Peak oil and climate change policy

Aviel Verbruggen[*] and Mohamed Al Marchohi[**]

The peak oil debate received much attention recently. One of the reasons is the higher oil price since 2003. This article provides an overview of both advocate and critical voices on the peak oil vision. A large part of the seemingly conflicting debate is explained by semantics. When considering a more holistic sources-sink view, tight constraints on oil use is needed by the limited carrying capacity of atmospheric sinks and not by scarcity in resources. Peak-oil belief stimulates a passive approach in climate policies when suggesting carbon emission will peak naturally simultaneously with oil consumption. However, carbon stocks in fossil fuel resources are very large making multiplication of the current carbon dioxide concentrations in the atmosphere possible. Avoiding further increase in concentration necessitates very limited use of fossil fuels by "setting higher end-use prices". When oil companies can charge the higher prices they can afford bringing new oil to the market for many decades, extending the carbon lock-in by fossil fuel technologies. Higher end-use prices therefore must result from tax reforms, charging for the public good atmosphere and recycling the revenues for efficiency and renewable energy options. The oil age will not end by lack of oil, but emission limits will trigger the reality of peak oil production in the coming years.

Keywords: peak-oil, climate policy, tax reform

1. INTRODUCTION

The lecture combines two subjects of high interest at present: peak oil and climate change. We discuss the relevance of belief in nearby peak-oil for designing climate policies. Concepts, data and mechanisms of resource exploitation are briefly reminded. We will provide an overview of the oil (and wider: fossil fuel) reserves and resources issues. Moreover, reference is made to the standard sequence of exhaustible resource exploitations, i.e. from nearby and easy to far and difficult ores, mines and fields. The peak oil debate is summarized showing arguments and statements of both camps. Weighing these arguments and statements by peak-oil adepts and critics reveals that semantics contribute to the conflict. Both adepts and critics confirm the standard sequence of natural resource exploitation from easier and cheaper reserves uphill to more difficult and expensive grades. The latter are available in immense quantities. To handle climate change issues, oil production and consumption need to be placed in the frame of a sinks-

[*] University of Antwerp, as full professor and correspondent: aviel.verbruggen@ua.ac.be.
[**] University of Antwerp, assistant.

sources industrial metabolism. Using a rudimentary quantification of the sources while comparing these numbers with the atmospheric sink values, provides evidence that atmospheric sink constraints are many times more binding than fossil fuel resources scarcity. This leads to the suggestion that peak oil is a non-problem, but that belief in it may be causing climate policy passivity. Avoiding further increase in concentration necessitates very limited use of fossil fuels. We will recall the growing insight that "the right carbon prices must be set". But the crucial choice is how (and who) is going to set such prices. When the care for the public good atmosphere is left over to private market forces, a new round of higher oil prices will bring more and dirtier fossil fuels into use. For reducing the use of fossil fuels and for stimulating energy efficiency and renewable sources, public pricing through tax reforms are necessary.

2. CONCEPTS, DATA AND MECHANISMS OF RESOURCE EXPLOITATION

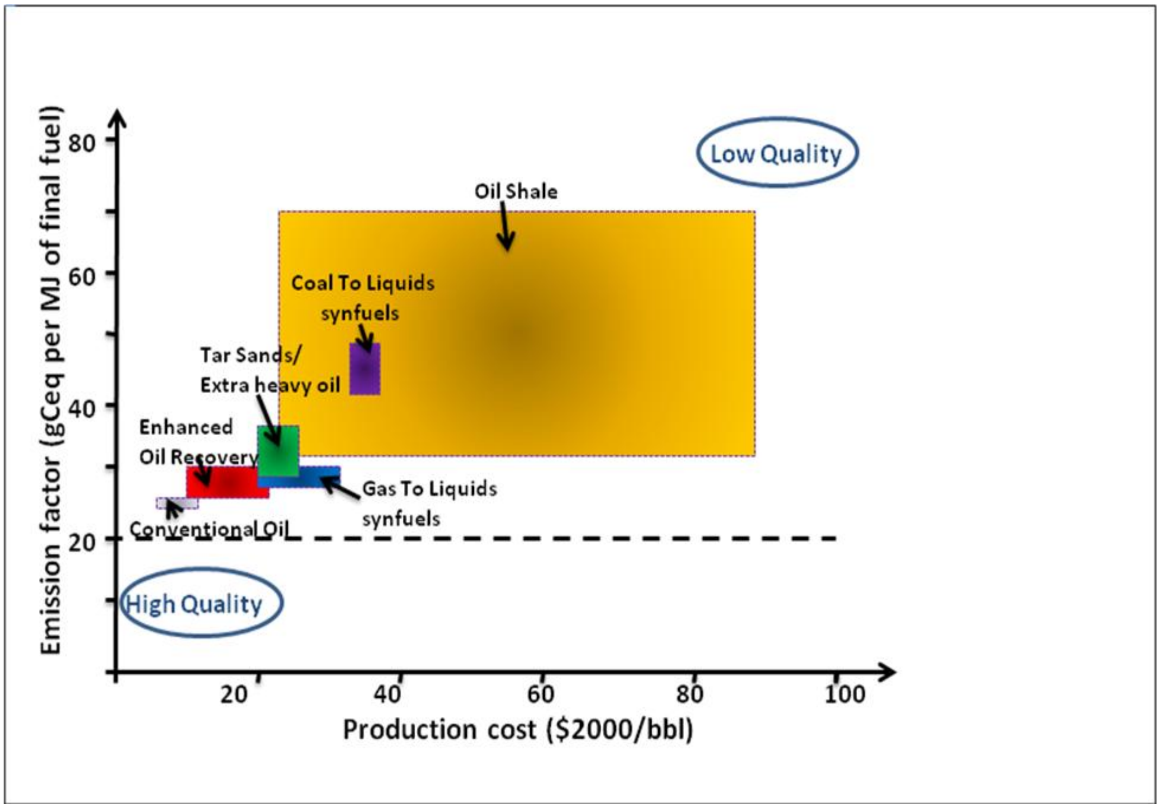
Natural resources consist of renewable and non-renewable resources (Craig et al., 2001). Renewable resources deliver regular returns, if not destroyed by over-exploitation. They are not discussed here, and we use the term resources only for non-renewable ones. Non-renewable resources occur in finite quantities that natural processes cannot augment or replenish in short time. Examples are fossil fuels (coal, oil, natural gas) and metallic ores. Resources are spread on earth in varying densities and qualities. Some deposits of a particular resource are highly concentrated while the remainder stock consists of spread and marginal concentrated findings.

Conventional and Non-Conventional Oil Resources, and Their Carbon Charge

Conventional oil is a liquid lighter than water (API gravity >10) of which a large portion will flow naturally from the bore hole because of the pressure within the reservoir (primary recovery). This article treats extra heavy oil, oil sands, oil shale, Gas to Liquids and Coal to Liquids as non-conventional oil. The carbon intensities of non-conventional resources are high. (Brandt and Farrell, 2007) Conventional crude causes 'upstream emissions'[1] from 5 gCeq per MJ fuel delivered onwards. Petroleum products from non-conventional resources cause upstream emissions up to 50gCeq/MJ (being the high end for shale oil). The downstream (combustion) emissions are almost equal for all petroleum products at 20 gCeq per MJ of fuel input. The differences in emissions are shown on the vertical axis of figure 1.

[1] Upstream emissions are emissions related to the different processes to make a barrel of oil available for consumption.

Figure 1: Quality of liquid hydrocarbon resources, rated by production costs and carbon emissions (source: based on Brandt and Farrel, 2007)



In figure 1, sources bottom-left are high quality and sources top-right are low quality in relative terms. Conventional oil has low production costs and relatively low carbon emissions per ton. The production costs rise with heavier and dirtier feedstock. The final petroleum products from non-conventional feedstock are more costly and only financially interesting when market prices of oil are high. The extent of the area in figure 1 expresses uncertainties about cost prices and emission factors of the resources. (Brandt and Farrell, 2007). Total carbon emissions from oil may increase at lower oil consumption when substituting non-conventional sources for conventional ones.

The Taxonomy Of Reserves And Resources

Next to the distinction between conventional and non-conventional oil one distinguishes reserves and resources. The German Federal Institute for Geosciences and Natural Resources (BGR[2]) uses as definitions: ***Reserves****: The quantity that can be recovered economically from a mineral deposit at current prices with current technology*. ***Resources****: demonstrated quantities*

[2] BGR in German stands for: *Bundesanstalt für Geowissenschaften und Rohstoffe*

that cannot be recovered at current prices with current technology but might be recoverable in the future, as well as quantities that are geologically possible but have not been demonstrated.

There is no consensus on how to assess reserves and there is no world organization to enforce one (Bentley, 2002; Laherrere, 2006). Tree levels of confidence regarding reserve estimates are standard: *proved, probable, possible*. An oil or gas field is considered as *proved or* **1P** *reserves* if the chance that the field will effectively be developed is higher than 90 %. For *probable reserves* the chances of being available for mining technically and economically are estimated at 50 to 90 % and for *possible reserves* at less than 50 %. The aggregates of proved and probable reserves are **2P** reserves, and after adding possible reserves on top one obtains **3P reserves**. Oil industry data typically refer to 2P reserves, while the financial sector awards loans for project developments of 1P reserves. For resources, analogously to the 1P, 2P and 3P classification for reserves, the Low Estimate, Best Estimate and High Estimate are used. Table 1 shows assessed fossil fuel reserves (2P reserves) and resources by the German Federal Institute for Geosciences and Natural Resources.

Table 1: Fossil Fuels 2P reserves and Best Estimate resources [assessed end 2007 by BGR]
(SKE= Steinkohleeinheit = German for hard coal unit)

Fuel	**Reserves**		**Resources**	
Status 31.12.2007	**Typical units**	**EJ (10^{18} J)**	**Typical units**	**EJ (10^{18} J)**
Conventional Crude oil	164 Gt	6,835	82 Gt	3,430
Oil sands / Extra heavy oil	65 Gt	2,720	66 Gt	2,761
Oil shale	1 Gt	42	184 Gt	7,699
Total Oil	**230 Gt**	**9,597**	**332 Gt**	**13,890**
Conventional Natural gas	183 T.m³	6,948	207 Tm³	7,857
Non-conventional Natural gas (tight gas, aquifer gas, gas hydrates, coal-bed methane)	ca. 2 Tm³	76	1533 Tm³	58,335
Total Natural Gas	**185 T m³**	**7,024**	**1740 Tm³**	**66,192**
Total Coal	**711 Gt SKE**	**20,852**	**14212 Gt SKE**	**416,516**
Fossil Fuel Total		***37,473***		***496,598***

Non-conventional oil resources (10460 EJ) are larger than total oil reserves (9597 EJ). Tremendous natural gas and coal reserves and resources may deliver synfuels that enlighten oil supply restrictions for the foreseeable future. Bentley (2002) and Kjärstad and Johnsson (2009) question whether synthetic crude oils and synfuels can be produced at similar flow rates as conventional crude, and argue that non-conventional sources cannot get on-stream fast enough to fully compensate the decline in the production of conventional crude. Non-conventional oil projects tend to have long and uncertain lead times (Bentley, 2002; Tsoskounoglou et al., 2008). With sufficient non-conventional oil resources and reserves physically available, other constraints may limit their extraction

Standard Sequence of Resource Exploitation

Herfindahl (1967) showed that, with constant marginal extraction costs, deposits should be extracted in strict sequence from lowest to highest cost. This is the well known 'least-cost-first extraction rule'. Others question the value of this principle (e.g. Kemp and Long, 1980; Amigues et al., 1998; Holland, 2003). It may not hold under certain conditions, such as the case with limited extraction capacity. The observed standard sequence of resource exploitation is starting at the cheap and easy deposits first, i.e. at the high grade seams, wells and ores (Craig et al., 2001). Per unit of gross material extracted, a relatively large part is useful what minimizes the mining and treatment costs. When high grade resources are exhausted, producers shift to lower grades at higher production costs. Resources are not homogenously distributed in the Earth's crust. Earth's stocks are typically composed of small amounts of high grade seams, ores or wells and of large amounts of low grade seams, ores or wells. Standard resource exploitation practice exhausts high grades reservoirs or stocks first. The American Nuclear Society (2001) provides a clear illustration[3] for uranium mining.

When high quality mines are getting exhausted, supply decreases pushing market prices up (assuming demand remains stable or increases). Uneconomic lower grade resources become economical to mine due to the higher market prices, and producers invest in exploiting lower grade ores often more widely available. This is the economic chronological order in exhausting resources along decreasing ore grades, from cheap and easy to expensive and difficult (figure 1; Craig et al., 2001: 173) Oil producers first start production from easy access and large reservoirs. Oil in such reservoirs is naturally pressurized allowing primary recovery of 20% to 30% of the oil by simply drilling a hole to the reservoir. When market oil prices are high, exploitation of non-conventional oil resources is economical. The earth owns large stores of non-conventional oil resources (table 1). Higher oil prices may thus lead to the use of non-conventional sources which are very carbon intensive (see figure 1). (Newell, 2006)

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[3] See: http://www.americanenergyindependence.com/library/images/nuclear/Uranium01.htm

3. PEAK OIL DEBATE

Peak oil propositions receive a lot of new attention since the price of oil is climbing since 2003, peaking in mid-2008 (Leder and Shapiro 2008; Tsoskounoglou et al., 2008).

King Hubbert's Peak And ASPO

Hubbert's graphs (figure 2) are well-known. Their approval rate was rising spectacularly after 1970, the year USA oil production peaked, precisely the year of one of the cases forecasted by Hubbert in 1956. US annual production at the high point in 1970, however, was 600 million barrels (20%) higher than Hubbert's projection of peak production for the US Lower 48 (Jackson 2006; figure 2).

Figure 2: Actual US production and predictions by Hubbert in 1956

(Source: US DOE EIA, 2008 and Hubbert, 1956)

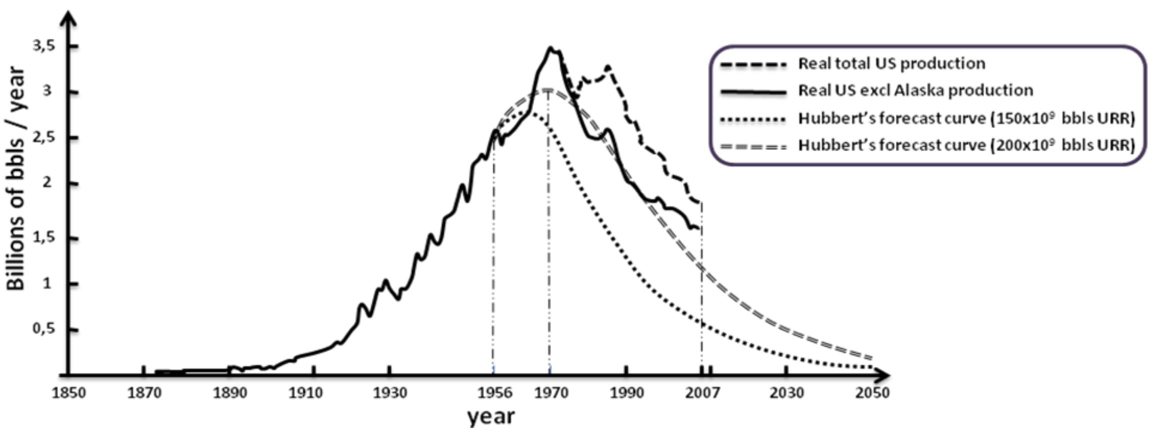


Figure 2 illustrates the high impact of geographical definitions on peak-oil production, comparing USA oil production without and with Alaska included. The observed data also tend to reject the symmetry of the production bubble assumption. Several investigations find the curves are not symmetrical (what Hubbert suggested). The right end of the curves is the predicted part and predictions seem to underestimate actual outputs skewing the curves at their right side (Watkins, 2006; Jackson, 2006; Brandt, 2007). One cause may be that past and present technologies extract only 35% of the oil from the fields, leaving huge potentials in the ground (Hall et al., 2008). The huge potentials could be accessed through Enhanced Oil Recovery delaying the decline of the individual production curves[4]. Aggregated curves then also change from Gaussian symmetry to multi-modal shapes.

Predictions on moment and height of "the" oil peak are sensitive to assumptions concerning the shape of the curve (growth and decline rates) and on the Ultimate Recoverable Reserves[5]. Brandt (2007: 3085) investigates the assumption of oil production curve following a symmetric bell-shape curve, and concludes "had history progressed differently and Hubbert used a linear model rather than a bell-shaped model, he would likely still have been hailed as correct due to the extremely good fit of US production to the linear model as well as the Gaussian model. Or, had Hubbert analyzed a different region than the US, he would have almost certainly been less correct, simply because US production is quite symmetric compared to the global average". Sometimes lessons from a limited area (e.g. USA) are considered to apply on the rest of the world, without detailed qualification of the differences. E.g. the Hubbert curves are perhaps valid for stable areas (such as the US-48 lower states), not disturbed by political turmoil, deep recessions, domestic wars, etc. Such events may distort exploration and extraction rates ending in irregular shapes of the aggregate exploitation curves in other regions of the world.

The Association for the Study of Peak Oil and gas (ASPO) follows Hubbert in generating bell shaped production forecasts[6] for the world (ASPO, 2005). The similarity of the global production curve with the Hubbert Curve is clear up to the 1970's when the oil crisis influenced the shape of the curve. The supporters of the peak oil vision have been disapproved by history so far. Peak oil models predicted the global oil production peak several times in the past (Lynch, 1999). The predicted peak was repeatedly *increased* and *postponed* a few years into the future. Campbell for example once predicted that 1989 was the year of 'peak' production (Maugeri, 2004: 1114).

Peak oil is developed and supported most by geologists stating that oil deposits are non-renewable and fixed, making stocks decrease with consumption. Peak oil authors argue that many estimates of oil reserves and resources are non-reliable and overestimated. Estimates are forthcoming from producing countries. Some countries may manipulate estimates for own gain, in particular OPEC countries declaring strange reserve volumes. Political and commercial bias in reporting reserves is due to OPEC's quota based assignment policy: the larger oil reserves a

[4] The individual oil production curve follows a plateau pattern over time. Production gradually increases to some maximum output followed by a long plateau and a gradual decrease. Improved technology may add live extensions.
[5] An accurate knowledge of the ultimate recoverable reserves is required by Hubbert's method, but his 1956 analysis could not incorporate the impact of giant discoveries in Alaska and the deepwater Gulf of Mexico (Jackson, 2006).
[6] See: http://wolf.readinglitho.co.uk/chartimages/p/p5oilprodworld.gif

country owns, the larger is the allowed production quota. Suspect reserves stay constant year after year (i.e. new discoveries exactly match production) or increase suddenly by large numbers (Campbell, 1994).

Another argument used by the peak oil supporters is the decreasing discovery rate. The largest fields are found first because they are too big to miss. The large fields are aging and fewer are discovered, while production mirrors discovery with a time-lag. Campbell (2006) states that in 1981 the world started to consume more oil than it found and that the gap between discovery and production is widening. Based on historical discoveries and stochastic simulation of future discoveries, Shell finds a normal distribution for new discoveries of regular conventional oil when smoothed for a 20-year moving average (Tsoskounoglou et al., 2008: 3800). The year 2005 knew the lowest oil discovery level ever and anno 2008 the world consumes 2 to 3 barrels (Tsoskounoglou et al., 2008: 3800) or even 4 to 5 barrels (Hall et al., 2008: 113) for every new discovered oil barrel.

Peak oil authors state that the largest and most accessible sedimentary areas have already been explored extensively. Therefore, future discoveries will likely occur in smaller quantities and in more remote areas, and production will be more difficult and costly. The rate of worldwide oil discovery has been decreasing and some areas have failed to yield any recoverable oil while once thought to possess significant oil potential (Craig et al., 2001: 168-169).

Critical and Opposite Visions On Peak Oil

Critical visions on Peak Oil on the other hand are stated mostly by economists. They consider reserves predominantly an economic concept; “oil reserves are the amount of oil that is minable at today’s *prices* using existing *technology*”. The economist vision rather ignores critical geological features of oil stocks (Hallock et al., 2004). Reserves and resources are no fixed numbers but constitute a dynamic flux depending on prices and technology.

Currently used technologies leave about 65% of the oil in the ground (Hall et al., 2008). Oil shortage will make prices rise. Increased prices convert part of the once uneconomic *resources* (e.g. small or deep oil wells remote from markets) to economic *reserves*. The resources are vastly greater than the reserves (table 1), so enough material is available if prices are sufficiently high. Long before the last fractions of exhaustible resources could be extracted, production costs will rise so high that demand will vanish. Both, decreasing use and the increased rates of discovery and recovery as a result of higher oil prices, will extend the life cycle of the petroleum reserves (Craig et al., 2001: 173).

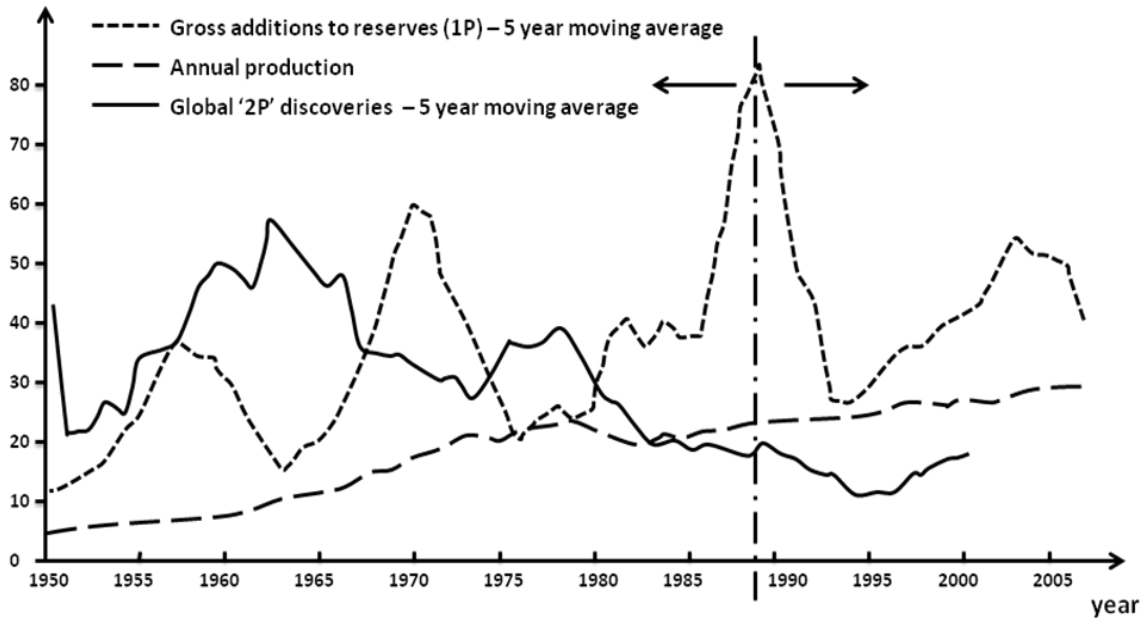
Watkins (2006: 512) criticizes the definition of ultimate reserves as a fixed, final or fundamental fact. He further argues that the exact estimate of Ultimate Recoverable Reserves, optimistic or pessimistic, would include the knowledge of future science and technology. Ultimate reserves are thus unknowable. Critics of the peak oil vision emphasize the large quantities of non-conventional oil in tar sands and oil shale (table 1) (Halle et al., 2008)

Peak oil critics mostly share an optimistic view on discoveries. In 1994, Odell spreads the view that most regions are under-explored because the global oil industry experiences a lack of maturity compared to the U.S. one, retarding the exploration of new reserves as quickly and intensively as in the U.S. Maugeri (2006a: 1) argues that during the last 25 years more than 70% of exploration effort took place in the USA and Canada that probably hold only 3% of the world's crude oil reserves. The Middle East region only experienced 3% of global exploration during the same period while holding around 70 % of the earth's crude oil reserves. Although OPEC countries own the largest oil reserves, these countries are still relatively underdeveloped and under-explored (Maugeri, 2006b: 150). After the 1970s, most Middle East countries nationalized their oil industries causing a decline in the regions geological and exploration know-how. Maugeri (2006b: 152) emphasizes most oil producing countries pump from old fields, most being in production since the first half of the 20th century, still using 50 to 60 year old technology and equipment. The price collapse in 1986 made OPEC countries worry about overproduction causing several OPEC countries not to develop new fields and only exploiting those already in production to maintain steady production levels. (Maugeri, 2006b:151-154). High prices are the result of economic disturbances, not of geological limitations. High prices are a prerequisite for greater investment. He concludes by saying: '*In other words, there is more than enough oil in the ground*' (Maugeri, 2006a:2).

Odell further shows that between 1950 and 1989 only once the annual use of oil exceeded the annual addition to reserves (1P) by the global oil industry and states: "the world is running into oil, not out of it" (Odell, 1992: 285). We updated Odell's graph, based on BP Statistical Review data for the post 1990 period, and show that Odell's findings hold for the post 1990 period until 2007 (latest data available). From 1990 onward, the 5 year moving average of gross additions to reserves always exceeded yearly production.

Figure 3: annual world oil production, gross additions to reserves and global 2P discoveries

(Sources; discoveries: HIS Energy; production/reserves: up to 1989: Odell, 1992 – 1990 onwards: author's additions based on BP, 2008))



Odell's statement of the world running into oil is however based on his original curve (additions to 1P reserves) that ends at the peak in 1989. In the post 1990 period, the moving average curve lays closer to the production curve. The sharp rise in the second period of the 1980s is partly explained by the high additions to the reserves by the OPEC countries in the context of their quota production system. The reliability of the additions may be as doubtful as are the assessments of the total stocks now in exploitation. The impact of the oil market conjuncture on the growth of reserves is a subject for further investigation. The full line on figure 3 (2P discoveries) is also added to the original Odell graph and will be explained later.

How Different Are The Visions?

Summarizing the main positions hold by peak oil followers (3.2) and critics (3.3.) we select quotes by respectively Bentley and Maugeri, adding our underlining:

"*The world's production of <u>conventional</u> hydrocarbons will soon decline. Hydrocarbon shortages are inevitable unless radical changes occur in demand, or in supply of <u>non-conventional</u> hydrocarbons…Best estimates put the physical peak of <u>global conventional</u> oil production between 5 to 10 years from now…*" (Bentley, 2002: 189).

"*We are not running out of oil, but <u>high oil prices</u> are needed to find it. There is an alarmist theory that the world is running out of oil. Quite the contrary. There is plenty of oil in the ground, and high prices are just what is needed to tap the earth's vast reserves*" (Maugeri, 2006a: 1).

Tilton (1996) attributes the differences between two *opposing camps* to *very different, opposing and competing paradigms*. Others refer to the groups by using antonymous denominations such as *pessimists* versus *optimists* (Tsoskounoglou et al, 2008; Aguilera et al., 2009). But the differences are less dramatic when every statement is fully characterized by content and by context. E.g. the quotes by Bentley and Maugeri seem very opposite, but in the end they cover different realities. Bentley emphasizes peaking of conventional oil unless “radical changes in supply of non-conventional hydrocarbons” occur. Maugeri replaces the “unless” by “high prices”. The emphasis and the language differ as do their analytical perspectives, but can one call these different paradigms?

Opinions on discoveries and additions to reserves also diverge. Peak oil supporters stress discoveries have decreased which means less oil is available for consumption. But statistics reveal reserves continue to increase with every year more oil being added to the reserves (figure 3). Here again, the two groups talk about two different things. Although proved reserves (1P reserves) do grow over time (BP Statistical Review, 2008), 2P reserves (proved plus probable reserves) remain quasi constant. Year after year some share of 2P reserves is converted to 1P reserves (Bentley et al., 2007). Figure 3 gives a clear representation of the two graphs (additions to 1P reserves and 2P discoveries) which do not run synchronously. Even without new discoveries oil quantities may be added to reserves because of increasing prices, advancing technologies and increased knowledge and confidence about field volumes (Jackson, 2006). Decreasing discovery rates (see figure 3) may result from little left to find or from decreasing prospecting efforts and investments, the latter very influenced by the oil market conjuncture.

In comparison to the 1980s, more authors refer to the concept of peak oil for analyzing the patterns of oil exploitation (Victor, 2008: 60).There is no consensus on the timing and height of the oil peak. Peak oil dates range from ‘already peaked’ [Deffeyes (2003) argued the year 2005, as does Simmons] to dates beyond 2035 (Jackson, 2006). Many articles have recently been published to project a peak oil date in the time interval 2010-2040 (Bentley et al., 2007; Hirsch, 2007; Kaufmann and Shiers, 2008; Tsoskounoglou et al., 2008; Leder and Shapiro, 2008; de Almeida and Silva, 2009; Kjärstad and Johnsson, 2009; Aguilera et al., 2009; Shafiee and Topal; 2009). Possible explanations for the different forecasts are: use of different data sources (high or low Middle East estimates), lack of data transparency, use of different assumptions in the models, use of different analytical frameworks, whether or not including some share of the non-conventional resources, etc.

When the positions are normalized for semantics, both groups agree on the peaking of conventional, easy-to-access "premium" oil, not too far in the future. This finding is conform to the standard sequence of resource exploitation and is repeatedly heard. For example, while senior oil executives traditionally avoid discussions on geological constraints, in January 2008 Shell CEO Jeroen van der Veer stated that after 2015 supplies of easy-to-access oil and gas will no longer keep up with demand. An increasing number of oil company executives believe oil production will never exceed 100 million barrels per day, e.g. Christophe de Margerie (Total), James Mulva (ConocoPhillips), and Shokri Ghanem (Libya's National Oil Company) (Strahan, 2008). Sadad al Husseini, recently retired head exploration and production of Saudi Aramco, claimed global oil production has reached its ultimate plateau, expecting a decline within 15 years (Strahan, 2007). Chevron admits the issue of peak oil by launching the website www.willyoujoinus.com (Campbell, 2006). Changed talk by oil industry executives may result from a variety of considerations. One may be that business-as-usual is not optimal in the long term and that they want to act differently to secure future activities. A more stable flow in exploration and production over the coming decades may better fit the strategies of the companies. Other reasons may be public concerns about peak oil and climate change.

4. NEW CONSTRAINTS: THE ATMOSPHERE AND CLIMATE CHANGE

Industrial Metabolism: Sinks and Sources

The ecological economics literature developed the concept of industrial metabolism for describing the interaction between living economies and nature (Georgescu-Roegen, 1971, 1975; Daly, 1980; Ayres and Ayres, 2002). As other living organisms, economies take in resources from the environment and discard residuals and waste back to the environment. This sources-sinks concept is useful to discuss peak oil and climate change in context.

External energy is a major input to industrial economies, and the largest share of commercialized energy inflows are fossil fuels (BP, 2008). By obeying the first law of thermodynamics, materials implied in fossil fuel combustion (H-C molecules, O_2 and N_2 (air) with some more substances) do not vanish but are converted into flue gases (a mixture of N_2, H_2O, CO_2, NO_X, SO_2, unburned or incompletely combusted H-C molecules, particulate matter, and some more substances) and ashes. Inputs and outputs are of equal mass flows when the combustion process is stationary.

The basic laws of thermodynamics are well known since the 19th century. It took until the last decades of the 20th century for industrial societies getting interest in the gaseous waste flows of fossil fuel combustion, first because of acid rain and health impacts (dioxins, PACs, PICs) and now mainly because of the massive emissions of the long-living greenhouse gas CO_2 (IPCC, 2007).

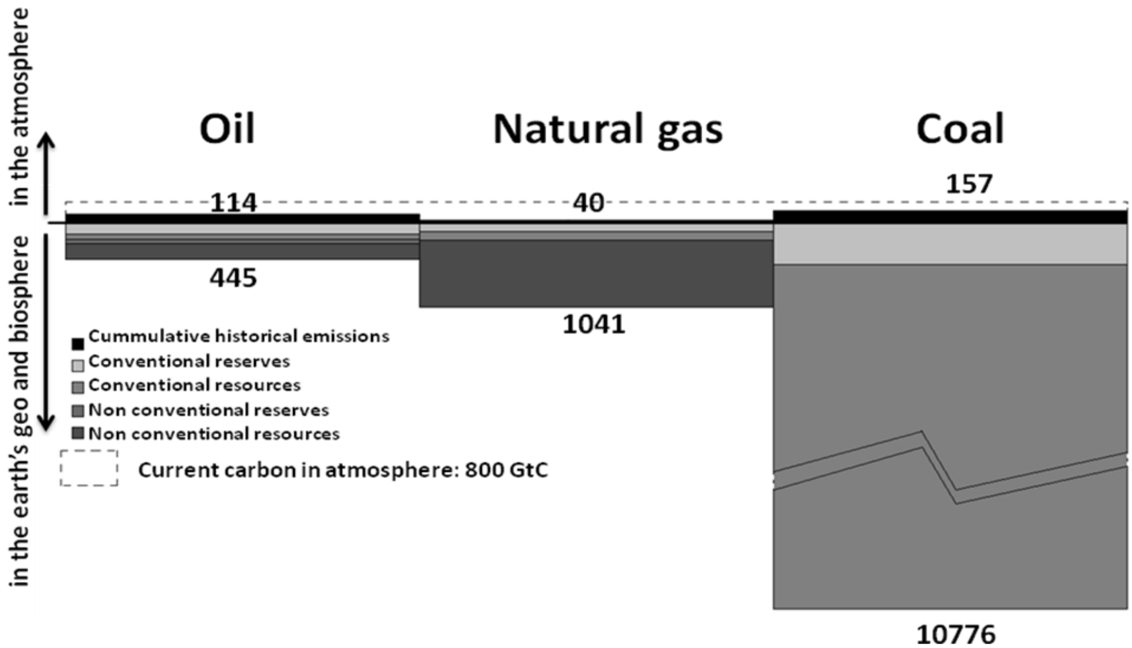
The exploitation and combustion of fossil fuels are directly related to the emissions of CO_2 in the sources-sinks model. Peak oil focuses on the sources side. IPCC focuses on the sinks side. The evident question is what of both sides is the one most constraining our ongoing activities. The answer on this question is not neutral for climate policies, in particular for "setting the carbon price" (Stern, 2006). When the tap of our fossil fuel supplies is running dry before the atmosphere is overloaded with greenhouse gases, emissions reduction can piggyback on the downward slope of the Hubbert bubbles (e.g. Chakravorty et al., 1997, Kharecha and Hansen, 2008, Koppelaar, 2008, Brecha, 2008, analyze such scenarios). When however the sink must be closed much earlier than the tap is running dry, such piggyback policies are inducing a passive attitude. Therefore one has to assess the magnitude of the fossil fuel sources and the completion of the atmospheric sinks in carbon numbers.

Extrapolating Emissions

Figure 4 provides an overview of Giga-tons of carbon (GtC) in the geo- and biosphere of the earth. The estimate of fossil fuel carbon stocks is obtained by multiplying estimated resources in EJ (BGR, 2008; table 1) with EIA specific carbon intensities (MtC per EJ) by fuel. The estimated conventional oil and gas reserves and resources hold about 405 GtC with non-conventional hydrocarbon resources adding more than the double of this number. When the world would transit to massive use of non-conventional fossil fuels with release of the carbon to the atmosphere, the climatic impacts will be disastrous. On top of hydrocarbons coal reserves and resources represent much larger carbon stocks (figure 4).

Figure 4: Carbon stocks in geo-and biospheres and in the atmosphere

(source: Marland et al., 2008; BGR, 2008)



The atmosphere contains nearly 800 GtC (Folger, 2008). The corresponding CO_2 dioxide concentration in 2005 equals ~380ppm, while the pre-industrial one was ~280ppm. The concentrations result from a complex carbon cycle (IPCC, 2007), but the 100ppm added is mainly due to the anthropogenic emissions of burning an assessed 311 GtC in fossil fuels (Marland et al, 2008). Emitting more CO_2 in the atmosphere is practically impossible in the future when the temperature increase has to be kept under 2°C, i.e. obeying the emissions ceilings imposed by the 450ppm CO_2-eq. stabilization trajectory (IPCC, 2007; Edenhofer, 2008).

Referring back to the metabolism, the real problem is not that the sources will fall dry shortly (Peak Oil, Peak Gas and Peak Coal) but that the sinks are already overfilled. It is difficult to imagine how the world could afford the luxury of the gradual decline in oil production after the eventual occurrence of a peak due to shortage in reserves. More problematic would further be a significant substitution of non-conventional oil for conventional oil.

Totally wrong is a relaxed attitude regarding climate change based on the false belief that peak oil will free energy use from fossil fuel consumption. The carrying capacity of the atmosphere is the real bottleneck, not the exhaustion of oil reserves and resources.

As sheik Yamani once stated that “the era of oil will not end by a shortage of oil”, this fact may be quite near in time. This may confirm the predictions of most peak oil believers that oil production will peak in the coming years. But this phenomenon then will not occur because of shortage in reserves and resources but because the atmosphere is unwilling to carry more carbon dioxide without jeopardizing human life on earth.

5. THE ROLE OF HIGHER OIL PRICES

Deliberate specific climate policies are a necessity, universally subscribed (UNFCCC, 1992). There are also strong arguments for setting the carbon prices right (Kümmel et al., 2008; Stern, 2006), but political reluctance for clear pricing systems such as energy and carbon taxes is deeply rooted (Aldy and Stavins, 2007). In this context, many parties concerned about climate change welcomed the oil price hikes of 2008. Such hikes indeed have a significant impact on oil consumers and their decisions, as was proven plainly during the years following the 1970 oil crises. However, one now should look deeper into the case. The experience of the 1970s-beginning 1980s reveals that price hikes are a temporally phenomenon to re-adjust price levels at new conditions of global supply and demand. It provides a brief impetus to energy efficiency and the development of alternative energy sources. The oil price tends to stabilize at a new plateau for a longer period (Petkov and Stratiev, 2008). The new price level provides the financial resources for the energy companies to add a new slice of the non-conventional resources to commercial exploitation. The new glut of fossil fuels continues the lock-in of the industrial energy economies in the incumbent technologies and habits. This phenomenon augments the climate change challenges because the shift to dirtier fuels will increase the carbon emissions (this may already occur at lower levels of fuel consumption).

Addressing the climate change challenges includes the reduced use of fossil fuels through a tremendous increase in efficiency of energy use and in renewable energy applications. Successful progress in such actions can only be built upon stable, predictable and irreversible higher end-use prices of fossil fuels (as of other non-sustainable energy sources). The transition towards a high-efficient renewable energy based energy economy also requires R&D financial incentives and resources. The key stone has to come from a deliberate, balanced taxing of non-sustainable energy sources and noxious emissions. How higher oil prices are established is not neutral, but one of the most crucial choices of our time.

6. CONCLUSIONS

Peak oil is widely debated again because of the increasing oil prices since 2003 and the price hikes in mid 2008. Confusion is fostered by lack of general agreed upon definitions of conventional and non-conventional, reserves and resources. Some realities are quite obvious such as the finite size of particular geological stocks; the natural sequence of exhaustible resource exploitation from nearby and easy to far and difficult; the ample availability of the latter type of resources. Opinions differ on the size of easy to exploit conventional oil reserves and therefore on the pattern of their exploitation. Peak oil purists refer to given limited ultimate reserves, exploited along logistic curves that would have generated symmetric bell shaped curves at the end of the oil era. However, too many physical and economic-technological factors disturb the smooth patterns. The concept of ultimate reserves is not a single number but a wide range broadened by new findings, technological innovation and shifting economic conditions. Every higher oil price plateau converts more resources into reserves, postponing the occurrence of the announced oil peak moment. The debate is often characterized in extremes of opposite paradigms but there is a large continuum in between the extreme positions with many apparent differences caused by foiled and diverging language.

Oil production and consumption placed in a sources-sinks framework, shows that the constraints at the sinks side are the most binding ones: the atmosphere is overloaded with carbon dioxide. The conviction is growing that we will (have to) leave many oil resources in the ground because the transition to a highly efficient, renewable energy based energy economy is urgent. So peak oil will actually be observed in the coming years, not because of oil shortage but because of scarcity of atmospheric dumping space. It is doubtful the oil use reduction patterns will be smooth. For the transition, a crucial role is played by the end-use prices of energy and of oil in particular. When pricing the public good atmosphere is left over to private market forces through higher oil prices, financial revenues will likely be used as in the past for a further lock-in and extension of non-sustainable energy options. Tax reform is a crucial element of the necessary climate change policies, organizing the transition to highly efficient renewable energy economies.

REFERENCES

Aldy, J.E, Stavins, R.N.,eds., 2007. Architectures for Agreement. ***Addressing Global Climate Change in the Post-Kyoto World***. Cambridge University press, 380p.

Aguilera, R.F., et al., 2009. ***Depletion and the Future Availability of Petroleum Resources.*** The Energy Journal 30, Number 1; 141-175.

Amigues et al., 1998. On the Optimal Order of Natural Resource Use When the Capacity of the Inexhaustible Substitute Is Limited. Journal of Economic Theory, Volume 80; 153-170.

Ayres, R. and L. Ayres. 2002. ***Handbook of Industrial Ecology***. Edward Elgar Publishing Ltd. Cheltenham, UK.

Bentley, R.W., 2002. ***Global oil & gas depletion: an overview***. Energy Policy, Volume 30; 189-205.

Bentley, R.W., et al., 2007. ***Assessing the date of the global oil peak: The need to use 2P reserves***. Energy Policy, Volume 35; 6364-6382.

Brandt, A.R., 2007. ***Testing Hubbert***. Energy Policy, Volume 35; 3074-3088.

Brandt, A.R., and Farrel, A.E., 28 July 2007. ***Scraping the bottom of the barrel: greenhouse gas emission consequences of a transition to low-quality and synthetic petroleum resources***. Climatic Change; Volume 84; 241-263.

Brecha, R.J., 2008. ***Emission scenarios in the face of fossil-fuel peaking.*** Energy Policy; Volume 36; 3492-3504.

Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), 2007. ***Reserves, Resources and Availability of Energy Resources 2006***. Online available at: http://www.bgr.bund.de/cln_006/nn_322882/EN/Home/homepage__node.html?__nnn=true.

Campbell, C., 1994. ***The imminent end of cheap oil-based energy***. SunWorld, Vol 18. No. 4.

Campbell, C.J., 2006. ***The Rimini Protocol an oil depletion protocol: Heading off economic chaos and political conflict during the second half of the age of oil***. Energy Policy, Volume 34; 1319-1325.

Chakravorty et al., 1997. Endogenous Substitution among Energy Resources and Global Warming. Journal of Political Economy. Vol 105; 1201-1234.

Craig, R., et al., 2001. ***Resources of the Earth; origin, use and environmental impact***. Prentice Hall, New Jersey, USA.

Daly, H.E.,ed., 1980. ***Economics, Ecology, Ethics. Essays toward a steady-state economy.*** W.H. Freeman and Company, 372p.

de Almeida, P., and Silva, P.D., 2009. ***The Peak of oil production – Timings and market recognition***. Energy Policy, Volume 37; 1267-1276.

Edenhofer, O., 2008. ***Mitigation of Climate Change.*** IPCC WG III. COP 14 - IPCC side event 'The IPCC scientific perspective: policies, instruments and co-operative arrangements for mitigation', Poznán, Poland. Online available at: http://www.ipcc.ch/graphics/presentations.htm.

Folger, P., 2008. ***The Carbon Cycle: Implications for Climate Change and Congress.*** Congressional Research Service Reports. Library of Congress, Washington DC, USA. Georgescu-Roegen, N., 1971. ***The entropy law and the economic problem***. In Daly, ed., 1980 o.c.: 49-60.

Georgescu-Roegen, N., 1975. ***Selections from "Energy and Economic Myths"***. In Daly, ed., 1980 o.c.: 61-81.

Hall, C.A.S., et al., 2008. ***Peak Oil, EROI, Investments and the Economy in an Uncertain Future***. Chapter 5 of book: Pimentel, D. (editor), ***Biofuels, Solar and Wind as Renewable Energy SystemsBenefits and Risks***. Springer Netherlands.

Hallock, J.L., et al., 2004. ***Forecasting the limits to the availability and diversity of global conventional oil supply***. Energy, volume 29; 1673-1696.

Hirsch, R.L., 2007. ***Peaking of World Oil Production: Recent Forecasts***. National Energy Technology Laboratory, US Department of Energy (DOE), online available at: www.netl.doe.gov/energyanalyses/pubs/Peaking%20of%20World%20Oil%20Production%20-%20Recent%20Forecasts%20-%20NETL%20Re.pdf.

Holland, S.P., 2003. Extraction capacity and the optimal order of extraction. Journal of Environmental Economics and Management. Volume 45; 569-588.

Hubbert, M.K., 1956. ***Nuclear energy and fossil fuels***. Exploration and Production Research Division, Shell Development Company, Publication Number 95, Houston, Texas, US.

IPCC, 2007. ***Climate Change 2007; Fourth Assessment Report***. Working Group I Report 'The Physical Science Basis'. Online available at: http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

Jackson, P., 2006. ***Why the Peak Oil Theory Falls Down – Myths, Legends, and the Future of oil***. CERA, Client Services Cambridge, MA, USA.

Kaufmann, R.K., and Shiers, L.D., February 2008. ***Alternatives to conventional crude oil: When, how quickly, and market driven?*** Ecological Economics, Volume 67; 405-411.

Kemp, M.C., and Long, N.V., 1980. On two folk theorems concerning the extraction of exhaustible resources. Econometrica. Volume 48; 663-673.

Kharecha, P.A., and Hansen, J.E., 2008, Implications of "peak oil" for atmospheric CO2 and climate. Global Biogeochem. Cycles, 22.

Kjärstad, J. and Johnsson, F, 2009. ***Resources and Future supply of oil***. Energy Policy, Volume 37: 441-464.

Koppelaar, R., et al., 2008. Minder olie, meer CO_2. Stichting Peak Oil Nederland.

Kümmel, R., Schmid, J., Lindenberger, D., 2008. ***Why production theory and the Second Law of thermodynamics support high energy taxes***, Universities of Würzburg and of Cologne, 14p.

Laherrere, J., 2006. ***Oil and gas: what future?*** ASPO (Association for the Study of Peak Oil & gas) & ASPO France, Groningen annual Energy Convention, 21 November 2006, online available at: www.oilcrisis.com/laherrere/groningen.pdf.

Leder, F., and Shapiro, J.N., June 2008. ***This time it's different. An inevitable decline in world petroleum production will keep oil product prices high, causing military conflicts and shifting wealth and power from democracies to authoritarian regimes.*** Energy Policy, Volume 36; 2850-2852.

Lynch, M.C., 1999. ***Oil scarcity, Oil crises, and alternative energies – don't be fooled again***. Applied Energy; Volume 64; 31-53.

Marland, G., Boden T.A., and Andres R.J. 2008. ***Global, Regional, and National CO2 Emissions***. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Maugeri, L., 2004. ***Oil: Never Cry Wolf – Why the Petroleum Age Is Far from over***. Science, Volume 304, issue 5674; 1114-1115.

Maugeri, L., 2006 (a). ***Oil, Oil Everywhere.*** Forbes, Volume 178, Issue 2.

Maugeri, L., 2006 (b). ***Two Cheers for Expensive Oil***. Foreign Affairs; Volume 85, Issue 2; 149-161.

Odell, P.R., 1992. ***Global and Regional energy supplies.*** Energy Policy, Volume 20, Issue 4, April 1992; 284-296.

Odell, P.R., 1994. ***World Oil Resources, Reserves and Production.*** The Energy Journal, Special Issue (The Changing World Petroleum Market) 1994; 89-114.

Petkov, K., and Stratiev, D., 2008. ***Long term prognosis of crude oil price variation***. Petroleum & Coal 50 (3): 62-66.

Shafiee, S., and Topal, E., January 2009. ***When fossil fuel reserves will be diminished?*** Energy Policy, Volume 37, Issue 1; 181-189.

Simmons, M.R., 2008. ***Twilight in the desert; the risk of peak oil.*** Simmons & Company International. Available at: www.simmonsco-intl.com/files/Twilight%20in%20the%20Desert%20Presentation.pdf.

Stern, N., 2006. STERN REVIEW: ***The Economics of Climate Change***. Executive Summary, xxvii p.

Strahan, D., 2007. ***Total boss on why oil production will never top 100 mb/d***. Lastoilschok.com; published on 2 November 2007. Online available at: http://www.davidstrahan.com/blog/?p=71.

Strahan, D., 2008. ***Peak oil and the seismic silver lining.*** Lastoilschok.com; published on 9 Feb 2008. Online available at: http://www.davidstrahan.com/blog/?p=141.

Tilton, J.E., 1996. ***Exhaustible resources and sustainable development; two different paradigms.*** Resources Policy, Volume 22, Nos1/2; 91-97.

Tsoskounoglou, M., et al., August 2008. ***The end of cheap oil: Current status and prospects***. Energy policy, volume 36; 3797-3806.

Watkins, G.C., 2006. ***Oil scarcity: What have the past three decades revealed?*** Energy Policy, Volume 34; 508-514.

World Resource Institute, April 2006***. Earth Trends Environmental Information***. Online available at: http://earthtrends.wri.org/updates/node/33.