate for the ultimate resource base, the peak oil community are excluding the enormous potential in probable and possible resources, and the yet to be found resources. They also leave out the importance of unconventional resources, like the oil sand in Canada, the tar belt in Orinoco, together with gas-to-liquid (GTL) and oil shale. According to CERA, the resource base is about 4.8 trillion barrels at a global scale, and only 1.1 trillion of these barrels have been exploited so fare (Jackson, 2006).

Anyway, looking at only the proven conventional reserves is conservative. One should be quite naive believing there will be no more discoveries of oil in the world, and that no technological progress will contribute to the ultimate reserve base. On the other hand, it is not easy to comment on CERA's numbers regarding the ultimate resource base. Even if these numbers are several times as large as the proven reserves, the numbers are based upon research, and will include the possibility of new discoveries and technological progress. On the other hand, the peak oil community numbers regarding the ultimate resource base are too low, based on the argument that there will be no future discoveries and technological improvement which will contribute to the size of the oil reserves.

Linking the debate to the methodology of Hubbert, which was presented in chapter 2, one needs accurate numbers regarding the ultimate resource base of an area to predict the future production. One can estimate the curve using the mathematical approach, which was presented in chapter 2.3. But, as shown in my analysis in chapter 3, the predictions made by the mathematical approach were poor. Nevertheless, it is not easy to predict the future, and one has to remember that the size of the ultimate resource base is never known for sure until the area is fully exploited. As an area is being exploited, the size of the known resource base is often expanding. As mentioned in chapter 2.4, the size of the resource base in the North Sea expanded with 86 percent from 1985 to 2006.

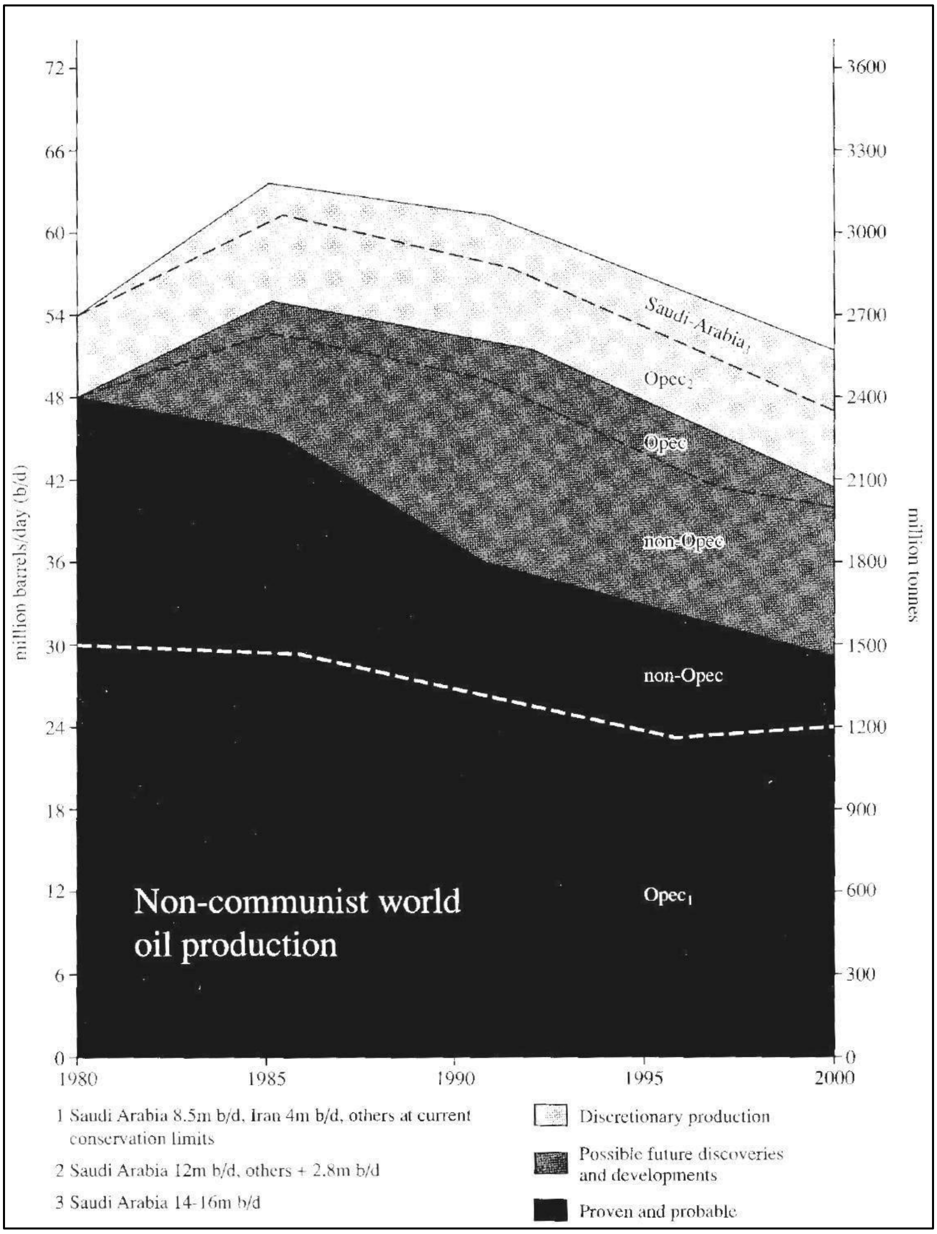
Since the size of the ultimate resource base is important to the outcome of the debate, I will use the rest of chapter 4.1, trying to throw light on some facts regarding the remaining global conventional reserves. I will do this by taking a closer look at the situation globally, OPEC and the influence of the Middle East, and how long the conventional reserves are expected to last.

4.1.1 The world

The United States was the world leading producer of oil between 1901 and 1970, which was the year when the US production reached its all time high (Simmons, 2005). At this time the output from the US lower 48 states and the Gulf of Mexico reached a production of about 10 million barrels per day. The US production started to decline in 1970, and then ended an almost century long dominance of world oil supply. Even if the giant oilfield, Prudhoe Bay, was discovered in Alaska in 1968, it did not ensure that the US would remain the world largest oil producer. As the world appetite for oil grew, there were only a few countries in the world which were able to make up the deficit. Saudi Arabia was in an exceptional position, since they had both the opportunity and the ability to increase its oil output fast enough, see section 4.1.2.

Oil has increased its importance as a source of energy after 1945, and in 1958 it contributed to about half of the world demand for energy (Odell, 2004). The belief that oil would never end continued through the 1960s. During that decade, the oil consumption increased by about 7 percent annually. It was not until the 1970s that people started to believe that oil is a scarce resource. According to Odell & Rosing (1983), the Centre for International Energy Studies at Erasmus University was in the beginning of the 1980s critically investigating 12 different pessimistic studies of oil prospects. This illustrates the fact that pessimisms according the prospects of oil are not a new idea, but is something which has been seriously discussed among expert for decades. The oil prospects made at the end of the 1970s were pessimistic, concluding the world supply of oil would start to decline within a few years. This is illustrated in the following figure:

Figure 17: British Petroleum's 1979 view of oil depletion.



Source: Odell (2004), page 37.

Even if the negative prospects from the 1970s did not become reality, it is a fact that many important producing areas today are experiencing a declining production rate. An example is the North Sea, where both Norway and United Kingdom are experiencing falling production. According to the BP Statistical Review (2009), the Norwegian production has declined since 2002 and the UK production reached its maximum in 1999. In 2008, the Norwegian production was down about 28 percent from its maximum production, while United Kingdom was down about 47 percent. Since the production in more and more important oil producing countries are declining, or is getting closer and closer to the peak, other regions in the world have to take over the lack of production. According to NPC Global Oil & Gas Study (2007), the peak of new field discoveries already occurred in the 1960s. The responsibility and ability to satisfy the world's increasing demand for oil does depend heavily on the Organization of Petroleum Exporting Countries (OPEC). This will be discussed in chapter 4.1.2.

In addition to the OPEC countries, there are several promising new areas around the world. According to Simmons (2005), the output from the Kashagan field in Kazakhstan is expected to exceed more than one million barrels a day in 2015. There are also promising discoveries in the Azerbaijan sector in the Caspian Sea. This statement is supported by Odell (2004), who argues that many countries in the former Soviet Union have huge potential, and that the current high activity levels of international oil companies in the Caspian basin and Siberia indicate that there are expectations of reserves expansion in these areas. Since 2000, Shell, BP and ExxonMobil have signed huge contracts with Russian oil companies. The question is to what degree these reserves can be realized. One factor which plays a significant role is a question of geopolitics rather than the geographical issues like the resource potential and infrastructure. In the context of promising areas in the world, one also has to remember the deepwater regions in the Gulf of Mexico and West Africa. There are also expectations regarding the South Chinese Sea. The prospects of unconventional resources will be discussed in chapter 4.2.

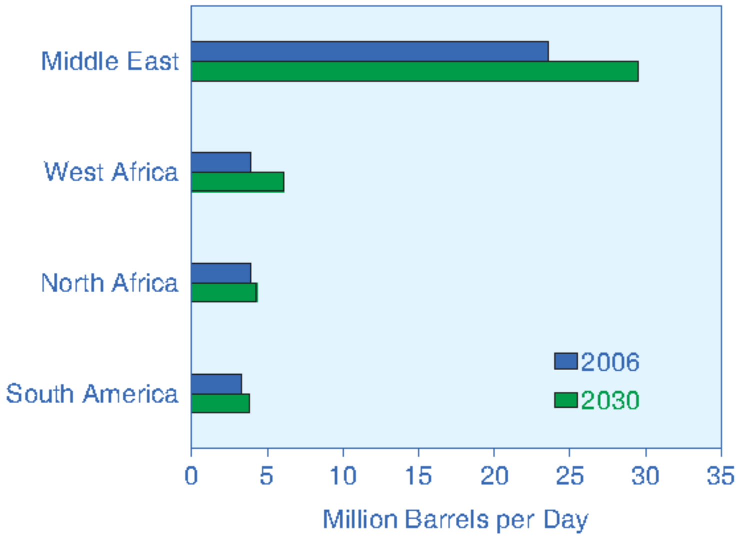
Deffeyes (2009) has a more pessimistic forecast, arguing the only promising petroleum province that remains unexplored is part of the South China Sea. The exploration has been delayed due to political problems, since there are dissensions regarding the boundaries and the rights to the oil. Even if the South China Sea is a promising area, there is little likelihood that the area is a new Middle East. If major reserves are found in a new province, it takes at least ten years to deliver the first barrel of oil.

4.1.2 OPEC and influence of the Middle East

The Organization of Petroleum Exporting Countries (OPEC) plays a vital role in the world oil market. Even if OPEC's importance was jacked down in the 1980s, the organization is expected to increase its influence in the future. Esser (2005), points out that although most OPEC countries are close to their capacity, they are in a strong position to expand their production capacity close to 50 million barrels per day within 2015. According to EIA – 3, OPEC's 2009 total production capacity was only about 34 million barrels per day. Much of this increase in capacity has to come from existing fields and existing discoveries. The 2006 OPEC production and 2030 forecast are presented in figure 18. It is important to stress how the price level will influence the evolvement in capacity, at least on a short term basis.

According to World Energy Outlook (WEO) 2009, the conventional oil production in non-OPEC countries are expected to peak around 2010, something which means that most of the future increase in output would need to come from the OPEC countries. The call on OPEC to sustain the global supply of oil is not only a question of the OPEC countries' ability to supply the world with enough oil, but it is also a question of transfering more and more political power towards OPEC. The organization consists of countries from all over the world, but as figure 18 illustrates, the most important region is the Middle East, including countries like Saudi Arabia, Iran, Iraq and Kuwait.

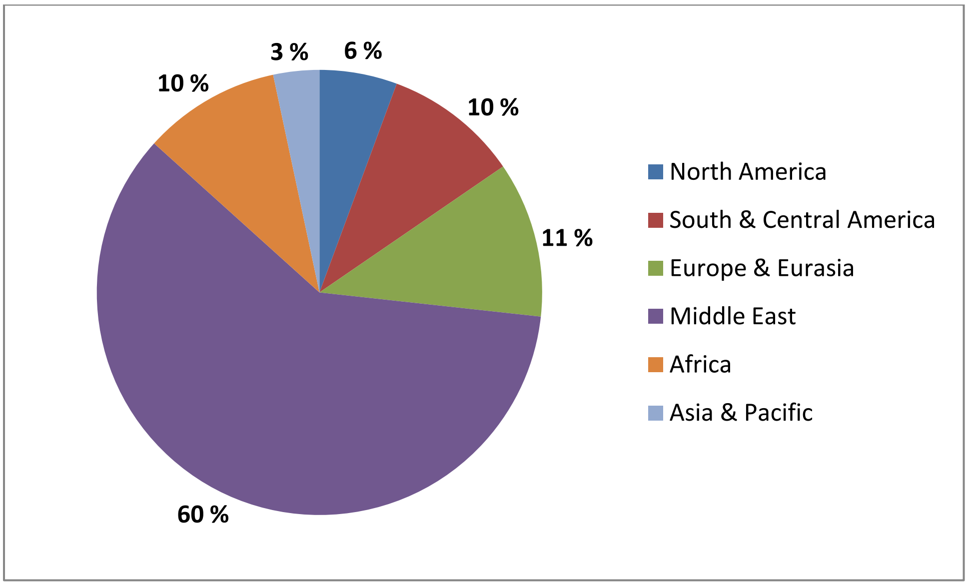
Figure 18: OPEC conventional liquids production by region, 2006 and 2030.



Source: IEO 2009, page 39

The oil age in the Middle East started in the beginning of the 20th century. Countries like Iran, Bahrain and Iraq made the region a serious oil producer almost 30 years before exploration even began in Saudi Arabia (Simmons, 2005). As illustrated in figure 19, over 60 percent of the proved reserves are located in the Middle East, giving the region an enormous influence in the world oil market.

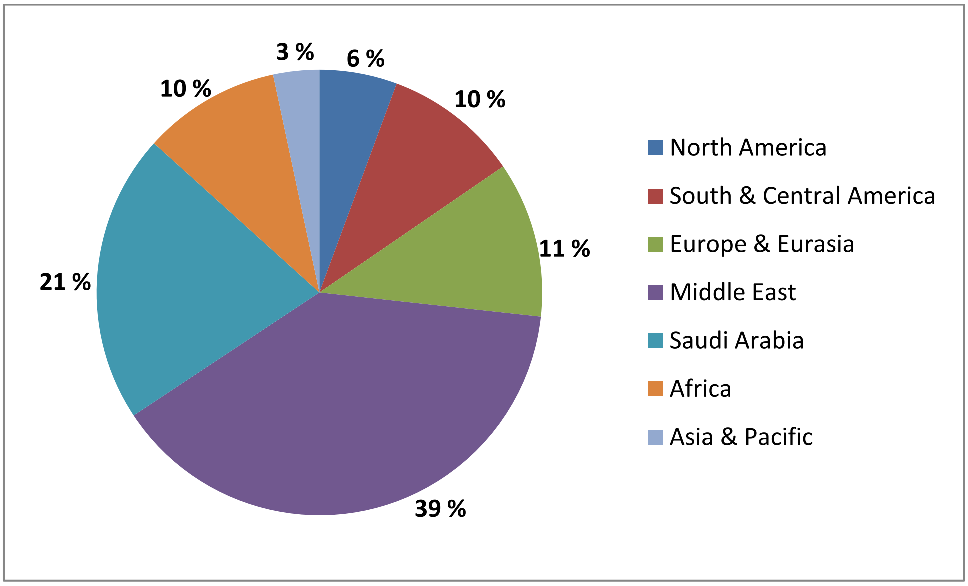
Figure 19: World proven reserves estimates.
Do not include unconventional resources.



Source: Illustration based on data from BP Statistical Review (2009).

The far largest producer in the Middle East is Saudi Arabia. Due to the large production, oil has become very important for the country. According to Simmons (2005), the income from oil counts for 70 to 80 percent of the state revenues and about 95 percent of total export revenues. Saudi Arabia plays the key role in the world economy when it comes to global energy and economic power. Their first oil discovery was done in 1938, and the last four decades the country has been the key supplier of oil to the rest of the world, a role which they got when the US production started to decline in 1970. Saudi Arabia was the only producer with the capacity to keep pace with the world appetite for oil. Their unique situation is linked to the enormous resource base which is located in the country. As figure 20 illustrates, Saudi Arabia alone has the hold of over 21 percent of world proven reserves. As a comparison, Norway contributes only 0.6 percent of world proven reserves.

Figure 20: World proven reserves estimates.
Data for the Middle East excludes Saudi Arabia.
Do not include unconventional resources.



Source: Illustration based on data from BP Statistical Review (2009).

It is no doubt that Saudi Arabia has enormous oil reserves, however the estimates vary. According to Simmons (2005), the country has over 100 discovered oil and gas fields, and five of them are exceptional by any world standard. The two largest fields, Ghawar and Safaniya, contribute about 75 percent of the Saudi Arabic production. Ghawar is clearly the largest one, and even if the field has been in production for more than 50 years, it still has proven reserves of 70 billion tons. Saudi Aramco, the state owned Saudi Arabic oil company, states that Ghawar contains about 1/8 of the global reserves, something which contributes a reserve of about 125 billion tons. This numbers does not only illustrate Saudi Arabia's unique position as a global supplier of energy, but it also illustrates the uncertainty related to the size of the reserves.

The estimates regarding the Saudi Arabian oil production are uncertain. The reason is that the Saudi Arabian estimates to a large extent is kept secret. Thus, most of the available data are estimated by different energy consultants and planners around the world. Therefore, the available data and calculations rely on assumptions rather than verifiable information.

Saudi Arabia has historically played an important role when it comes to stabilizing the oil market. If it wasn't for Saudi Arabia, we can expect that the oil price in the 1970s would have increased more than it actually did. Saudi Arabia enjoyed a once-in-a millennium revenue windfall. But it also had no other choice than to step into the vacuum created by the unexpected decline in the US production. If they hadn't done so, it could have lead to the development of a global oil supply imbalance, which could have severely damaged the world economy.

The capacity of the Saudi Arabian production increased very quickly in the beginning of the 1970s, and several experts have questioned if the rush in increased production caused long term damage to the reservoirs. According to Simmons (2005), the experts of Saudi Aramco knew about the overproduction, but simply ignored it. We also have to remember that all the four owners of Saudi Aramco's at that time were American. They all knew it was not long before the Saudi Arabian Government would nationalize the company. In that way, they had no incentives to have a long-term production profile regarding the Saudi Arabian wells. Saudi Aramco has been controlled by a Saudi Arabian management team since 1975.

The Saudi Arabia production increased again in the beginning of the 1980s, something which was a result of Iran suddenly stopping its production due to the Iranian revolution in 1979. Also under the Iraq-Kuwait war in 1990, Saudi Arabia increased their production to compensate for the 5 million barrels a day which disappeared from the market.

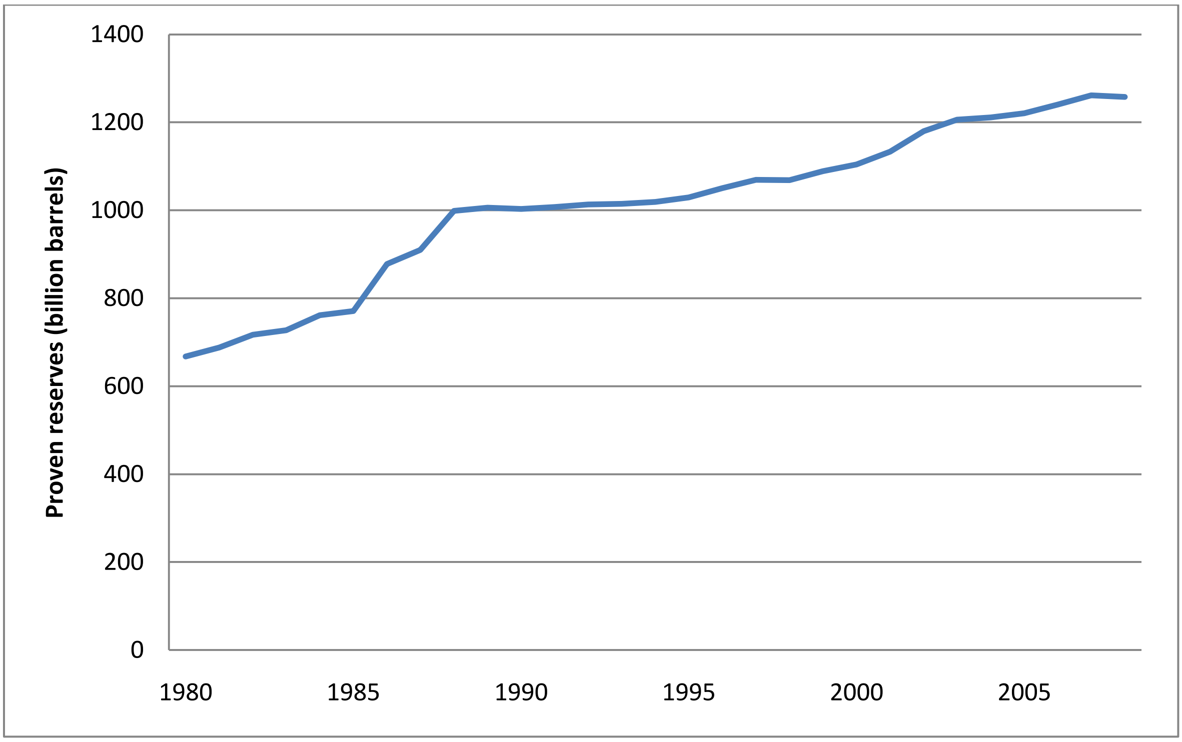
Looking back in time, it may seem like Saudi Arabia has had a long-standing desire to be a responsible and reliable provider of oil. But it has probably inadvertently caused damage to the Saudi Arabian reservoirs. When the oil price has decreased, their production has typically been reduced. Many people have seen it as a way of keeping the price up, but it may also be a result of the Saudi Arabian reservoirs needing to rest.

Even if the reserves in Saudi Arabia are enormous, there are questions to be asked about what can be expected from Saudi Arabia in the future. The secrecy connected with the Saudi Arabian oil production has created a data vacuum. On the one hand, we can expect Saudi Arabia to overestimate its reserves to achieve power in OPEC. On the other hand, Simmons (2005) argues that the secrecy is a result of Saudi Arabia not wanting the rest of the world to know the conditions of their reservoirs. As discussed earlier, there may have been severe damages done to the Saudi Arabian reservoirs, and that even former experts in the state owned company Saudi Aramco is concerned about the Saudi Arabian prospects. The Golden Age of oil discoveries in Saudi Arabia was between 1941 and 1965 (Simmons, 2005). Most of the new discoveries have been small, complex and not very productive. Even if the resource base of Saudi Arabia is enormous compared with other countries and regions, there are reasons to question Saudi Arabia's ability to compensate for the falling production in other countries.

4.1.3 How long will the conventional reserves last?

Even if the prospects back in the 1970s were not that positive, the growth in reserves from new discoveries and appreciation of reserves in fields that have been discovered a long time ago, ran quickly ahead of the consumption. Between 1971 and 2000, almost 1 200 billion barrels of oil was added to the proven reserves, while only 682 billion barrels was consumed. As we see in figure 21, this caused a net increase in the proven reserves.

Figure 21: Evolvement in global proven reserves



Source: Based on data from BP Statistical Review (2009).

Based on data from BP Statistical Review (2009), the average daily consumption of oil was 84 455 thousand barrels (2008 numbers), and the proven reserves was equal to 1 258 billion barrels. By using these numbers we can easily calculate that the proven reserves will last for more than 40 years. This is the so called *reserves to production ratio*, which is the remaining reserves divided with yearly production, giving us how many years the known reserves will last with current consumption. According to Odell (2004), the annual rate of additions to reserves and the maintenance of adequate reserves to production ratio are one of the three main drivers influencing the future of oil production. The reserves to production ratio from 1980 to 2008 are calculated and presented in table 2.

Table 2: Evolvement in the reserves to production ratio.

Year	Proven reserves each year	Production each year	Gross additions to reserve	Net growth or decline in reserves	Reserves to production ratio
1980	667,2	23,0	-	-	29,0
1981	687,6	21,7	42,1	20,4	31,6
1982	716,9	20,9	50,2	29,3	34,3
1983	727,2	20,7	31,0	10,3	35,2
1984	761,6	21,1	55,5	34,4	36,2
1985	770,9	21,0	30,3	9,3	36,8
1986	877,9	22,1	129,0	106,9	39,8
1987	910,2	22,2	54,5	32,3	41,0
1988	998,4	23,1	111,3	88,2	43,3
1989	1005,8	23,4	30,8	7,4	43,0
1990	1003,2	23,9	21,2	-2,7	42,0
1991	1007,6	23,8	28,3	4,5	42,3
1992	1013,3	24,0	29,7	5,7	42,2
1993	1014,4	24,1	25,1	1,0	42,1
1994	1019,2	24,5	29,3	4,8	41,6
1995	1029,1	24,9	34,8	9,9	41,4
1996	1050,6	25,5	47,0	21,5	41,2
1997	1069,3	26,3	45,0	18,7	40,6
1998	1068,5	26,8	26,1	-0,8	39,8
1999	1088,6	26,4	46,5	20,1	41,2
2000	1104,5	27,3	43,2	15,9	40,4
2001	1133,0	27,3	55,8	28,5	41,5
2002	1180,0	27,2	74,2	47,0	43,4
2003	1206,3	28,1	54,4	26,3	42,9
2004	1211,3	29,3	34,3	5,0	41,4
2005	1220,3	29,6	38,5	9,0	41,2
2006	1240,6	29,7	50,0	20,3	41,7
2007	1261,0	29,7	50,2	20,5	42,4
2008	1258,0	29,9	26,8	-3,0	42,1

Source: Calculations based on data from BP Statistical Review (2009).

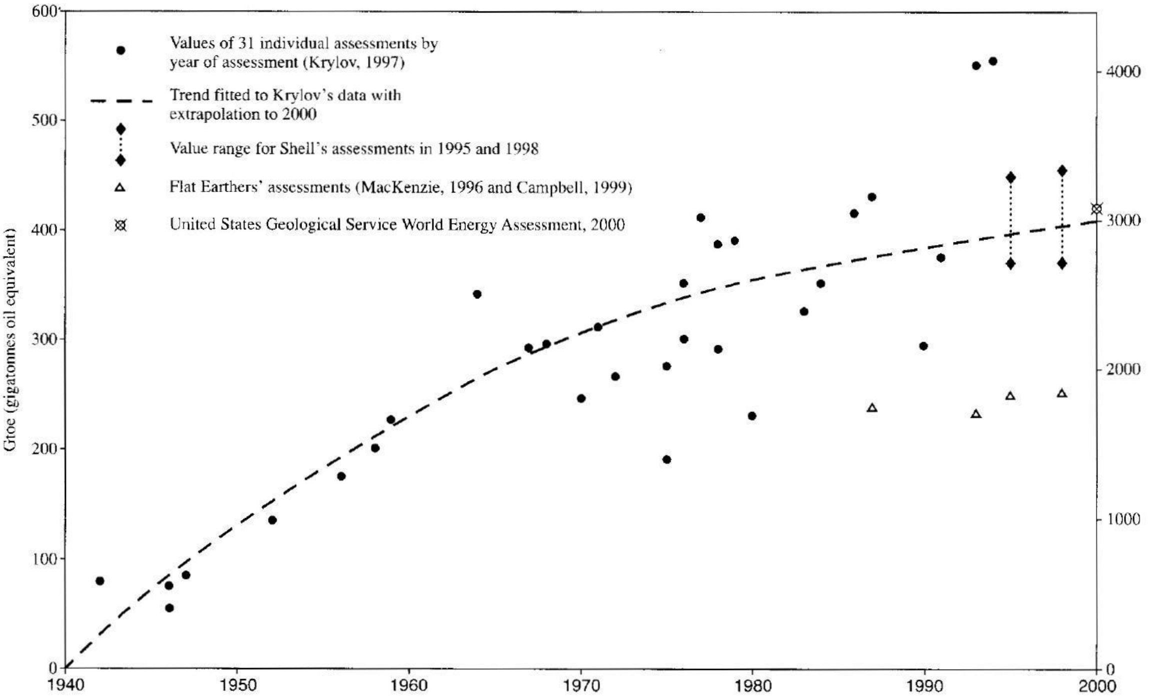
Table 2 also demonstrates the weakness of using the reserve to production ratio as a measurement of future resource availability. The reason is that it is based on the proven reserves, which is an accounting concept based on known projects. Thus, this is not an appropriate measurement for judging resource availability in the long term. Over time, new resources will be added to the proved reserves. This means that even if large amount of oil is consumed every year, the ratio stays the same.

Even if the reserve to production ratio is not an accurate measurement for future resource availability, it is still a measurement illustrating the fact that the world is not running out of oil on a short term basis. As table 2 illustrates, the reserve to production ratio has been stable for the last 20 years, fluctuating around 40 years. However, it is important to remember that peak oil supply may not occur due to the lack of oil in a geological view, but because of problems getting the oil quickly enough to the market. There is a possibility of limited supply as a result of limited capacity. The issue of limitations regarding capacity will be covered in chapter 4.

International Energy Outlook (IEO) 2009, published by the Energy Information Administration (EIA) of the US Department of Energy, argues the global supply of crude oil, other liquid hydrocarbons, and biofuels is expected to be adequate to meet the world’s demand for liquid fuels for at least the next 25 years. As already mentioned, there is substantial uncertainty regarding the levels of future demand and supply. In the IEO 2009, EIA reflects some of this uncertainty by using both low and high oil price cases, in addition to a reference case. But, the oil resources currently remaining, in combination with expected volumes of other liquid fuels, are estimated to meet the total demand for liquid fuels in all three prices cases.

It is interesting to see how the assessments of proven reserves have evolved over time. This is illustrated in figure 22.

Figure 22: Assessments of total world initial oil reserves over the period 1940 -2000.



Source: Odell (2004), page 47.

Even if the assessments have increased gradually in the period from 1940 to 2000, it is obvious that the rate of increasing proven reserves is waning. The most common explanation is that the largest oil reservoirs are already found, leaving only smaller and smaller reservoirs left to be found. This statement is supported by Roberts (2005). But it may also be a result of incidental historical happenings. In the first part of this period, from 1940 to 1970, large explorations were done in Saudi Arabia and other countries in the Middle East (Odell, 2004). From the 1970s, the oil industry in these countries was nationalized, and the interest in ultimate reserves in the Middle East evaporated. In addition to the evaporating interest of developing the oil industry in many of the most important oil regions in the world, the growth rate in demand fell sharply in the 1970s, after a annually growth rate of 7.5 percent between 1950 and 1973. This undermines the previously perceived need for large volumes of future supplies. At the same time, more intensive appraisal for the oil wealth in other parts of the world became of great interest, both in developed and developing countries. All these factors added together may give a rational explanation to the waning increase in addition to proven reserves, and throw light on the fact that there are other explanations than just the lack of new resources which decide the size of the proven reserves.

Another interesting observation is the fact that the growth rate in conventional oil production is flattening. This is used by the peak oil community as a sign that we are very close to the peak. According to Jackson (2006), the slowing growth in conventional production may reflect two factors. Firstly, there is a lack of knowledge about what hydrocarbon resources the industry will develop in the future. Secondly, the high oil price will increase the development of unconventional reserves. As an example, Norway's largest oil company, Statoil, is heavily involved in projects regarding the oil sand in Canada. Just like many others, the company diversifies its portfolio away from conventional reserves, something which relieves the pressure on the traditional conventional resources. In addition to the unconventional resources, there is also more attention paid to other sources of energy.

One of the latest interesting claims in the debate of peak oil is given by the chief economist in the International Energy Agency (IEA), Fatih Birol, who belives the output of conventional oil will peak in 2020 (Economist, 2009). This claim is based on the assumption that no big new discoveries are made. It is just recently that the IEA committed itself to a prediction of when the world oil production will stop growing. The conventional oil is expected to reach the maksimal production, the platau, sometime before 2030. IEA made this conclusion after analysing the historical production trends of 800 individual oilfields. IEA concluded that oil-fields that are past their prime can experience a decline in annual output equal to 8.6 percent in average in 2030. Even if unconvential resources are expected to take a lot of the slack, one has to remember that unconventional sources liberate more carbon dioxide than conventional resources, something which is in conflict with the request of mitigation due to climate change. Unconventional resources will be discussed more closely in chapter 4.2.

In addition to IEAs Fatih Birol, various top leaders in large international oil companies have made public their rather pessimistic prospects of oil production (Roberts, 2008). One of them is James Mulva, chief executive officer (CEO) of ConocoPhillips. He predicts that in 2030, almost all the oil needed has to come from fields not currently in operation, and he emphasizes his concern regarding where that oil is suppose to come from. His statement is supported by the Royal Dutch Shell's CEO, Jeroen van der Veer, who argues that after 2015 the supply of easy-to-access oil and gas will no longer keep up with demand. It is a fact that smaller fields cost more to operate than larger ones, and even if the world has numerous small fields all over the globe, it will in most cases not be economically or technically feasible to extract the oil. Van der Veer states that the biggest fields were discovered decades ago, and most of today's oil is coming from big mature fields which are already in decline or close to their peaks.

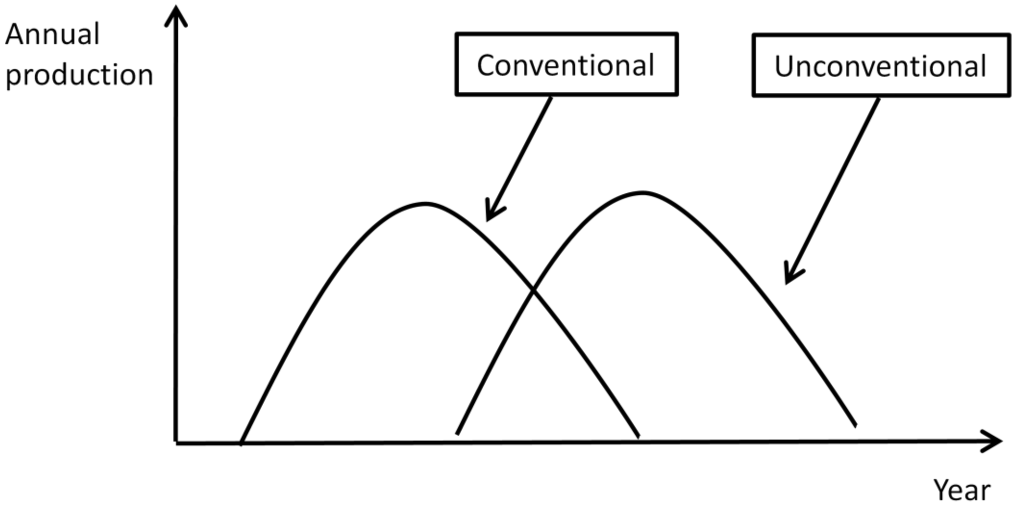
4.2 Unconventional reserves

As discussed in chapter 4.1, the production from conventional reserves is expected to peak within 10 to 20 years. But, one has to remember that the future of oil does not only include conventional oil. In addition, the future will also involve production of so called unconventional oil. According to Odell (2004), *unconventional oil* can be defined as oil which has to be recovered from habitats other than reservoirs in which oil occurs as a liquid with a viscosity which makes it capable of flowing or being pumped to the surface. There is no absolute distinction between conventional and unconventional oil. From an economic point of view, it reflects the ability to derive useful petroleum products, or products which may work as substitutes for traditional oil products.

The idea of developing unconventional resources is definitely not a new idea. Both the offshore fields in the Gulf of Mexico and the fields in the North Sea are examples of what earlier would have been impossible to extract and therefore classified as unconventional. It is the same case with extraction of heavy oil, where technological improvements have made it economically feasible to extract the oil. This illustrates the fact that unconventional resources become conventional over time, as a result of technological progress. This is a continuous process, meaning that what is unconventional today may be conventional tomorrow. According to Odell (2004), increased knowledge and improving technology have already led to more than 50 percent real cost reduction in unconventional oil production. With the oil price level remaining at a relatively high level, we may expect large scale developments to come, especially in Canada and Venezuela.

The prospects of oil will give significant motivation to a comprehensive and systematic evaluation of the ultimately recoverable resource base, and as production from non-conventional resources are getting relatively more and more favorable, the production will increase, and thus compensate for the declining supply from conventional resources. This is illustrated in figure 23.

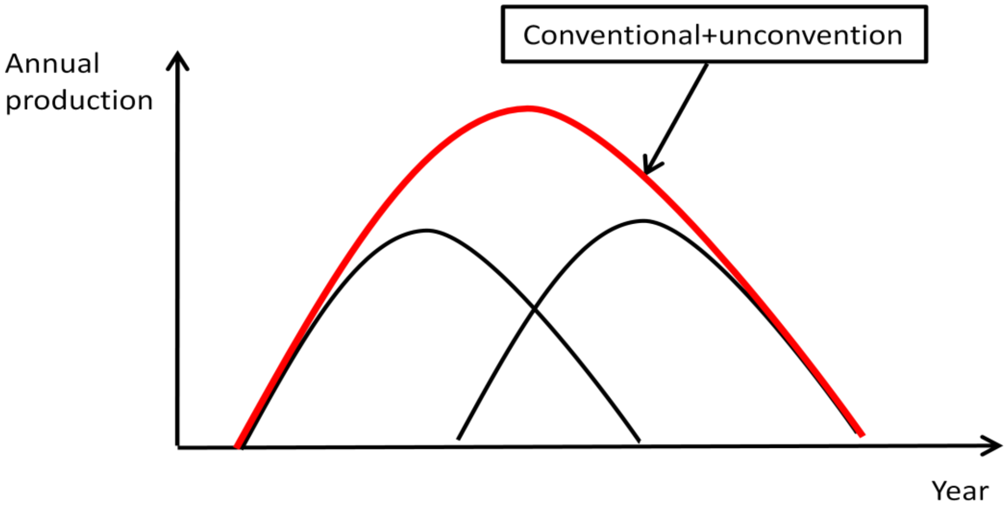
Figure 23: Production curves for conventional and unconventional oil



Source: Replication of Odell (2004), page 49.

As figure 23 illustrates, taking the unconventional resources into account will move the peak further into the future. How far is a question which remains open, since nobody is able to predict the future for sure. But, as more and more of the conventional resources are consumed, the unconventional resources are getting more and more important as a future source of energy. Figure 24 illustrates the importance of how unconventional resources play an important role in the debate of when a peak will be reached.

Figure 24: Illustration of the complementary relationship of conventional and unconventional production.

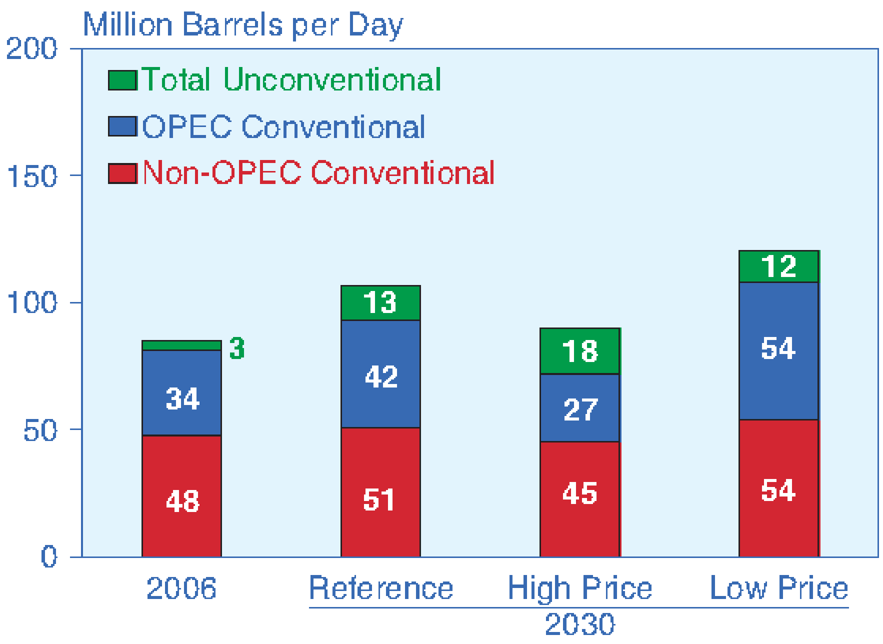


Source: Replication of Odell (2004), page 49.

Odell (2004) argues that the sum of both conventional and unconventional reserves will not peak until 2060, even if the peak in conventional reserves is expected to be reached 30 to 40 years earlier. The calculations are based on an assumption of a total ultimate recoverable resource base of non-conventional oil equal to 3000 billion barrels. The supplies of conventional and unconventional resources can be viewed as complementary for most of the 21st century. But, even if a lot of emphasis is put on the use of unconventional resources, it will take until 2030 for the production to exceed 1 gigatons of oil equivalent (Gtoe) per year. It will take until 2060 before non-conventional oil becomes the most important source of supply.

According to IEO 2009 reference case, the demand for liquid fuel and other petroleum products like natural gas liquids, biofuels and liquids derived from other hydrocarbon sources will increase from 85 million barrels a day in 2006 to 107 million barrels per day in 2030. Unconventional liquids will in 2030 count for 13.4 million barrels per day, or 12.6 percent of the total demand. Today, unconventional liquids only count for 3.6 percent of the total demand. The relative share is illustrated in figure 25.

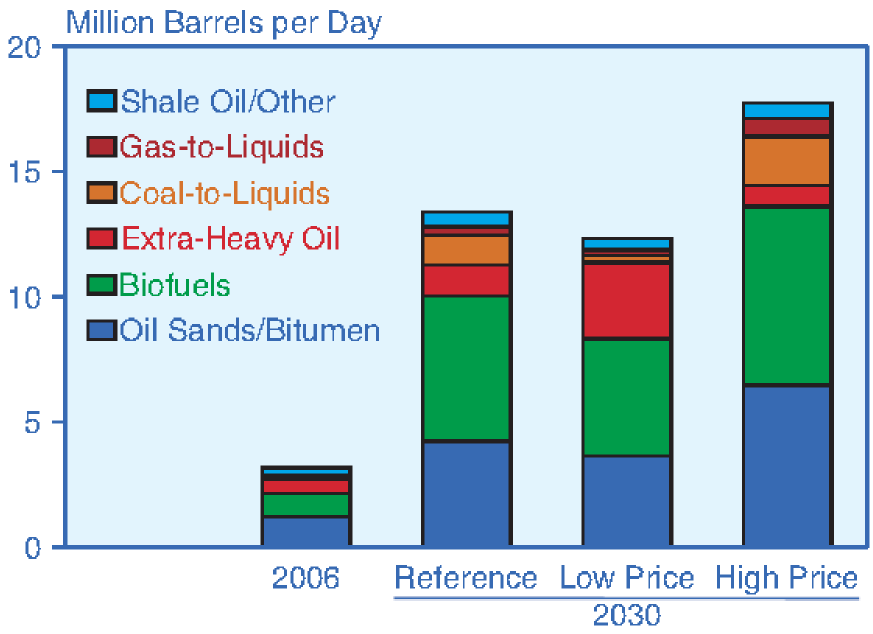
Figure 25: World liquids supply in three price scenarios, 2006 and 2030.
Reference price equal to 130 US $.
Low price equal to 50 US $.
High price equal to 200 US $.



Source: IEO 2009, page 31.

As figure 25 illustrates, there is an increased supply of unconventional resources in both the reference case and in the low and high price scenarios. The reference case is based on a price equal to 130 US dollars per barrel in 2030, respectively, while low and high oil prices are set to 50 and 200 US dollars per barrel. As expected, the supply of unconventional liquids will be highest in the case of a high oil price. The expected growth in the use of unconventional resources is illustrated in figure 26.

Figure 26: World production of unconventional liquid fuels, 2006 and 2030.
The figure contains three different price scenarios.
Reference price equal to 130 US $.
Low price equal to 50 US $.
High price equal to 200 US $.



Source: IEO 2009, page 23.

As the figure illustrates, the increased use of unconventional liquid fuels are mainly based on increased use of extra-heavy oil, biofuels and oil sand. The potential of all these unconventional resources is heavily debated. It is well known that huge amount of resources is needed to support production, and large investments will be needed to bring the oil to the market. Another issue is the uncertain timing of such investments. According to IEO 2009, OPEC's unconventional production consists mainly of extra-heavy oil from Venezuela's Orinoco belt and gas-to-liquids (GTL) production from Qatar. In the IEO 2009 reference case, the Venezuelan and Qatar unconventional production in sum increases from 0.6 million barrels per day in 2006 to 1.4 million barrels per day in 2030. The known Venezuelan reserves have increased significantly since 2005. According to E24 (2010), the Venezuela reserves have recently been adjusted upwards with 39.9 billion barrels. It means that the Orinoco belt now may account for as much as 235 billion barrels of oil. If these numbers are correct, it means that Venezuela unofficially has the second largest oil reserves in the world.

Outside OPEC, the unconventional resources are located in many different countries, and include a diverse group of resource types. In total, non-OPEC countries will increase their production with about 9.6 million barrels a day from 2006 to 2030, with 65 percent coming from OECD countries. The country with the largest contribution is Canada, with an increased production of 3.1 million barrels per day. In 2002, no less than 178 billion barrels of non-conventional oil in western Canada were formally declared as proven reserves. This means that Canada officially is the second largest oil country in the world, measured by the size of the global known reserves. According to the reference case in IEO 2009, the Canadian production from oil sands will make up more than 35 percent of the total non-OPEC unconventional production in 2030. Another large producer is the United States, which is expected to increase its production of unconventional oil with 2.2 million barrels per day, with 1.5 million barrels per day coming from biofuel production. In total, the world's production of biofuels will increase by 0.9 million barrels per day in 2006 to 5.9 million barrels per day in 2030. The increased production corresponds to an annual increase of 8.6 percent. The growth of biofuel production slows in all the cases in the near term as current generation crops reach their economic potential. The long term potential is larger due to the advent of new technologies using cellulosic feedstock. The countries with the largest potential in different unconventional reserves are summarized in table 3.

Table 3: Summary of the largest unconventional potential

Country	Size of reserve (billion barrels)	Expected production in 2030 (million barrels per day)	Type of oil
Venezuela (OPEC member)	235	1.4	Extra-heavy oil
Canada (non-OPEC member)	178	3.1	Oil sand
United States (non-OPEC member)	Mainly biofuels, which give no reserves	2.2	Biofuel

Source: E24 (2010) and IEO 2009.

In order to achieve national goals of reducing greenhouse gas emissions and bolstering energy security, many countries have targeted use of biofuels and provided tax credits to biofuel producers. Biofuel is supposed to be economically favorable, since the cost of production is likely to fall over time, and the price of oil is likely to increase. The higher the price of conventional oil becomes, the more economically competitive will biofuel be. According to the IEO 2009 reference case, the low oil price scenario will lead to a production of 4.8 million barrels per day in 2030, while a high oil price scenario will lead to a production of biofuel of 7.2 million barrels per day.

4.3 Summary

Based on the discussion in chapter 4, I will conclude that is not easy to predict the size of the ultimate resource base. In the debate, one has to take into account the fact that human's ability and needs are dynamic, and today's energy resource incorporate some of yesterdays unknown. Thus, while tomorrow's energy resources of carbon fuels will undoubtedly induce components relating not only to already known, but as yet unproducible reserves, they will also incorporate reserves from today's unknown potential in still unexplored habitats. It is difficult to predict the future, but one has to be rather naive believing there will be no technological progress making more and more resources economically feasible. As discussed in chapter 4.1, most of the remaining conventional reserves are located in OPEC, something which will increase OPECs influence in the energy market. But as the production of conventional reserves will flatten, and eventually start to fall, the unconventional resources will be more important moving energy political power towards new countries. But, the question of how unconventional resources can work as substitutes for conventional oil still remains open.

One has to question the quality of the dataset used in my discussion. The estimates of proven reserves are available in a number of different publications, such as the BP Statistical Review and the Oil and Gas Journal. But there are reasons the question if these data can be relied upon. This means that my conclusion may rely on data which is not accurate and reliable.

5.0 The importance of above ground factors

As discussed in chapter 3, the size of the world's oil reserves is a critical factor in the traditional peak oil theory. Further, chapter 4 showed us that we cannot take the size of oil reserves as given. To allow for both human ability and human needs in the evaluation of carbon fuels prospects, two basic assumptions must be made. Firstly, one has to assume the world knowledge in geology and technology regarding extraction will continue to evolve in the future. Secondly, the world's growing population and economy will generate a continuing increase in the demand for energy on a long term basis.

The historical evolution requires a constant evolvement of which oil reserves that can be set in to use, for instance the importance of unconventional reserves. This acknowledgement tells us that when predicting the future supply of oil, we have to take into consideration not only the uncertainty connected to geological factors in the reservoirs, but we also have to pay attention to the above ground risk. Critical factors are found on both the supply and the demand side, for instance lack of investments, politics, and economic growth.

One has to remember that supply and demand are closely related. Demand normally follows macroeconomic fluctuations. Due to the recent recession, the focus has been on demand constraints. As the world economy recovers, there will probably be a shift in focus back to the supply side. The reason is that many of the world's producers of oil have reached their maximum production, and some have already started to decline. Even if there has been excess supply during the recessions, there may be problems satisfying the expected demand. According to Fattouh (2010) there have, until recently, been expectations that short time oil price behavior are resting on the assumption that changes in oil prices would induce responses or feedback from supply, demand or policy. A feedback in one of these, or a combination of all three, would prevent prices from getting below a certain floor or above a certain ceiling. This can be illustrated in the following two examples:

Firstly, in the case of a price increase, some feedback mechanism will prevent the price to go above a certain ceiling. On the demand side, the feedbacks from the high price level operate through both a price effect and an income effect. A high oil price will slow economic growth, something which will have a detrimental effect on the oil demand. On the supply side, higher oil price will encourage higher investments in the oil sector, something which induces increasing supply. However, there will be a multiyear lag; since it takes years from investments are done until they influence the supply. If the oil price rises relatively to other sources of energy, the high oil price will encourage substitution, and thus put a downward pressure on the oil price.

Secondly, in the case of a price decrease, some feedback mechanisms will prevent the price to fall below a certain level. On the demand side, lower prices induce economic growth, something which increases the demand for oil. On the supply side, lower prices discourage investments in the oil industry. Less investment induces lower supply, especially in the non-OPEC countries. A low oil price discourages substitution, since oil is a relatively cheaper source of energy when the price is low. This will put a upward pressure on the oil price.

5.1 Critical factors on the supply side

Lack of supply may be a result of one or several factors, including both geological and above ground factors like lack of investments and political factors. As discussed in chapter 4, the world long term supply of oil heavily depends on the Middle East, where 60 percent of the world's proven conventional reserves are found. Thus, the possibility to increase the world's supply is also high in this area.

On a medium and longer term basis, one can argue that there are problems regarding increased production in the Middle East. Firstly, there are huge political risks in many of these countries, especially in Iran and Iraq. Secondly, there is a trend of increasing nationalization of oil fields. Thirdly, there may be problems regarding increased protectionism. Based on these three factors, there may be problems increasing the future capacity in the Middle East. In total, the above ground risk is mainly connected to the lack of investments and politics. I will discuss these two factors further in chapter 5.1.1 and 5.1.2.

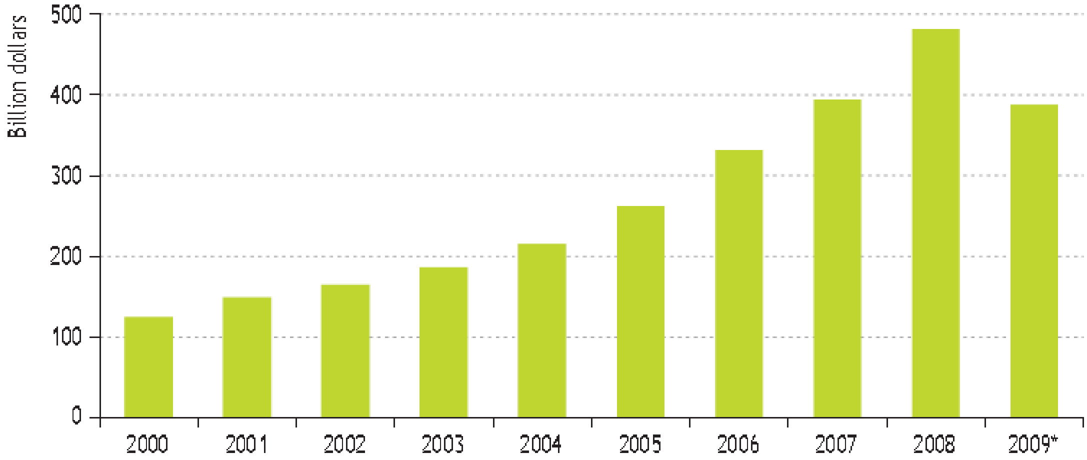
5.1.1 Lack of investments

According to the NPC Global Oil & Gas Study (2007), both sides in the peak oil debate emphasize the importance of facilities and capital equipment. In many areas the technology and infrastructure is aging, and new technologies are required to maintain production and explore new areas. The situation differs heavily from country to country. According to Odell (2004), investments in new technology to enhance the capabilities of oilfields have largely been limited to North America and the North Sea. In the Middle East, the impact from nationalization of oil companies in the 1970s and 1980s, combined with subsequent financial, managerial and technical limitations, has made the upstream oil industry in the world's most significant oil producing region now being outdated. Taking into account how large the already proven reserves are in the Middle East, we may expect enormous additional reserves to be proved when new technology are incorporated in these areas. An appreciation of oil fields in these areas may take place as joint ventures between the various state corporations and international oil companies, and lately agreements to update the industry are emerging. Similarly, the oil industries in the former Soviet Union have a large potential and we may expect new technologies and methodologies to revolutionize the upstream oil industry in countries like Russia, Ukraine, Azerbaijan, Kazakhstan and Turkmenistan. The proven reserves in these countries have increased by 40 percent in 2002, compared with one decade earlier.

According to WEO 2009, the lack of investments will have far-reaching consequences. Due to the recent financial crises, the energy investments worldwide have decreased. It has resulted in energy companies drilling fewer oil and gas wells, and cutting back investments in infrastructure such as for instance pipelines and refineries. In addition, many ongoing projects have been delayed. As illustrated in figure 27, the global oil and gas upstream investment budget for 2009 have been cut by about 19 percent compared with 2008.

Figure 27: Worldwide upstream capital expenditures.

* Based on company plans.



Source: WEO 2009, page 146.

The oil sand projects in Canada account for a large share of the investment cut. One reason may be the cost level of production. The falling investment level in the energy sector may have long lasting effects, and depending on how governments are responding, it may lead to problems regarding the security of future energy supply. It is especially the long term projects which are suffering. This probably has to do with the risk connected to these projects. Since many of the most economically feasible wells already have been drilled, one has to go into project were the net present value of the project is lower.

Jackson (2006) interestingly points out that even the peak oil community is now putting more emphasis on issues like infrastructure and other above ground risks, and less emphasis on the argument that the world is running out of oil in terms of physical resources. This may be the initial phase of a new way of thinking for the peak oil community, and indicates that the actual risk may lie above ground.

Even though the investment level have been cut, figure 27 shows us that the level of investment in 2009 was still relatively high compared with the last ten years.

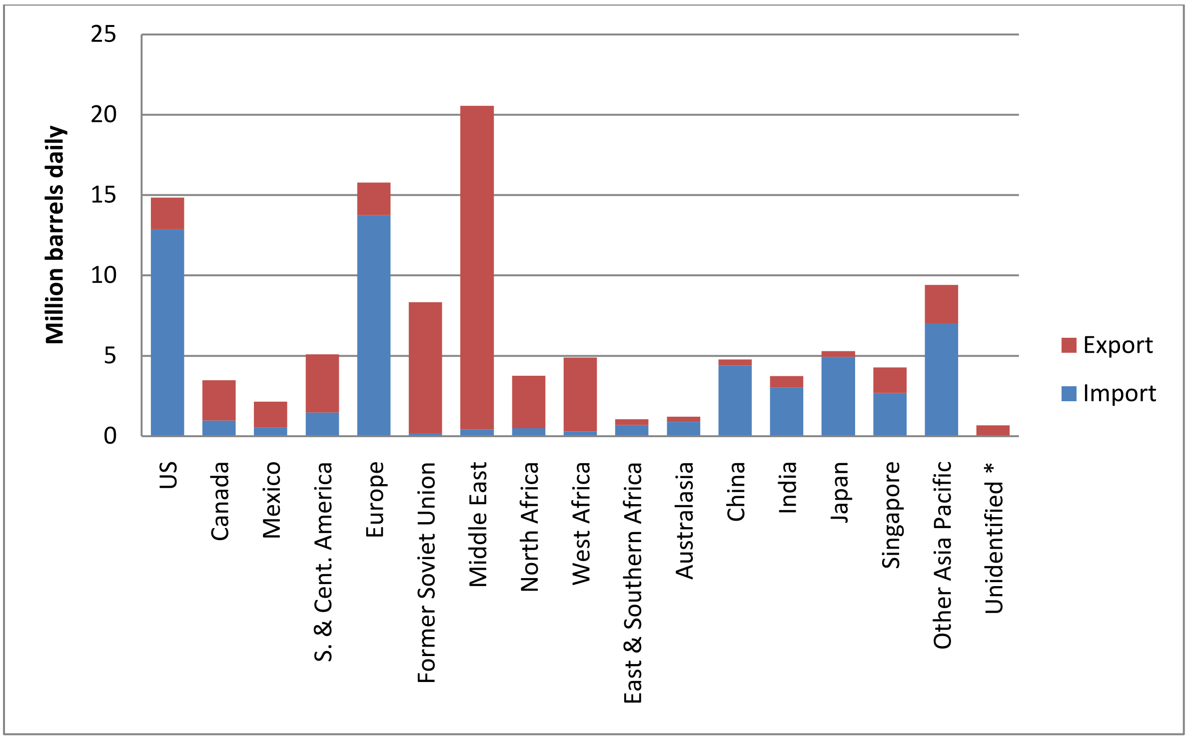
5.1.2 Politics

According to Odell (2004), the importance of regional issues will be less for oil supply compared with coal and gas. The reason is that both the producers and suppliers are dispersed all over the world, and due to low cost of transportation there is a well functioning global oil market. As discussed in chapter 4.1.2, about 60 percent of the world’s proven reserves are concentrated in the Middle East. Odell argues that if no big discoveries are done outside the Middle East, it is likely that the Middle East’s share of the world ultimately recoverable conventional oil will remain over 50 percent in the future. Secure future oil delivery therefore heavily depend on Saudi Arabia’s willingness to bring the oil to the market.

Since the 1970s, there has been a much stronger relative growth in the upstream industry outside the Middle East. Development of new technologies and the desire of being less dependent on oil supply from the Middle East, made continents like Europe and North- and South America invest in their own production capacity. It seems like geopolitical factors have been the main driver for the development of the industry, rather than the geographical location of the oil. At the same time, the enormous economic growth in Southeast Asia has made a market for the Arabian oil.

Even if both production and consumption of oil is highly spread around the globe, there are some huge players on both sides. As illustrated in figure 28, the main importers of oil are the United States and Europe, while the main exporters are the Middle East and the former Soviet Union.

Figure 28: Oil import and export
Numbers are including both export and import of crude and products.



Source: Based on data from BP Statistical Review (2009).

As already discussed in chapter 4, many important oil producing countries do have a declining production rate. On a short term basis, this means that the world may face a period of more dependence on the Middle East as an oil supplier. If the counties in the Middle East are willing to supply the demanded amounts of oil remains to see. Historically, countries like Saudi Arabia have been pioneers when it comes to stabilizing the world market for oil. The future dependence on Arabic oil will to a great extent depend on countries in the former Soviet Union. In these countries we see increasing activity of large international oil companies in joint venture with local corporations. Based on my discussion in chapter 4, we may expect the production in these areas to increase. But as stressed before, increasing production depends heavily on geopolitical factors, rather than the geological existence of oil.

But in the longer term, Odell (2004) argues that we can expect this global energy situation to change as the production from conventional resources will start to decline and more and more non-conventional resources are brought into the market. Odell expects the contribution from unconventional resources to be about 50 percent of the world’s supply in 2060. As the production of conventional oil is peaking, countries like Canada and Venezuela will gradually be more important suppliers of oil. This illustrates the fact of changing world economic power, as non-conventional oil resources are situated in countries which have not historically been large suppliers of oil.

Another important issue when it comes to politics is the limitations on some very oil abundant countries. According to IEO 2009, the total production in Iran is expected to be restricted for years to come due to political factors. The production is not limited to international factors, but rather as a result of low effectiveness in the national oil company's operations and the government and foreign investor's ability to agree on contract terms. In the IEO 2009 reference case, Iran's oil production will decline through 2020 due to both financial and political constraints. However, in the longer term, the production is projected to increase. In Venezuela, the government's reaction to the recent high oil prices was to limit foreign direct investments and access to its reserves. IEO 2009 expects this to limit the Venezuelan potential.

This illustrates that politics are an important factor in the energy market. The key challenge is to understand the impact of decision making and political uncertainties on project execution.

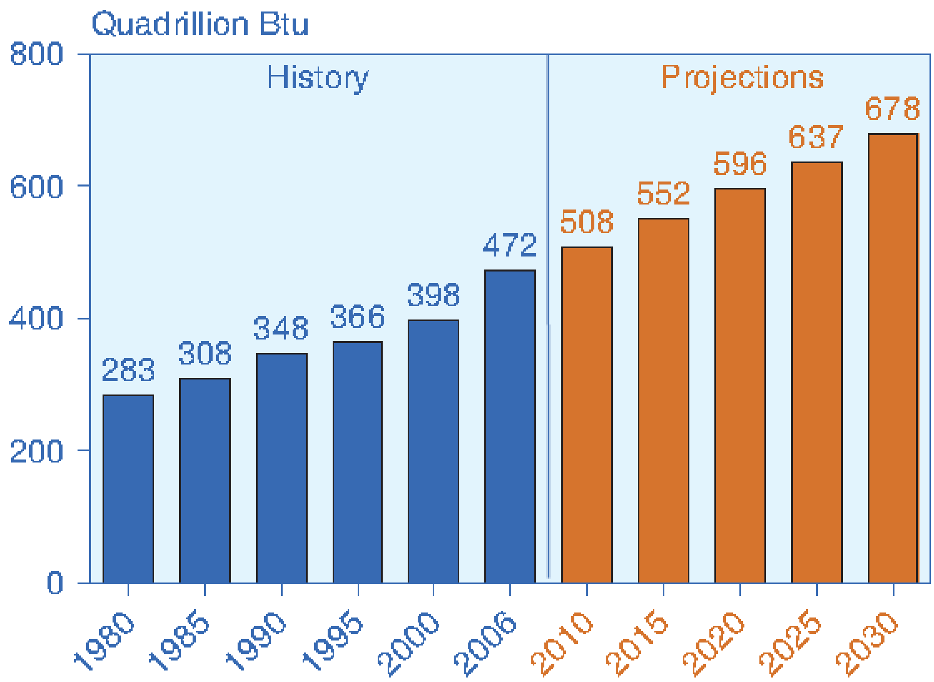
5.2 Critical factors on the demand side

The future of demand is an important factor when it comes to the discussion of future supply of oil. The demand side is not only something which has to respond when the peak is reached, and the supply side does not manage to satisfy the increasing demand. The future demand will also play an important role in shaping the peak. As the NPC Global Oil & Gas Study (2007) argues, the demand will influence when the peak is reached. High demand will force the peak to come earlier and increase the post-peak decline rate in the oil production. In this context one has to remember that as the demand for oil rises, and the risk for a peak oil production to be close in time also increases.

The prospects for future energy demand are not easy to predict. According to Odell (2004), there is a historical trend of overestimating future demand. Demand for oil will increase with 1.5 percent annually as long as the evolution of reserves makes it possible. Odell predicts the increase in demand to continue until about 2060.

According to IEO 2009, the consumption of oil is expected to continue to grow until at least 2030. As illustrated in figure 29, the consumption for oil will increase from 472 quadrillion British thermal units (Btu) to 678 quadrillion Btu between 2006 and 2030, something which represents an increase of 44 percent.

Figure 29: World marketed energy consumption, both historical and projections.



Source: IEO 2009, page 7.

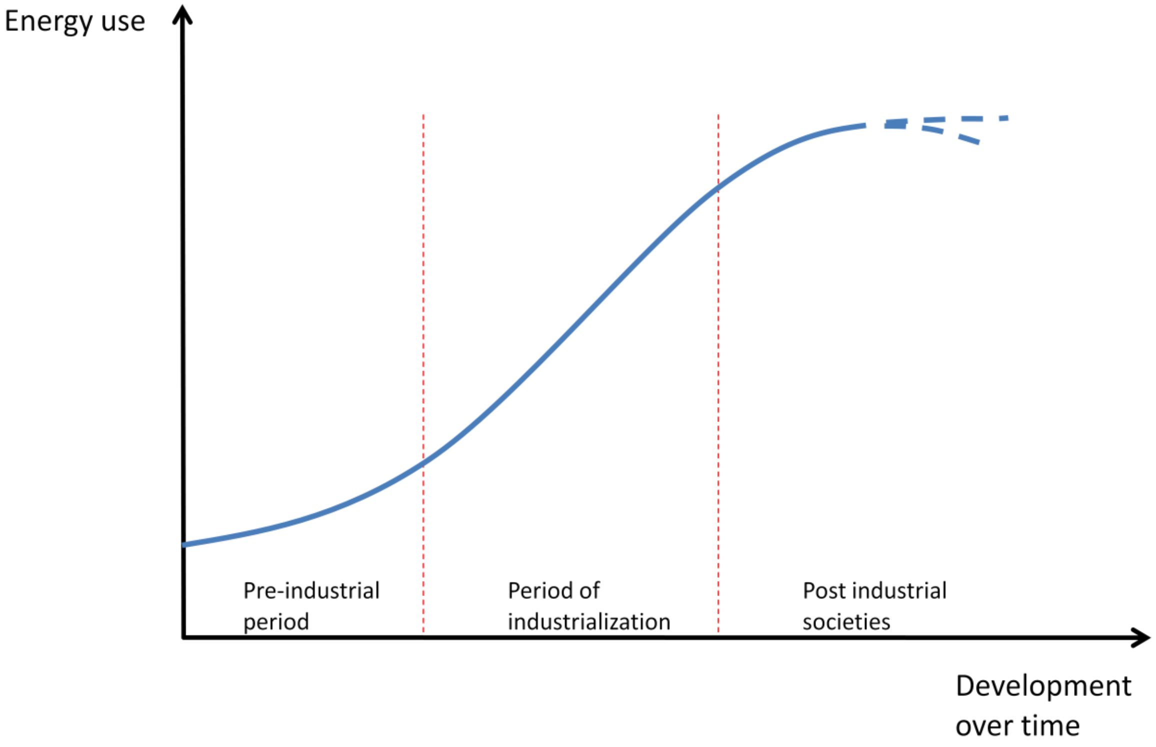
In the discussion regarding the demand side, it is important to stress what will be the main drivers. Demand is a question of price. A high oil price will both put a downward pressure on demand and give incentives to develop substitutes. It is a question of the existence of a backstop price, which is the price level where substitutes are getting cheaper than oil and therefore are taking over as the supplier of energy. Examples of such substitutes may be different sources of renewables, coal, natural gas and nuclear.

Odell (2004) stresses the point of natural gas as a substitute for oil. Through the 21st century, oil's contribution to the total hydrocarbon supply will fall from 63.8 percent in 2000, down to only about 29 percent in 2100. This reflects the resource base constraint, and is also likely to indicate demand constraint. During the 21st century, it is likely that the global hydrocarbon industry will turn its attention and investments towards natural gas. This is due to both economic reasons and environmental reasons. This reasoning illustrates that the world will not run out of oil, and that natural gas may become the most significant contributor to the global hydrocarbon market in the 21st century. Due to new technology one is able to extract enormous amount of gas from sources, which earlier have been classified as unconventional. Thus the future prospects of gas may be very promising.

Deffeyes (2009) stresses how the oil cost as a percentage of the world domestic product is evolving. As the price of crude oil is increasing, more and more of the total GDP is connected to the cost of oil. In that way the increasing crude oil price is working as a brake on the growth in the world economy. Around the globe we see the consequences of high oil prices rippling through the economy. For instance, the cost of food production is highly and positively correlated with the cost of fuel, making food more expensive when the fuel price is increasing. Another example is how producers of large and heavy cars, due to higher fuel prices, are losing market shares to smaller and more fuel efficient cars.

Another factor which is important regarding future demand for oil is economic growth. IEO 2008 declares that *''economic activity remains the principal driver of oil demand in all regions. Since 1980, each 1 % per year increase in GDP has been accompanied by a 0.3 % rise in primary oil demand''*. This illustrates that there is a strong relation between oil and economic growth. Thus, the prospects of economic growth will be an indicator of future oil demand. But, the relationship between energy use and economic development is differentiated between different levels of development. As illustrated in figure 30, economic growth in developing countries requires a relatively higher increase in the use of energy compared to developed countries.

Figure 30: Relationship between energy use and economic development over time.



Source: Replication of Odell (2004), page 3.

The high economic growth in very populous countries like India and China is likely to require enormous amounts of energy. According to Odell (2004), the world's developing countries will play a rising relative role in both global energy use and CO2 emissions. We may expect few of these countries to pay attention to climate change. In their choice between clean energy and economic growth, they are expected to pay more attention to the cost of energy, than the source of energy. Looking at the costs related to the different sources of energy, we may expect the demand for oil, gas and coal to increase in the future. After 2050, the world population is predicted to stabilize at about 9 billion inhabitants. Since a growing world population is one of the factors causing the world demand for energy to increase, a stabilizing population is likely to make the growth rate for energy fall gradually.

According to Dagens Næringsliv (2010), there has already been a demand peak in the use of oil in the developed countries. Due to improvement in energy efficiency, there are no reasons to believe that the demand for oil in the developed countries will ever reach the old peak level again. British Petroleum chief economist Christof Rühl argues that economic growth needs energy, but that the developed countries only need about 1/3 of the energy which developing countries need to achieve the same economic growth. It is all about fundamental change, where the OECD countries never will use the same amount of oil again. One consequence is that in a short time perspective, the world will not face a new dramatic increase in the oil price like we saw in 2008.

The main reason why Rühl argues that the peak demand has been reached is because the oil consumption started to decrease in 2005, years before the financial slowdown. In Dagens Næringsliv (2010), British Petroleum states that the developed countries consume about 52 percent of world oil consumption, a share that will decrease to 33 percent in 2030. This statement is supported by Brad Corson, vice president of ExxonMobil Corporation. He argues that the world energy consumption will increase by about 35 percent from 2005 to 2030. This is only half the increase which was expected by ExxonMobil in 2005, and it strongly illustrates the effect of improving energy efficiency.

The fact of decreasing oil demand in the developed world supports the idea of a demand peak. Even if the only sign of falling oil demand is found in the developed countries, it does illustrate that there may be a future peak in oil production, not due to lack of oil, but because the global demand of oil starts to decrease.

5.3 Summary

As discussed in this chapter, there are different critical factors affecting the future of oil, which is not directly connected to geological factors. Critical factors are found on both the supply and the demand side, and are including investment level, politics and falling demand. Each of these, or combination, may lead to a production peak. This illustrates how there may be a future peak in production, not as a result of traditional peak oil arguments, but due to critical above ground factors.

6.0 Conclusion

Future evolution in oil production and oil prices are highly debated. During the last few years the world has faced a rapid price increase, reaching a maximum close to 150 dollars per barrel in July 2008. Even if the world has faced fast growing prices before, especially in the 1970s, the world looks a bit different today. In the 1970s, new oil provinces like the Gulf of Mexico and Norway was ready to compensate for the reduced OPEC production. Today, several major oil production provinces are facing, or are close of reaching, a declining production rate. Unlike the 1970s, there are no obvious new oil provinces ready to replace this production, at least not on a short term basis. In addition, some very populous countries like China and India have a high economic growth, something which demands enormous amounts of energy.

During this thesis I have done a critical review of the peak oil phenomenon, and tried to look closer into the fundamental concept behind the debate. In short, the debate is divided by the peak oil community and the non peak oil community. The former community argues that geological factors in near future will trigger a production peak followed by a rapid decrease in oil production. On the other hand, the latter community believes that oil production will continue to grow for many decades before it eventually flatten.

The Hubbert curve has undoubtedly given fuel to the peak oil debate. As presented in chapter 2, the Hubbert curve has both a geometrical and a mathematical approach. Through my analysis of the mathematical approach in chapter 3, I found that both the US and the Norwegian, but also partly the UK production, follows the Hubbert curve. The fact that these countries' production paths seems to follow the Hubbert curve adds weight to peak oil community's arguments.

In my further analysis of the mathematical approach I revealed that the Hubbert curve gives very inaccurate predictions for the US, the Norwegian and the UK production paths. In fact, as long as the peak is not reached, my analysis revealed that the methodology systematically predicts the peak in production to arise within 2 to 6 years. The Hubbert curve's generally tendency to predict the production peak in near future may explain the peak oil community's rather unsuccessful attempt in predicting peak oil for more than half a century. The community's ardency for predicting peak oil in near future may also rely on their need for reaching the headlines to keep the debate alive. Based on my analysis of the mathematically approach, I will conclude that the Hubbert methodology is a useful tool when explaining the past, but it has very limited practical use when it comes to predict the future.

It is important to stress that even though each province or country may have a production path similar to the Hubbert curve, the global peak is getting higher and higher and moves ahead in time as we continuously add new resources and look at them collectively. Looking back in history, the reserves have evolved over time, and will probably continue to do so for many years to come. When discussing future reserves, it is important to stress how the reserves are likely to evolve over time. Even if the demand for oil has increased more or less gradually the last decades, the net proven reserves have continued to grow. It seems like most experts now predicts the peak to arise within 10 to 20 years. For oil production in total, it remains to see how unconventional resources may work as a substitute for conventional oil. Personally, and based on historically progress, I expect that unconventional resources will play an important role in the future, at least on longer terms.

The next important issue I want to summarize is what will happen when the peak is reached. On the one hand, the peak oil community argues the global production will fall rapidly. This statement may have its origin in the Hubbert curve which is symmetrical in time. There is no doubt that a fast decreasing global production will strongly influence the world economy. On the other hand, the non peak oil community has a more dynamic view. Higher price will give incentives to develop new fields and technology to make use of unconventional resources, something which will secure the supply of oil for many years to come. This supports the idea that the global production does not necessary need to fall rapidly after peaking, but rather stabilize at a production plateau which can be maintained for decades. At least I expect the global production path not to be symmetrical in time, but rather have a long tale. Based on this reasoning, the world will have plenty of time to adapt to a world without oil, and the policymakers do not have to fear a sudden lack of long lasting oil supply. Still, I do think policymakers should prepare for an establishment of a much higher oil price level in the future.

As discussed in chapter 5, various non-geological factors may trigger peak oil. This means that a peak in production may arise due to factors which are not grounded in the traditional peak oil arguments. On the supply side, lack of investment may cause bottlenecks which can prevent the oil to get fast enough to the market. Further, both national and international politics can influence production. As more and more of the relative share of remaining oil are situated in fewer and fewer countries, the right to the oil will give more power in the future international politics. This is something policymakers should be aware of. Demand is another above ground factor which can trigger a production peak. This simply because changing demand will regulate when the peak is to arise. Both the supply side factors and demand side factors are closely related to macroeconomic fluctuations. Thus, policymakers in countries where oil is the main economic driver should be aware that a major downturn in the global economy can have dramatically consequences for their country's economy.

Even if my thesis has revealed that the production of oil seems to remain high for many years to come, it has also revealed that there are some dark clouds in the horizon. Based on my personal view, peak oil will not occur as a result of oil scarcity, at least not in a geological sense, but rather as a result of above ground risks. Further, I believe that a change in energy regime will be a slow process, something which will make carbon fuel dominate the 21st century's global energy economy.

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Appendixes

Appendix A – United States crude production (1900 – 2008)

Dataset is based on EIA – 1.

Data is given as million barrels annually, and includes all 50 states.

Year	Production	Year	Production	Year	Production
1900	64	1937	1278	1974	3203
1901	69	1938	1213	1975	3057
1902	89	1939	1264	1976	2976
1903	100	1940	1503	1977	3009
1904	117	1941	1404	1978	3178
1905	135	1942	1385	1979	3121
1906	126	1943	1506	1980	3146
1907	166	1944	1678	1981	3129
1908	179	1945	1714	1982	3157
1909	183	1946	1733	1983	3171
1910	210	1947	1857	1984	3250
1911	220	1948	2020	1985	3275
1912	223	1949	1842	1986	3168
1913	248	1950	1974	1987	3047
1914	266	1951	2248	1988	2979
1915	281	1952	2290	1989	2779
1916	301	1953	2357	1990	2685
1917	335	1954	2315	1991	2707
1918	356	1955	2484	1992	2625
1919	378	1956	2617	1993	2499
1920	443	1957	2617	1994	2431
1921	472	1958	2449	1995	2394
1922	558	1959	2575	1996	2366
1923	732	1960	2575	1997	2355
1924	714	1961	2622	1998	2282
1925	620	1962	2676	1999	2147
1926	771	1963	2753	2000	2131
1927	901	1964	2787	2001	2118
1928	901	1965	2849	2002	2097
1929	1007	1966	3028	2003	2073
1930	898	1967	3216	2004	1983
1931	851	1968	3329	2005	1890
1932	785	1969	3372	2006	1862
1933	906	1970	3517	2007	1848
1934	908	1971	3454	2008	1812
1935	994	1972	3455		
1936	1099	1973	3361		

Appendix B – Alaskan crude production (1977 – 2008)

Dataset is based on EIA – 2.

Data is given as million barrels annually.

Year	Production
1977	164
1978	449
1979	512
1980	591
1981	592
1982	627
1983	665
1984	638
1985	667
1986	670
1987	718
1988	749
1989	683
1990	652
1991	656
1992	625
1993	579
1994	571
1995	540
1996	510
1997	473
1998	437
1999	388
2000	328
2001	355
2002	361
2003	357
2004	334
2005	312
2006	242
2007	261
2008	248

Appendix C – Norwegian crude production (1971 - 2008)

Dataset is based on BP Statistical Review (2009).

Data is given as million tons annually.

Year	Production
1971	0,3
1972	1,6
1973	1,6
1974	1,7
1975	9,2
1976	13,7
1977	14
1978	17,4
1979	19,5
1980	25
1981	24,3
1982	25,2
1983	31,4
1984	36
1985	39,2
1986	43
1987	50,1
1988	57
1989	74,9
1990	82,1
1991	93,8
1992	106,9
1993	114,1
1994	128,6
1995	138,4
1996	154,7
1997	156,2
1998	149,6
1999	149,7
2000	160,2
2001	162
2002	157,3
2003	153
2004	149,9
2005	138,2
2006	128,7
2007	118,8
2008	114,2

Appendix D – United Kingdom crude production (1965 – 2008)

Dataset is based on BP Statistical Review (2009).

Data is given as million tons annually.

Year	Production
1965	0,1
1966	0,1
1967	0,1
1968	0,1
1969	0,1
1970	0,2
1971	0,2
1972	0,3
1973	0,4
1974	0,4
1975	1,6
1976	12,2
1977	38,3
1978	54,0
1979	77,9
1980	80,5
1981	89,5
1982	103,2
1983	115,0
1984	126,1
1985	127,6
1986	127,1
1987	123,4
1988	114,5
1989	91,7
1990	91,6
1991	91,3
1992	94,3
1993	100,2
1994	126,5
1995	129,9
1996	129,7
1997	127,9
1998	132,6
1999	137,4
2000	126,2
2001	116,7
2002	115,9

Year	Production
2003	106,1
2004	95,4
2005	84,7
2006	76,6
2007	76,8
2008	72,2

Appendix E – Crude oil prices (1861 – 2008)

Dataset is based on BP Statistical Review (2009).

Prices are given in US dollars.

Year	$ money of the day	$ 2008	Year	$ money of the day	$ 2008	Year	$ money of the day	$ 2008	Year	$ money of the day	$ 2008
1861	0,5	11,8	1898	0,9	23,6	1935	1,0	15,3	1972	2,5	12,8
1862	1,1	22,7	1899	1,3	33,5	1936	1,1	17,0	1973	3,3	16,0
1863	3,2	55,3	1900	1,2	30,9	1937	1,2	17,8	1974	11,6	50,8
1864	8,1	111,5	1901	1,0	24,9	1938	1,1	17,4	1975	11,5	46,3
1865	6,6	93,1	1902	0,8	20,0	1939	1,0	15,9	1976	12,8	48,6
1866	3,7	55,2	1903	0,9	22,6	1940	1,0	15,7	1977	13,9	49,6
1867	2,4	37,2	1904	0,9	20,7	1941	1,1	16,8	1978	14,0	46,5
1868	3,6	58,9	1905	0,6	14,9	1942	1,2	15,8	1979	31,6	94,1
1869	3,6	59,1	1906	0,7	17,5	1943	1,2	15,0	1980	36,8	96,6
1870	3,9	66,0	1907	0,7	16,7	1944	1,2	14,9	1981	35,9	85,4
1871	4,3	78,3	1908	0,7	17,3	1945	1,1	12,6	1982	33,0	73,8
1872	3,6	65,7	1909	0,7	16,8	1946	1,1	12,4	1983	29,6	64,1
1873	1,8	33,0	1910	0,6	14,1	1947	1,9	18,4	1984	28,8	58,3
1874	1,2	22,4	1911	0,6	14,1	1948	2,0	17,9	1985	27,6	55,2
1875	1,4	26,6	1912	0,7	16,6	1949	1,8	16,2	1986	14,4	28,3
1876	2,6	52,0	1913	1,0	20,8	1950	1,7	15,4	1987	18,4	34,9
1877	2,4	49,1	1914	0,8	17,5	1951	1,7	14,2	1988	14,9	27,2
1878	1,2	26,7	1915	0,6	13,7	1952	1,7	13,9	1989	18,2	31,6
1879	0,9	19,9	1916	1,1	21,8	1953	1,9	15,6	1990	23,7	39,3
1880	1,0	21,3	1917	1,6	26,4	1954	1,9	15,5	1991	20,0	31,7
1881	0,9	19,2	1918	2,0	28,5	1955	1,9	15,6	1992	19,3	29,7
1882	0,8	17,5	1919	2,0	25,2	1956	1,9	15,4	1993	17,0	25,5
1883	1,0	23,2	1920	3,1	33,2	1957	1,9	14,6	1994	15,8	23,2
1884	0,8	20,2	1921	1,7	21,0	1958	2,1	15,6	1995	17,0	24,3
1885	0,9	21,1	1922	1,6	20,8	1959	2,1	15,4	1996	20,7	28,6
1886	0,7	17,1	1923	1,3	17,0	1960	1,9	13,9	1997	19,1	25,9
1887	0,7	16,1	1924	1,4	18,1	1961	1,8	13,0	1998	12,7	17,3
1888	0,9	21,1	1925	1,7	20,8	1962	1,8	12,9	1999	18,0	23,6
1889	0,9	22,6	1926	1,9	23,0	1963	1,8	12,7	2000	28,5	36,2
1890	0,9	20,9	1927	1,3	16,2	1964	1,8	12,5	2001	24,4	30,1
1891	0,7	16,1	1928	1,2	14,8	1965	1,8	12,3	2002	25,0	30,2
1892	0,6	13,5	1929	1,3	16,1	1966	1,8	12,0	2003	28,8	33,7
1893	0,6	15,4	1930	1,2	15,4	1967	1,8	11,7	2004	38,3	43,6
1894	0,8	21,0	1931	0,7	9,3	1968	1,8	11,2	2005	54,5	60,1
1895	1,4	35,3	1932	0,9	13,8	1969	1,8	10,6	2006	65,1	69,6
1896	1,2	30,6	1933	0,7	11,2	1970	1,8	10,0	2007	72,4	75,1
1897	0,8	20,5	1934	1,0	16,2	1971	2,2	12,0	2008	97,3	97,3