Giant oil field decline rates and their influence on world oil production

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ABSTRACT

The most important contributors to the world's total oil production are the giant oil fields. Using a comprehensive database of giant oil field production, the average decline rates of the world's giant oil fields are estimated. Separating subclasses was necessary, since there are large differences between land and offshore fields, as well as between non-OPEC and OPEC fields. The evolution of decline rates over past decades includes the impact of new technologies and production techniques and clearly shows that the average decline rate for individual giant fields is increasing with time. These factors have significant implications for the future, since the most important world oil production base – giant fields – will decline more rapidly in the future, according to our findings. Our conclusion is that the world faces an increasing oil supply challenge, as the decline in existing production is not only high now but will be increasing in the future.

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1. Introduction

It is well known that oil production from many oil fields worldwide is in decline and that more fields transition into decline each year. In roughly mid 2004, total world oil production ceased to expand. Instead, new production has only succeeded in keeping world oil production relatively flat (Fig. 1).

A recent analysis by Cambridge Energy Research Associates estimated that the weighted decline of production from all existing world oil fields was roughly 4.5% in 2006 (CERA, 2007), which is in line with the 4–6% range estimated by ExxonMobil (2004). However, Andrew Gould, CEO of Schlumberger, stated that *an accurate average decline rate is hard to estimate, but an overall figure of* 8% *is not an unreasonable assumption* (Schlumberger, 2005). Pickens (2008), agreed with Gould in recent testimony before the US Senate Committee on Energy and Natural Resources. Duroc-Danner (2009) gives a blended average decline rate for oil and gas today of about 6%. The International Energy Agency (IEA) came to the conclusion that the average production-weighted decline rate worldwide was 6.7% for post-peak fields (IEA, 2008), which means that the overall decline rate would be less, since many fields are not yet in decline.

In this study we estimate world decline rate behaviours based on the Uppsala University giant oil field database, described in detail by Robelius (2007). Given the dominance of the giant oil fields, understanding giant oil field behaviour provides important insights into likely future total world oil production.

2. Giant oil fields and world production

Giant oil fields are the world's largest. There are two ways to define a giant oil field. One is based on ultimately recoverable resources (URR), and the second is based on maximum oil production level. The URR definition considers giants to have more than 0.5 Gb of ultimately recoverable resources. The production definition assumes a production of more than 100,000 barrels per day (b/d) for more than one year (Simmons, 2002). In this analysis we consider the worlds conventional oil fields, regardless of location, e.g. shallow or deep water, the Arctic, etc. Conventional oil fields refer to reservoirs that dominantly allow oil to be recovered as a free-flowing dark to light-coloured liquid (Speight, 2008). Consequently, heavier crude oils that require special production methods are excluded.

The American Association of Petroleum Geologists (AAPG) has published a series of memoires about giant oil fields and their geology (see for instance AAPG, 1970, 1980, 1992, 2003, 2005). Other studies have used essentially the same definition system (Nehring, 1978; Robelius, 2007). Giant fields covered by both the AAPG and the Simmons definitions were used in this study.

Using our definition of giant oil fields, we find that roughly 500 (about one percent of the total number of world oil fields) are classified as giants. Their contribution to world oil production was over 60% in 2005, with the 20 largest fields alone responsible for nearly 25% (Fig. 2). Giant fields represent roughly 65% of the global
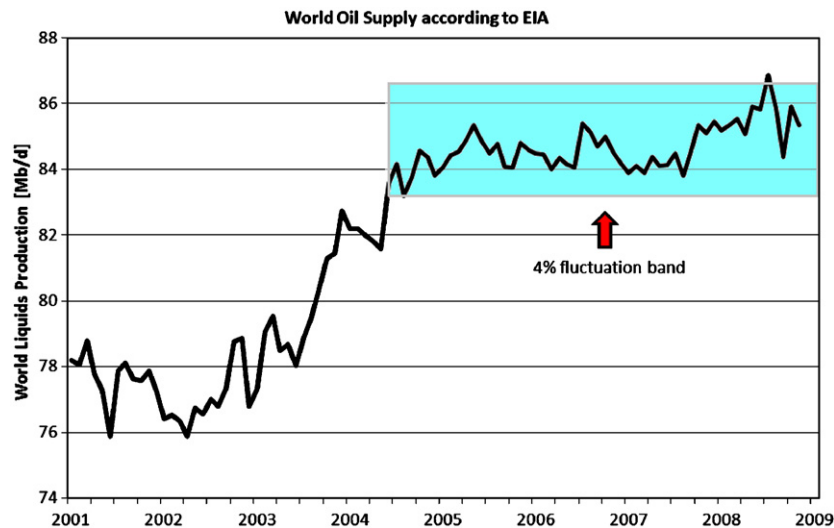
World Oil Supply according to EIA

Fig. 1. World liquid fuels production from January 2001 to November 2008. Since mid-2004, production has stayed within a 4% fluctuation band, which indicates that new production has only been able to offset the decline in existing production. *Source*: EIA (2009).

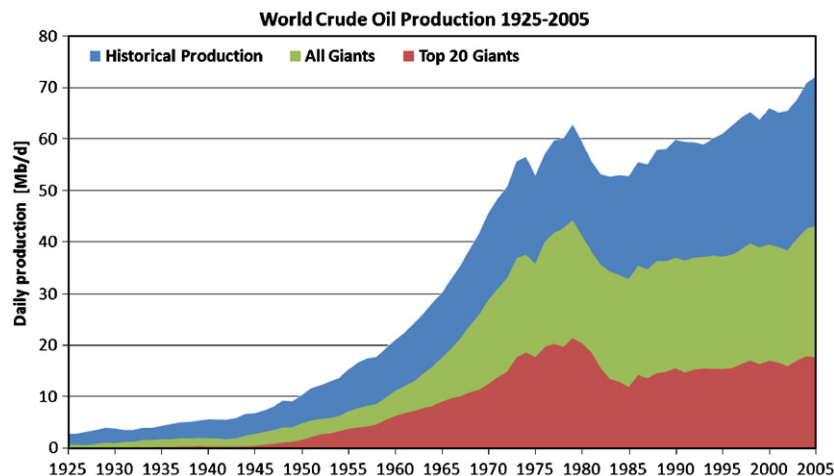**World Crude Oil Production 1925-2005**

Fig. 2. World crude oil production from 1925 to 2005. The dominance of the giant oil fields can clearly be seen. Modified from Robelius (2007).

ultimate recoverable conventional oil resources (Robelius, 2007). Many studies have pointed out the importance of giant oil fields, for instance Campbell (1991), Hirsch (2008), Meng and Bentley (2008).

Individual oilfields can be operated in various ways. Important field operating options and planning models have been described (Palsson et al., 2003; Ortíz-Gómez et al., 2002; Barnes et al., 2002). For specific fields, much is dependent on specific reservoir characteristics, investments, production strategies, and technology use, as a function of time.

The overall production from giant fields is declining, because a majority of the largest giant fields are over 50 years old, and fewer and fewer new giants have been discovered since the decade of the 1960s (Fig. 3). The average contribution from an individual giant oilfield to world production is less than 1%. Thus, with few exceptions, e.g., Ghawar, the contribution from a single field is generally small compared to the total. On this basis, our approach is to estimate collective behaviours.

3. Giant field data

The data used in this analysis was taken from the giant oil field database compiled by Robelius (2007). AAPG publi-

cations on giant oil fields were the main source of information on year of discovery, year of first production, URR, and cumulative production. Production data were obtained from annual reports in Oil & Gas Journal and various AAPG development papers and project reports. Other sources included statistical yearbooks from the Norwegian Petroleum Directorate, PEMEX, the UK department of Trade & Industry and similar sources.

Fields with production over 100,000 b/d were included in our analysis, but they numbered only 20 fields in our total. A more detailed discussion of the giant field data can be found in Robelius (2007). This study uses the same data set as Höök et al. (2009) and a better description of the data set together with complementary results can be found therein.

4. Decline curve analysis

Production profiles of giant fields generally have a long plateau phase, rather than the sharp "peak" often seen in smaller fields. The end of the plateau phase is the point where production enters the decline phase. We adopted the end-of-plateau as the point where production lastingly leaves a 4% fluctuation band, as Hirsch (2008) postulated in a prior study.
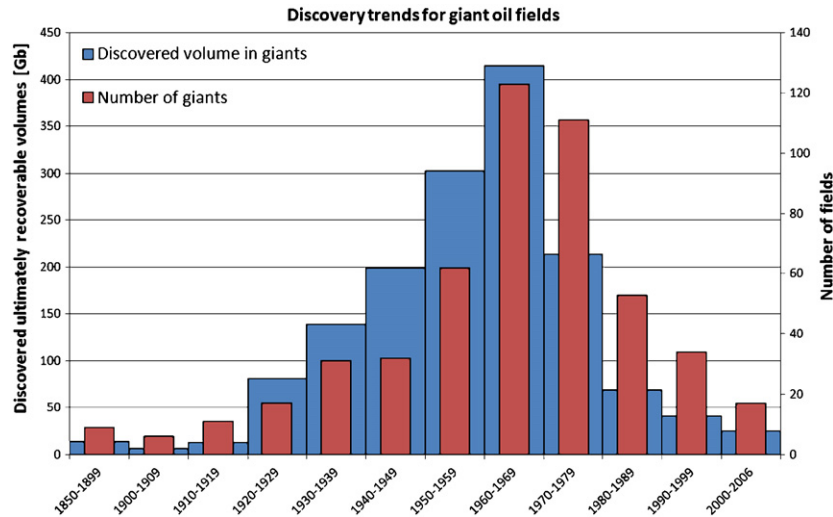
Fig. 3. Discovery trends for giant oil fields in both number and annual discovered volume, based on the most optimistic, backdated URR values. Modified from Robelius (2007).
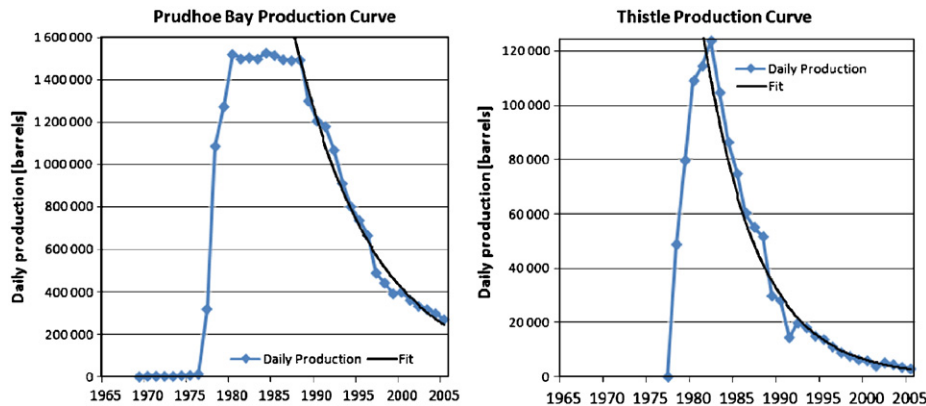

Fig. 4. The production curves of the land-based US giant Prudhoe Bay and the giant UK Thistle offshore field. The approximately exponential average decline rate is clearly seen in these two well-behaved fields.

In this analysis the exponential decline model, originally developed by Arps (1945), was used to model field behaviours and to forecast future production. One advantage of the decline curve analysis is that it generally applies independent of the size and shape of the reservoir or the actual drive-mechanism (Doublet et al., 1994), avoiding the need for more detailed reservoir data. This approach is the same used by CERA (2007). Accordingly, each field is assumed to have a constant decline rate, and the production for an individual oil field fluctuates around some average value over time. Examples of how well this approximation agrees with actual production in a few cases are shown in Figs. 4 and 5.

In some cases, wars, sabotage and politically motivated shut downs are evident, making these fields more difficult to describe in a simple manner. Many OPEC fields have been on a plateau for a very long time, and some were even mothballed for various periods. Non-conforming fields, such as Eldfisk, Ekofisk and some fields in Nigeria, were treated separately, and production disturbances such as guerrilla attacks or accidents were disregarded (Fig. 5).

Decline curves can be made much more detailed and complicated (hyperbolic, etc.), so the simple exponential model used here should be seen as a simplified model for future outlooks. One disadvantage of the exponential decline curve is that it tends to underestimate tail production, which usually flattens out to a harmonic decline. However, the production levels far out in the tail region are generally very low compared to the plateau level, so this approximation is a minor problem for the model. In the near and medium term future the exponential decline curve is a suitable tool for realistic outlooks.

Some fields can also show complex behaviour with several exponential decline phases or even production collapses, where the decline can be doubled in the end stage of the field life. In other cases introduction of new technology can revive the field and significantly dampen the decline temporarily. This is the case in some Russian fields, which were reworked after the fall of the Soviet Union. However, Höök et al. (2009) found that such events are likely to result in higher decline rates later on, compensating the temporal decrease in decline rate.

Modelling future field behaviour is done by extrapolating the historical production data with an exponential decline curve. This does not take dramatic deviations into account and assumes that declines will continue approximately exponentially. This leads to a somewhat optimistic extrapolation. The decline rate of a field is affected by introduction of new technology, investments, changes in strategies and other factors affecting production. Studying
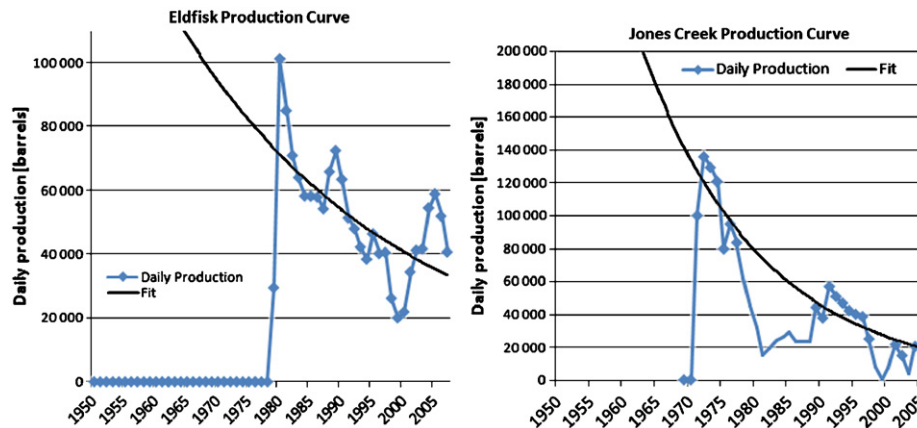
Fig. 5. The exponential decline curve fits reasonably well with the production of the Norway giant Eldfisk, where pressure depletion has caused major reservoir compaction and subsidence problems. The Nigerian Jones Creek, which has been severely disturbed by wars, rebel attacks and sabotage, provides a good fit with the model if disturbed data points are disregarded. In both these cases the production curve has been fluctuating around an approximately exponential decline curve.
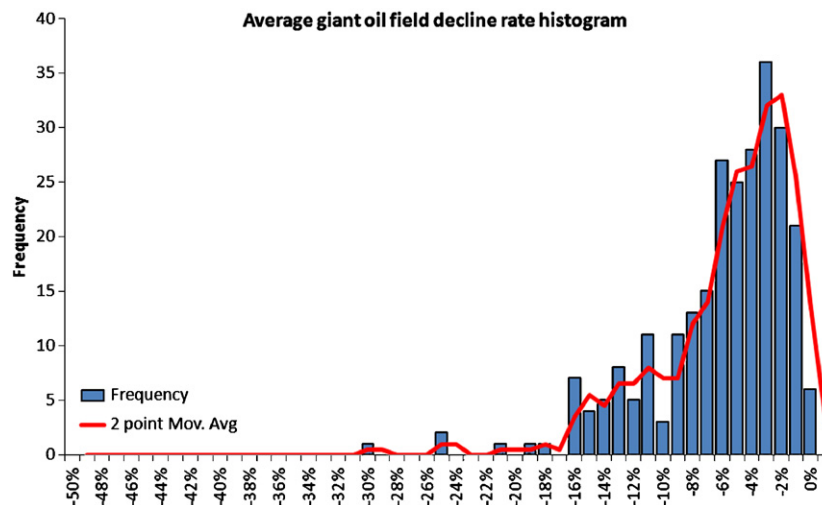

Fig. 6. Histogram of the decline rate distribution of the 261 post plateau giant fields as of the end of 2005. About 65% are onshore and 35% offshore. Significant differences occur between different subgroups. The offshore fields cluster together around −10% and the land fields around −4%. OPEC fields tend to decline slower than non-OPEC fields.

decline rates and their development gives some hints about the effects of technology and field investments.

5. Average decline rate

The Uppsala giant field database includes 331 giant oil fields with a combined estimated URR of over 1130 Gb, using estimates adopted by Robelius (2007). A total of 214 fields are land-based (about 65% of the total), while 117 are offshore installations (about 35%). To calculate the decline rate of giants that were in decline as of the end of 2005, we considered only the 261 fields classified as post-plateau and in decline. Of these, 170 were land-based and 91 offshore. IEA (2008) gives an average depletion factor, defined as cumulative production divided by initial 2P reserves, of 48% for their super-giants and giants. Höök et al. (2009) found that most giant fields leave the plateau phase and reach the onset of decline when around 40% of the URR has been produced, and combined with IEA's average depletion factor, it is not surprising that the majority of the fields are categorized as in decline.

Because the number of fields is so large, our approach provided reasonable statistics and reasonable mean, median and produc-

tion-weighted values for the giant oil fields as a group. The production-weighted values were created by weighting the decline rate against the peak or plateau production level for each field, thus giving greater importance to fields with high production. The production-weighted decline is lower than the mean value, because fields with high production levels often tend to be larger and decline slower than the rest. More details can be found in Höök et al. (2009).

The statistical uncertainty is difficult to estimate, since production data contains political influences, differences in definitions, reporting practice and many other parameters, making conventional statistical error estimate hard to apply. A histogram showing the distribution of the decline rates for all the post-plateau fields considered in this analysis is shown in Fig. 6.

A traditional statistical analysis based on the assumption that production data measures approximately the same thing, results in standard deviations of around 5% and may be seen as a rough attempt to put a number on the inaccuracy (Höök et al., 2009). In comparison, neither IEA (2008) nor CERA (2007) provides any uncertainty estimates and hence it is hard to judge the statistical variations in their results. This study makes no attempt to provide detailed analysis of the uncertainty; rather, it only concludes that

the results are accompanied with significant uncertainty. Two significant digits will be used here, to make comparisons with CERA (2007) and IEA (2008) easier, despite the fact that the results of Höök et al. (2009) indicate that only one digit should be utilized because of the significant uncertainties in many of the underlying reserves estimates and production figures.

In Table 1 an average annual decline rate for the world's giant oil fields is seen to be roughly −6.5%, which is in line with the average observed decline rate worldwide of −6.5% and the −5.8% production-weighted average annual decline rate obtained by IEA (2008). The agreement with the 5.8% production-weighted annual decline for large fields obtained by CERA (2007) is good. However, it should also be noted that the weighting methods and field size classifications are slightly different.

CERA (2007) did not treat giant oil fields in the same way as this study. Instead their study was performed on a set of "*large fields*", classified as fields with more than 300 million barrels of originally present 2P reserves of oil and condensate. In total, their dataset represent 1155 billion barrels of original 2P reserves in place, accounting for approximately half the current annual global production. Consequently, their dataset is deemed approximately equal to the data set used in this study. When it comes to production weighting, CERA (2007) takes each field's latest oil and condensate production into account for the averaging.

IEA (2008) uses a similar classification in their study. IEA classify "*super-giants*" as fields with more than 5 Gb of initial 2P reserves, "*giants*" contain more than 500 million barrels of initial 2P reserves, and "*large fields*" contain initial reserves of more than 100 million barrels. In IEA (2008), super-giants are treated as a subclass, while this study includes them in the giant category. In total, IEA covers 317 super-giant and giant fields, which makes their data set similar to ours. Their production weighting is done by using the cumulative production of each field in the averaging.

Because of financial and practical differences between land-based and offshore fields, a division is needed to establish a comprehensive picture of how each subclass behaves. A further division into OPEC fields and non-OPEC fields was also made to better reflect the potentially different behaviours of giants managed with no political restrictions on production and those sometimes limited by quota systems.

OPEC controls or formerly controlled 143 of the fields in our database. Gabon is no longer a part of OPEC, but used to be a member; consequently, their fields were classified as OPEC fields because they were previously subjected to the quota system. Ecuador suspended their OPEC-membership, but recently rejoined the organization. In total, OPEC has 104 land and 39 offshore fields in our database. Outside of OPEC, 190 fields were considered with 110 fields onshore and 78 offshore. The North Sea, Russia and the US were the most important regions within the non-OPEC group.

An analysis of giant oil fields divided into onshore and offshore fields yields the results in Table 2. Land-based fields decline much slower than offshore fields, as expected and in agreement with both IEA (2008) and CERA (2007). The reason for this difference is generally the higher production capabilities built into offshore installations in order to repay expensive investments as soon as possible. Also, a significant number of land-based fields started to decline far back in time, before the introduction of modern production techniques such as water injection and other pressure managing methods. In comparison, there were virtually no deepwater offshore fields before 1970.

The offshore group can be even further divided into shelf and deepwater fields, where deepwater fields tend to decline faster and shelf fields somewhat slower. This separation was made and discussed by IEA (2008). Interestingly, IEA (2008) did not find lithology to be a dominating factor for field behaviour, while field size and OPEC-control seemed to be key factors in determining decline.

The results for the non-OPEC fields are shown in Table 3. Once again the high decline of offshore fields compared to land fields can be seen. The average decline of all non-OPEC giant fields is above 7%, indicating that non-OPEC production is dropping relatively rapidly.

Many of the low decline rates can be found in fields in the US that peaked prior to 1970s. In fact most of the non-OPEC land group is dominated by the US giant fields. The non-OPEC offshore group is dominated by giant fields in the North Sea. Many fields, both giant fields and smaller ones, in the North Sea, show a high decline rate, for instance in Norway and the UK (Zittel, 2001; Höök and Aleklett, 2008).

In comparison to the non-OPEC group, the OPEC group generally displays lower decline rates (Table 3). One quite intriguing detail is that OPEC fields tend to exit the plateau phase at a lower percentage of their URR volumes. This is an explanation for the lower decline rate. Instead of a prolonged plateau, a longer decline phase with less annual decrease has generally been favoured as a production strategy compared to non-OPEC. This is examined in greater detail in another study (Höök et al., 2009). An alternative explanation is that OPEC URR estimates are exaggerated, as claimed by former Aramco vice-president Sadad Al-Husseini (2007).

Both land and offshore fields within OPEC tend to have lower declines than their non-OPEC counterparts in good agreement with the findings of IEA (2008) and CERA (2007). The conclusion is that the OPEC quota system has been quite efficient at moderating production and maintaining the longevity of fields, instead of extracting oil rapidly with an accompanying high decline rate.

Table 1
Characteristic parameters for all 261 post peak giant fields covered by this study.

	Mean	Median	Prod. Weight
Decline rate	−6.5%	−5.3%	−5.5%

Fields that had not reached the decline phase as of the end of 2005 were excluded.

Table 2
Characteristic decline rates of land and offshore fields.

# Fields	Field type	Mean (%)	Median (%)	Prod weight (%)
170	Land fields	−4.9	−4.4	−3.9
91	Offshore fields	−9.4	−9.0	−9.7

Fields that had not ended their plateau phase or were in build-up phase as of the end of 2005 were excluded.

Table 3
Characteristic decline rates of OPEC fields and Non-OPEC.

# Fields	Group	Mean (%)	Median (%)	Prod. Weight (%)
97	All OPEC fields	−4.8	−4.1	−3.4
73	OPEC land	−3.8	−3.8	−2.8
24	OPEC offshore	−7.7	−6.1	−7.5
164	All non-OPEC fields	−7.5	−6.3	−7.1
97	Non-OPEC land	−5.7	−4.7	−5.2
67	Non-OPEC offshore	−10.0	−9.4	−10.3

Fields that had not ended their plateau phase or were in build-up phase as of the end of 2005 were excluded. In total 87% of all giants outside OPEC were classified as post-plateau, which corresponds to having 83% of all the URR in giant oil fields outside OPEC in post-plateau. In total 67% of all OPEC giant fields can be classified as post-plateau, which corresponds to 48% of all URR in OPEC giants in post-plateau.

6. Evolution of decline rate in time

It is useful to consider the historical evolution of field decline rates, since many giant fields are old and passed into decline before much of modern oil field technology was developed and implemented. The year that fields left plateau production was used to form subgroups, e.g., if a field started to decline in 1950–1959, it is included in the 1950s group and so on. This approach is different from IEA (2008), which used the year of first oil production to form subgroups in their study of decline rate evolution. We believe that the year of the onset of production decline is of greater importance because it better reflects the impacts of improved technology and alternate production strategies.

The results are shown in Tables 4–9. For all offshore fields (Table 4), a clear trend towards higher decline rates over time was found. For all land-based fields (Table 5), the trend is not as clear

Table 4
Evolution of the decline rate of offshore giant fields.

# Fields	Time period	Mean (%)	Median (%)	Prod. Weight (%)
0	Pre 1960	–	–	–
2	1960s	−2.8	−2.8	−3.7
17	1970s	−6.0	−6.1	−6.3
16	1980s	−7.9	−7.5	−8.9
35	1990s	−10.4	−11.4	−10.6
19	2000s	−12.5	−12.6	−10.8

The decade that the fields left plateau production was used to form the subgroups.

Table 5
Evolution of the decline rate of land-based giant oil fields.

# Fields	Time period	Mean (%)	Median (%)	Prod. Weight (%)
23	Pre 1960	−4.2	−4.4	−4.2
18	1960s	−5.1	−5.5	−6.0
72	1970s	−4.2	−3.9	−3.0
25	1980s	−4.4	−4.1	−3.9
28	1990s	−6.9	−5.6	−5.6
4	2000s	−10.7	−9.9	−10.1

The decade that the fields left plateau production was used to form the subgroups.

Table 6
Evolution of the decline rate of non-OPEC land-based giant fields.

# Fields	Time period	Mean (%)	Median (%)	Prod. Weight (%)
13	Pre 1960	−4.2	−3.8	−4.3
10	1960s	−5.3	−5.4	−6.0
36	1970s	−5.5	−4.7	−4.9
20	1980s	−4.8	−4.1	−4.6
16	1990s	−8.2	−6.3	−6.5
2	2000s	−11.5	−11.5	−9.9

The decade that the fields left plateau production was used to form the subgroups.

Table 7
Evolution of the decline rate of non-OPEC offshore giant fields.

# Fields	Time period	Mean (%)	Median (%)	Prod. Weight (%)
0	Pre 1960	–	–	–
2	1960s	−2.8	−2.8	−3.7
10	1970s	−6.8	−6.5	−7.9
13	1980s	−8.5	−7.5	−9.3
24	1990s	−11.5	−12.1	−11.5
18	2000s	−11.7	−11.8	−10.3

The decade that the fields left plateau production was used to form the subgroups.

Table 8
Evolution of the decline rate of OPEC land-based giant fields.

# Fields	Time period	Mean (%)	Median (%)	Prod. Weight (%)
10	Pre 1960	−4.3	−4.7	−4.0
8	1960s	−4.9	−5.5	−5.9
36	1970s	−2.9	−3.0	−2.2
5	1980s	−2.8	−3.0	−1.9
12	1990s	−5.1	−5.1	−4.0
2	2000s	−9.8	−9.8	−10.2

The decade that the fields left plateau production was used to form the subgroups.

Table 9
Evolution of the decline rate of OPEC offshore giant fields.

# Fields	Time period	Mean (%)	Median (%)	Prod. Weight (%)
0	Pre 1960	–	–	–
0	1960s	–	–	–
7	1970s	−4.7	−3.9	−4.3
3	1980s	−5.2	−6.3	−6.2
12	1990s	−8.2	−7.0	−7.9
2	2000s	−19.6	−19.6	−20.8

The decade that the fields left plateau production was used to form the subgroups.

but is directionally similar. Separating OPEC and non-OPEC fields reveals larger differences. Data for the decade of the 2000s are limited because less declining field data was available as of the end of 2005.

The non-OPEC land group shows an inclination towards somewhat higher decline rates (Table 6). The increasing decline rate trend for non-OPEC offshore giant oil fields is much clearer (Table 7). The trends for the land-based fields deviate in the 1970s and 1980s, which is probably due to the twin oil crises that occurred during those decades. For the OPEC group, a tendency towards lower decline rates is observed and can be explained by the fact that fields were taken from their plateau phase for political reasons, resulting in subsequent less steep decline rates.

From this data, it is evident that average decline rates for giant oil fields as a group are increasing with time, even though individual field decline rates are essentially constant once a field has reached the onset of decline. This is in agreement with CERA (2007). However, CERA failed to note that fields that are declining now, or will begin to decline in the near term, will do so with an average decline rate generally higher than the fields that left their plateau levels in earlier years. Our results show this trend in line with the findings of IEA (2008), where the higher decline rates as a function of time were clearly evident. Unfortunately, their study did not provide a great deal of related detail.

The important conclusion is that higher decline rates must be applied to giant fields that enter decline in the future. Prolonged plateau levels and increased depletion made possible by new and improved technology result in a generally higher decline rates. Detailed case studies of giant oilfields suggest that technology can extend the plateau phase, but at the expense of more pronounced declines in later years (Gowdy and Juliá, 2007). Our findings verify their conclusion.

Since a large number of important giants are subject to enhanced production methods, such as waterflooding, gas injection, fracturing or other measures, it is reasonable to expect relatively higher declines after those fields depart their plateau phase. Comprehensive discussion on development of mature oilfields and a few examples of utilization in giant fields can be found in Babadagli (2007). The collapse of production from the Cantarell field in Mexico, which was extensively subjected to technologies aimed at increasing production, meant that the field

declined even faster than the government's pessimistic scenarios (Luhnow, 2007).

7. Future trends in giant field decline rates

As more giant fields go into decline in the future, the average decline rates for all giants will increase. This situation is shown in simple terms in Fig. 7. We have no reason to doubt that the giant field discovery trend shown in Fig. 3 will continue, since large fields are harder to miss than small fields.

Since the 1970s, the share of giant oilfields in decline has increased, showing the overall maturity and lack of new fields brought into production. Many giants have been in production for many decades without reaching the onset of decline, but sooner or later they will eventually do so. By 2030 one can expect 80% of total giant oilfield production to come from fields in decline, if one extrapolates the trend since 1985 (Fig. 8). The share could be even
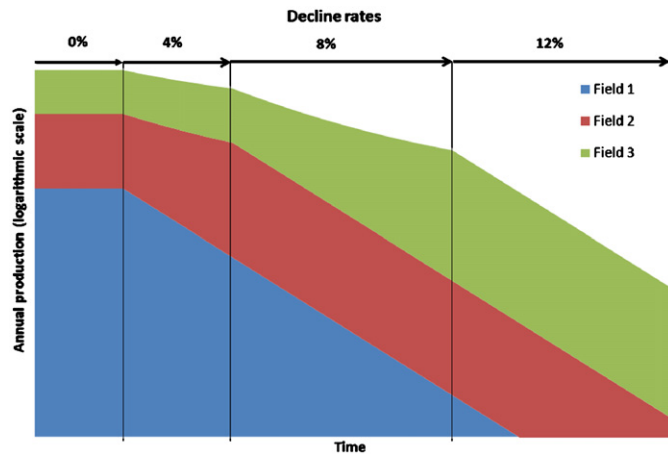
higher when important OPEC "super giants", such as Ghawar or Safaniyah, leave the plateau phase in the intervening years.

Based on the Norwegian experience, a good picture of how giant oilfield decline rates might behave was constructed. Using the same data as Höök and Aleklett (2008), a picture of the relation between the average and the production-weighted decline rate can be made. Norwegian oil production has been generally free-market managed using advanced technology. Production increases and stable production were treated as a 0% decline rate, because we were interested in the decrease in production and including increases would obscure fundamental decline trends. A single field in build-up phase can massively increase production and compensate for the production losses in several declining fields. Our aim was to show the underlying overall decline in production that must be compensated by production additions. Norwegian data shows how both average and production-weighted decline can converge over time (Fig. 9).

Analysis of our 331 giant field dataset going back in time showed that the world average decline rate was near 0% until roughly 1960, when overall decline began to increase, as more and more giant oil fields left the plateau phase. Thereafter, production from new giants failed to compensate for the declines of existing giant production. The average decline rate of the giant oilfields was found to increase by around 0.15% per year. Extrapolating the 1960–2005 trend yielded an average decline rate of nearly 10% by 2030 (Fig. 10). This giant field trend should have a strong influence on the future global decline rate in oil production.

The production-weighted decline rate has been behaving somewhat differently, especially since 1985, compared to the average decline rate. The reason for this change is the introduction of new technologies, most notably horizontal drilling and fracturing techniques, in many major fields in former Soviet Union and the Middle East. Using new technologies, it was possible to halt the decline in many giants and keep production stable for some time. Eventually the average and the production-weighted declines must follow each other. The currently stable production-weighted decline cannot be expected to continue far into the future, once technology-enhanced fields reach the final onset of decline.

A limit for the average decline rate of the giant oil fields occur when all the fields in the population have reached the onset of decline. In other words the average decline rate cannot increase
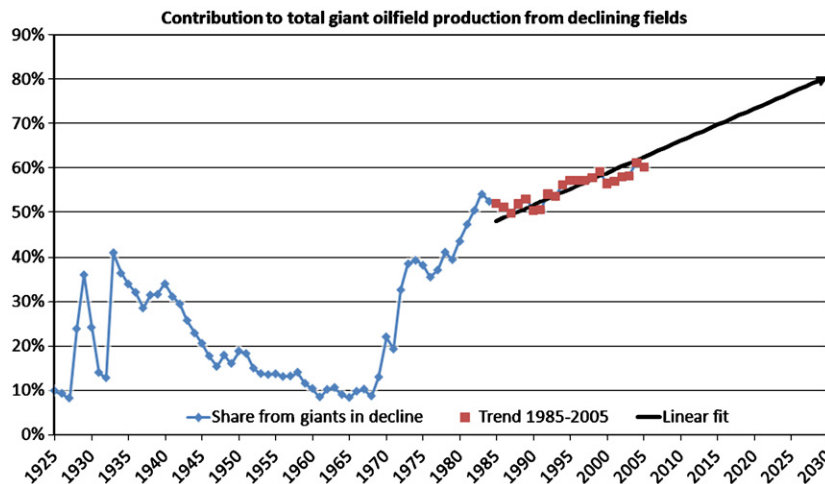

Fig. 7. The decline rate of existing oil production within total world oil production will increase with time. This is because more fields go into decline as time goes on. To illustrate, consider three identical oil fields that start to decline at three different times, each with a 12% decline rate, similar to the average 13% found typical for Norway. In this example, the overall decline rate starts at zero and progressively increases.

Fig. 8. Contribution to total giant oilfield production from fields that have reached the onset of decline. In the 1920s oil was chiefly extracted in the US and when their giants started to decline, new giant fields all over the world were brought into production, which reduced the share from the declining fields. In the 1970s, production from many fields was interrupted for political reasons. Since 1985, the share from declining fields has been steadily increasing, despite the overall lack of political restrictions and turmoil. If extrapolated, this trend shows that over 80% of total giant oilfield production will come from fields in decline by 2030. However, the linear fit is only temporary and should be used with care if extrapolated far into the future.
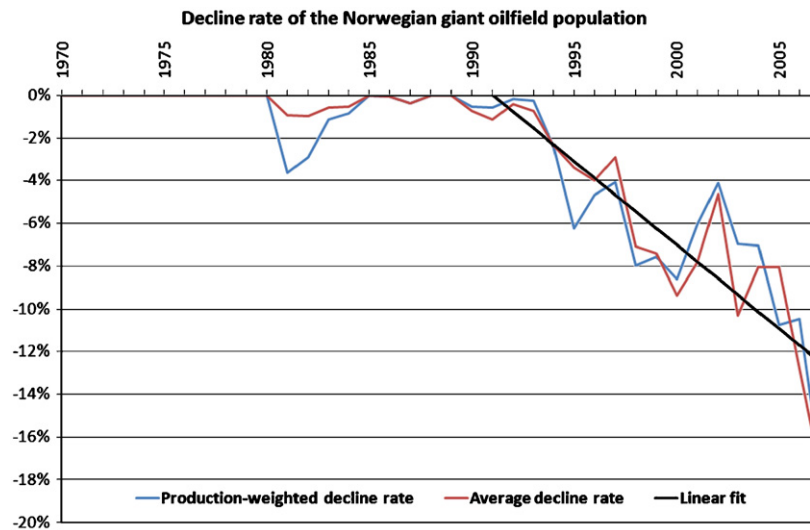
Fig. 9. The decline of the Norwegian giant oilfields. Ultimately the onset of national decline could not be prevented and decline rates soared. Both the average and the production-weighted decline values agree well. Norway is an example of how technology can temporarily maintain production at the expense of a rapid future decline rate.
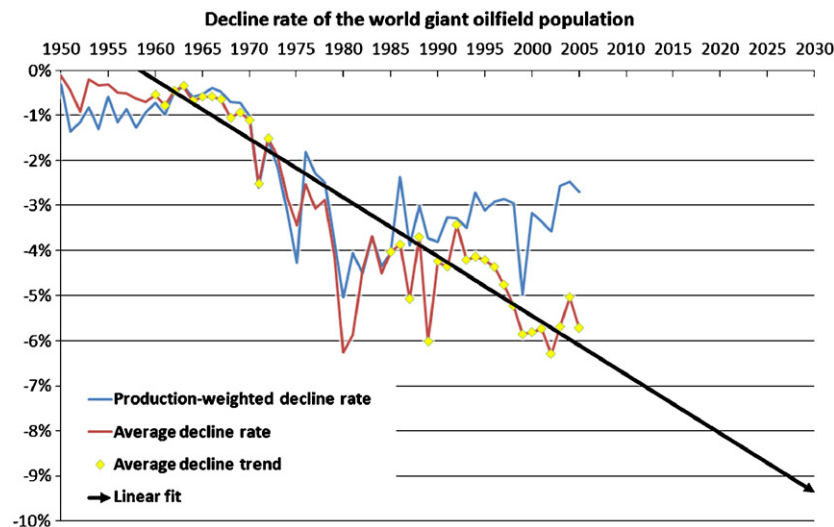

Fig. 10. The decline rate of the world's giant oilfields. The trend toward an increasing average decline rate is very clear and explained by ever decreasing volumes of newly discovered and declining production from new giant fields. The time period 1973–1982 was disregarded since production was deliberately reduced during that period by OPEC. The divergence between the two decline rates after 1985 is caused by the introduction of new technology and the revival of giant fields in primarily Middle East and Russia.

monotonously, but will sooner or later reach a limit. In the case of Norway, where all the giant fields now are in decline, the transition towards the decline rate limit was roughly linear (Fig. 9) and similar behaviour is expected globally. In the case of the world, OPEC and non-OPEC, the limit of average decline rate is not known, but will be reached when all the giants have reached the onset of decline.

Separating non-OPEC and OPEC giant field production yields the trends seen in Figs. 11 and 12. In the non-OPEC case, the 2030 decline rate is roughly 11%, while the OPEC 2030 rate is roughly 8%. Sooner or later the production-weighted decline rate must catch up with the average decline rate, but exactly how soon and how fast this development will happen is hard to forecast. Currently, the world may have a false sense of security, temporarily created by decline-delaying technology introduction in underdeveloped fields. When fewer giants can be momentarily revived, the production-weighted decline must eventually begin to increase.

8. Future global production

Without good data on a large fraction of the world's oil fields, an accurate estimate of future global oil production cannot be developed. While various databases exist, all include approximations and estimates, so none are fully definitive. Nevertheless, a number of factors can provide insights into what might evolve. First, the world's giant oil fields are the dominating contributors to total world oil production. Second, it is found that the decline of smaller fields is equal to or greater than those of the giants (see for instance IEA, 2008; CERA, 2007). A detailed study of Norwegian fields showed that giants declined at an average of 13%, while the small fields, condensate, and NGL declined at 20% or more (Höök and Aleklett, 2008).

A small field requires fewer wells to fully develop; hence it is more easily depleted. A large field requires many more wells, often widely separated, so it is typically depleted more slowly. High depletion rates, which are common in small fields,
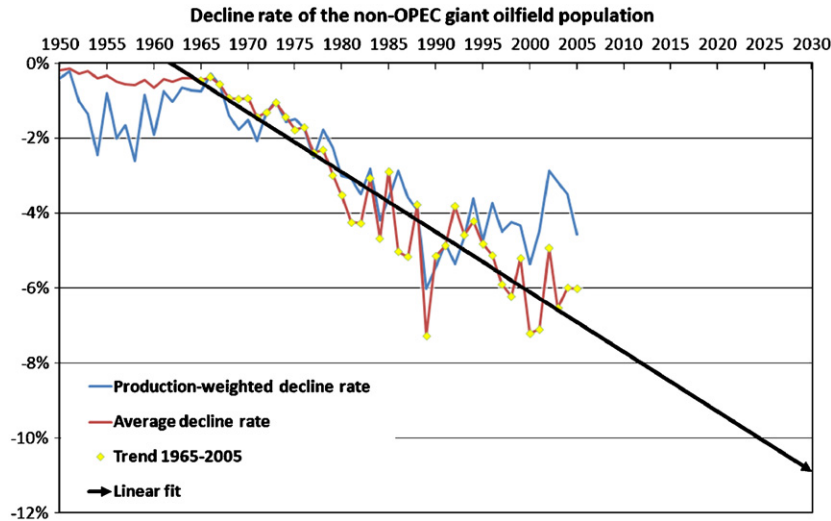
Decline rate of the non-OPEC giant oilfield population

Fig. 11. Decline rate of the non-OPEC giant fields. The average decline rate started to grow in 1965 and has been increasing as more and more giants reached the onset of decline. The deviation after 1995 was caused by the fall of the Soviet Union and the introduction of new technologies that managed to temporarily revive Russian giants.
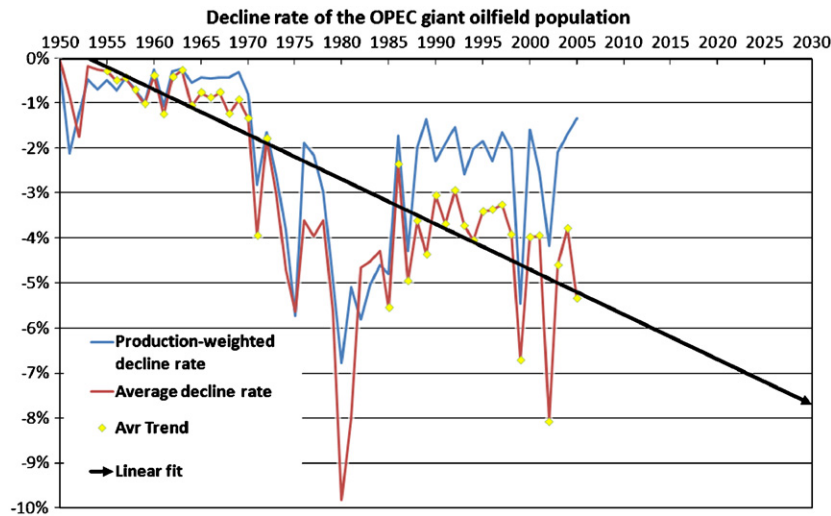
Decline rate of the OPEC giant oilfield population

Fig. 12. The decline of the OPEC giant fields. The trend in average decline broke from near zero in the 1950s and grew more slowly that in the non-OPEC case. This is likely the result of the OPEC quota system. During the period 1973–1985 significant production capacity was withheld deliberately or otherwise unavailable for short periods, so related data points were excluded. The production-weighted decline rate has been virtually constant since 1985.

have been shown to strongly correlate with high decline rates (Höök et al., 2009). Thus, giant oil field decline rates are useful for estimating the likely average world decline. Accordingly, we believe that the decline in existing production, both for giants and other fields, will be at least 6.5% or 5.5% if production-weighted. The findings of Höök et al. (2009) indicate that the decline rates are only significant in the first digit. Consequently, we use 6% for our production outlook to reflect uncertainty. The average and the production-weighted values will ultimately coincide, as they did in Norway (Fig. 9).

As a comparison, in a field-by-field study of predominantly giant fields, IEA (2008) derived an average decline rate worldwide for all oil fields of 6.7%. IEA (2008) stated that field size was a large determinant of field decline behaviour, noting that large fields decline relatively slower than small fields. This reasoning also supports their expected increases in future decline rates, as the world moves towards generally smaller oilfields. In their published forecast, they used a decline of 4.1% for fields in production for reasons they did not explain.

The exact annual increase in world average decline rate is difficult to estimate and requires a more comprehensive database than was available to us. Accordingly, the value of −0.15% per year derived here should be taken as a rough estimate. The important point, however, is that the average decline rate in existing production is clearly increasing with time. Also, the contribution from declining fields is increasing (Fig. 8). Consequently, "*we must run faster and faster just to stand still*".

Using our 6% production-weighted average decline and extrapolation of the contribution from declining fields (Fig. 8), one can create a future outlook for world crude oil production. By incorporating the increasing average decline, another possible future can be envisioned. The difference between using a constant decline rate and a growing decline is as much as 7 Mb/d by 2030 (Fig. 13).
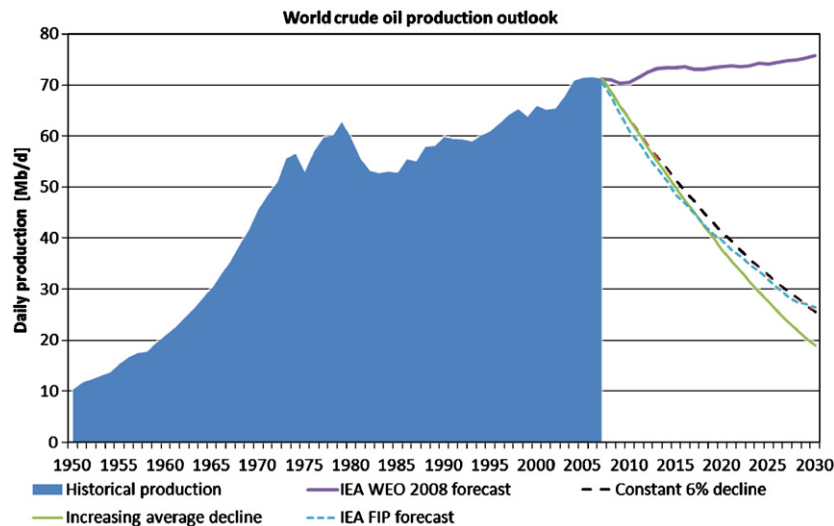
Fig. 13. The historical world oil production along with crude oil forecast the reference scenario from IEA World Energy Outlook 2008. A constant decline rate of existing production of 6%, combined with an increasing share of fields in decline, is displayed as one possibility. Our other scenario is a case with increasing average decline. The IEA WEO 2008 forecast for fields in production (FIP) is compared to our own estimates of reasonable decline rates and the contribution from declining fields. The IEA forecast is reasonable in the near-term, but towards 2030, it seems optimistically biased. Using a constant decline rate compared to an increasing rate can mean as much as 7 Mb/d of production capacity by 2030.

There are significant uncertainties regarding future oil production from our study and similar works. Nevertheless, reasonable future decline rates can be estimated. Our outlook and the forecast for fields in production from IEA (2008) agree reasonably well (Fig. 13). While there is a few million barrels per day of difference, the overall picture is similar. However, IEA (2008) seems to lean more towards the optimistic case and a more comprehensive study of their oil forecast is recommended.

9. Conclusions

Based on a comprehensive database of giant oil field production data, we estimated the average decline rates of the world's giant oil fields that are beyond their plateau phase. Since there are large differences between land and offshore fields and non-OPEC and OPEC fields, separation into different subclasses was necessary. In order to obtain a realistic forecast of future giant field decline rates, the subclasses were treated separately to better reflect their different behaviours.

Thus, our average total decline rate for post-plateau giant fields of 6.5% and CERA's overall 6.3% are in good agreement, and our 5.5% production-weighted giant field decline rate compares reasonably with IEA's 6.5% and CERA's 5.8% (Table 10). Offshore fields decline faster than land fields, and OPEC fields decline slower than non-OPEC fields. There are small differences in the data sets and definitions between the studies, but the results from these three studies can be considered approximately equivalent.

The evolution of decline rates over time includes the impact of new technologies and production techniques and clearly shows that average decline rates are increasing. This verifies the results of Gowdy and Juliá (2007). Furthermore, prolonged plateau levels come at the cost of higher subsequent decline rates. This conclusion is in line with the findings of IEA (2008) regarding trends in average decline.

The trends in average decline rate and production-weighted decline rate indicate that technology transfer, primarily to the Middle East, was able to dampen the decline in many highly productive fields (Figs. 10–12). This cannot continue, and

Table 10
Comparison of our findings with the results from IEA (2008) and CERA (2007).

Parameter	This study	IEA	CERA
Average decline (%)			
Total	6.5	n.a	6.3
Land	4.9	n.a	5.3
Offshore	9.4	n.a	7.5
Non-OPEC	7.5	n.a	6.4
OPEC	4.8	n.a	5.4
Production-weighted decline (%)			
Total	5.5	6.5	5.8
Land	3.9	5.6	n.a
Offshore	9.7	8.6	n.a
Non-OPEC	7.1	7.4	n.a
OPEC	3.4	4.8	n.a

It should be noted that the weighting methods differ and the studies used somewhat different data sets and definitions. In some cases a value for comparison was not available.

ultimately, production-weighted decline must approach the average decline rate, as in the case of Norway (Fig. 9). How the production-weighted decline will behave in the future is difficult to estimate, but an increase appears inevitable.

Future decline rates of giant fields that have not yet left the plateau phase can be expected to be higher than those that are now in decline. This is in line with a recent statement about a decline of 10% in mature fields from Petrobras downstream director Paulo Roberto Costa (2008). The crash of the Cantarell field in Mexico and the experiences of the North Sea giants are a vivid example of what can happen to other giant oilfields in the future.

These findings have large implications for the future, since the most important world oil production base – giant oilfields – will decline more rapidly. In the extreme, a potential 10% annual decline in Ghawar would be very challenging to compensate and would create severe problems for Saudi Arabia and the world. The future behaviour of the remaining giants, especially in OPEC, will be a key factor in future oil supply.

Based on the decline behaviour of giants, decline rate estimates for world oil production are possible because of the large influence of the giants. Many studies have shown that smaller fields, condensate, and NGL will decline at least as fast or faster than giant oilfields, once the onset of decline is reached (CERA, 2007; Höök and Aleklett, 2008; IEA, 2008). Consequently, we believe that there is a strong basis for believing that giant oilfields can be used to set a floor for future decline rate assumptions.

In conclusion, this analysis shows that the average decline rate of the giant oil fields have been increasing with time, reflecting the fact that more and more fields enter the decline phase and fewer and fewer new giant fields are being found. The increase is in part due to new technologies that have been able to temporarily maintain production at the expense of subsequent more rapid decline. Growing average decline rates have also been noted by IEA (2008). The difference between using a constant decline in existing production and an increasing decline rate is significant and could mean as much of a difference of 7 Mb/d by 2030 (Fig. 13).

By 2030 the production from fields currently on stream could have decreased by over 50% in agreement with IEA (2008). The struggle to maintain production and compensate for the decline in existing production will become harder and harder. Our conclusion is that the world will face an increasing oil supply challenge, as the decline in existing production is not only high but also increasing.

Acknowledgments

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