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Development journey and outlook of Chinese giant oilfields

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Abstract:
Over 70% of China's domestic oil production is obtained from nine giant oilfields. Understanding the behaviour of these fields is essential to both domestic oil production and future Chinese oil imports. This study utilizes decline curves and depletion rate analysis to create some future production outlooks for the Chinese giants. Based on our study, we can only conclude that China's future domestic oil production faces a significant challenge caused by maturing and declining giant fields. Evidence also indicates that the extensive use of water flooding and enhanced oil recovery methods may be masking increasing scarcity and may result in even steeper future decline rates than the ones currently being seen. Our results suggest that a considerable drop in oil production from the Chinese giants can be expected over the next decades.

Key words: Giant oil fields, future Chinese oil production, decline curve analysis, production modelling, oil production strategy,

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1. Introduction

Only the largest of oil fields may be called giants, a common definition is that they must have ultimately recoverable resources (URR) of at least 500 million barrels according to the American Association of Petroleum Geologists (AAPG) [1-5], while others use the production rate to define giant oil fields and require them to deliver flows of more than 100 000 barrels per day (b/d) for at least a year [6]. This study will use both definitions of a giant oil field. Several studies have focused on the immense importance of giant oil fields for world oil supply [7-10]. In fact, giant oil fields have even been called "*the highway to oil*" as they represent roughly 65% of the global conventional oil recoverable resources [11]. Conventional oil fields refer to reservoirs that predominantly allow oil to be recovered as a free-flowing dark to light-coloured liquid [12]. Consequently, heavier crude oils that require special production methods are excluded.

The revised Geological and Mineral Industry Standard of Peoples Republic of China [13] states that Chinese field reserves should be calculated from recoverable reserves and gives five different field classifications: *super giant*, *large*, *medium*, *small*, and *extra small* [14]. The large class includes fields with ultimate reserves ranging from 0.18 to 1.8 billion barrels. Accordingly, our giant classification will include all Chinese fields denoted as super giant as well as some of China's large fields.

The dominance of giant oil fields can be seen on both a global and a national level. The 20 largest giants account for 25% of world oil production [10]. Similarly, one can see how the Norwegian or the Danish production has been governed by the behaviour of their giant oil fields [15, 16]. Robelius [11] even states that global and national peak production will be chiefly determined by the giants and their behaviour.

As the world's second largest oil importer, China is of significant interest. China's future domestic oil production will determine its future oil import requirements. Currently, the Chinese demand for oil is growing and is likely to increase even more with continued development and modernization.

1.1 Aim of this study

In this analysis we consider China's nine giant oil fields, Changqing, Dagang, Daqing, Huabei, Liaohe, Shengli, Tarim, Xinjiang and Zhongyuan (Table 1). In addition to these fields, China contains a number of smaller fields, such as Jilin, Tuha, and Henan, that will be briefly discussed in relation to the giants.

This study will utilize decline curve analysis to project possible production scenarios for the Chinese giant oil fields. This methodology is chosen because of a strong theoretical background from natural science as well as a strong agreement with numerous empirical studies. In addition, decline curves are also one of the oldest and most used production forecasting techniques employed by petroleum engineers [17, 18]. Furthermore, they have been used to provide reasonable production outlooks in numerous cases without requiring extensively detailed data [9-10, 19].

Understanding how the core of China's domestic oil production might behave in the future is essential. It is important for Chinese planners and policymakers in order to plan for the future and to anticipate problems before they occur. Proper understanding of the future behaviour of Chinese oil production is also helpful for other countries that will be competing with China for future oil imports.

Figure 1: *Approximate geographical location of the nine Chinese giant oil fields.*

1.2 Data gathering
Historical production data for the Chinese giant oil fields were taken from the statistics compiled by mainly Robelius [11], but complemented with sources such as Kang et al. [20] and Xin [21-23]. In addition, some 2008 figures were taken from press releases from various oil companies. The production data were found to be in good agreement with each other and aggregated production agreed well with national data figures, such BP [24]. URR estimates were compiled from various sources, mainly from the compiled estimates of Robelius [11], Laherrere [25], and various other sources. Alternatively, decline curve analysis could be used to create our own URR estimations derived from the production data based on methodology described by Höök et al. [19]. Generally, the URR figures were found to be in reasonable agreement.

2. Overview of Chinas petroleum sector
Chinese oil production prior to 1960 was practically nonexistent. Xinjiang, Liaohe were discovered in late 1950s, but only a few sites produced petroleum and there was a widespread shortage of petroleum products. However, in 1959 geologists pointed to the petroleum potential of the barren plains of Northern China. Oil workers were sent to the area and faced an undeveloped region with harsh conditions. Wang Jinxi – better known as the legendary *Iron Man* due to his unwavering passion for hard work – and his drilling team unloaded 60 tons of drilling equipment by themselves with shoulders, crowbars and home-made tools and carried it across the prairie to the drilling site due to a lack of trucks and horses. Soon they had uncovered the

giant Daqing oil field, which became a pillar in the industrial development. Exploitation of the vast reserves in the wide Daqing region was almost completely done without any foreign expertise or equipment. Likewise, Daqing and the effort of its oil workers were presented as a model for all other industrial sectors and became an important political symbol [26].

Experience from Daqing, new knowledge, and increased efforts quickly lead to additional discoveries of new oil areas. Shengli and Dagang were located in 1960s and Changqing, Huabei and Zhongyuan were discovered in the next decade. The giant discovery peak occurred in the 1960s and most reserve additions have been from non-giant fields. Wang [27] states that the Chinese oil reserve growth has reached a plateau and that discovery of new giants are unlikely.

During 1971-1978, China's oil output soared and saw an average annual growth rate of 16.5% [28]. Much of this spectacular growth can be connected to giant oil fields as the Daqing, Shengli and Huabei fields alone accounted to over 80% of the total Chinese oil production in 1980. However, in early 1980s production stagnated due to geological, technological, and institutional factors [28]. After 1984, new production methods, increased investments, changes in the institutions and management and increased exploration managed to make production increase again, although at less rapid pace than before. Tarim was discovered in 1989 and was the last and smallest Chinese giants.

Chinese oil production has still managed to increase since the 1980s, but this is becoming more and more challenging to sustain as more and more of the giants are reaching the onset of decline. Total giant contribution has been kept virtually constant since 1985, despite limited new field additions (Figure 2). Most of the production increases has been derived from non-giants and this resembles the behaviour of Norway prior to their peak production, where giants reached a plateau for some years before the onset of decline [15].

Table 1. *Chinese giant oil fields*

Field name	URR [Gb]	Discovery year	First oil	Peak year	Peak production [b/d]
Changqing	2.2	1971	1975	-	-
Dagang	1.5	1965	1965	-	-
Daqing	24.1	1959	1959	1999	1 100 000
Huabei	2.2	1975	1975	1979	350 000
Liaohe	5.0	1958	1970	1995	312 000
Shengli	15.8	1961	1961	1992	672 000
Tarim	1.1	1989	1989	-	-
Xinjiang	5.5	1951	1951	-	-
Zhongyuan	1.3	1975	1976	1988	145 000

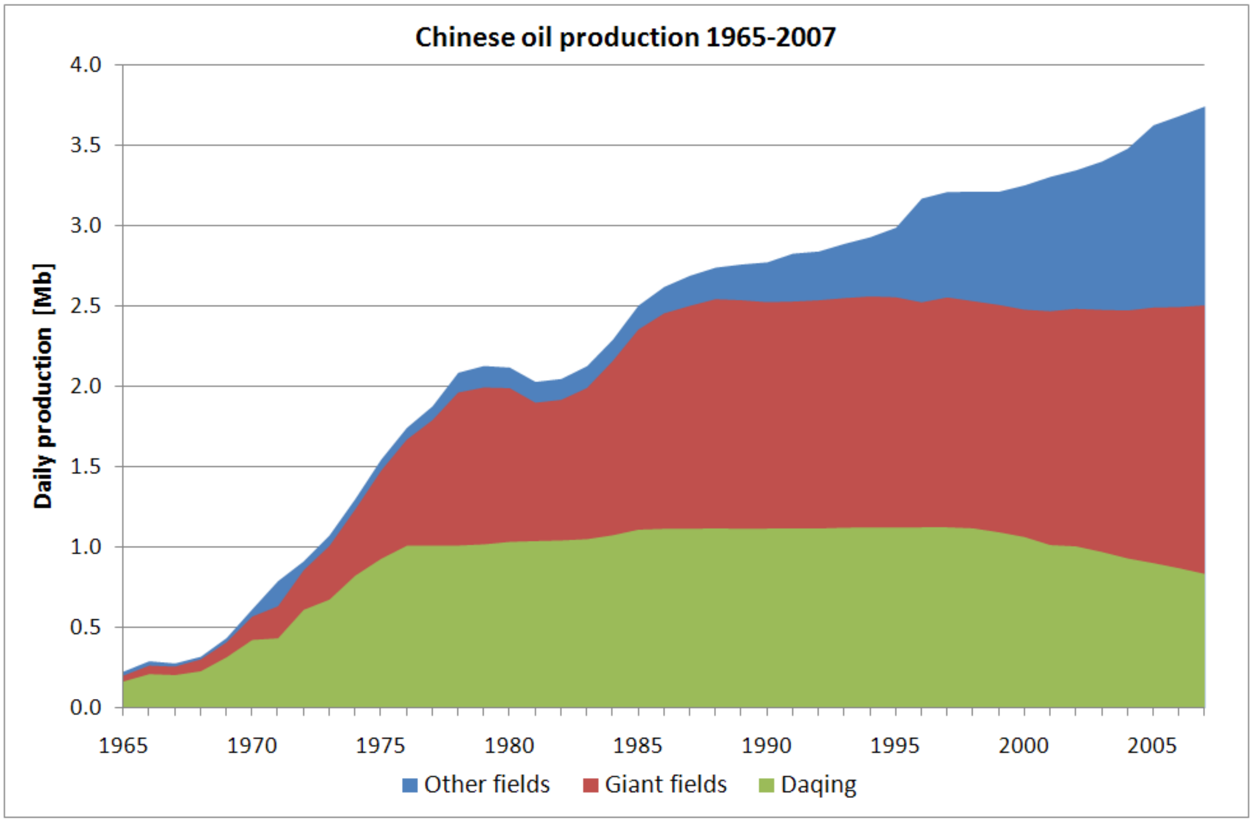

Figure 2: *Chinese oil production from 1965 to 2007. The giant fields have dominated production, although their share is dwindling. Daqing has been the single most important contributor since its discovery and remains an integral part of Chinese domestic oil supply.*

2.1 Geological overview

China's sedimentary basins developed and took shape mainly during the Himalayan movement period (~65 Ma ago), which involves strong continent-to-continent collision and continuous compression between the India Plate and the Eurasia Plate [29]. A basic overview of the petroleum geology has been done by Desheng [30]. Reservoir rocks are commonly made of sandstone or the mixture of sandstone and conglomerate rock composed of mostly clastic detritus [31]. Most of the oil fields belong to river-deltaic sedimentary systems with apparent multicyclicity, resulting in multiplayer folding traps with sharp discrepancies. Consequently, permeability varies widely in different directions for many oil sediments [31].

An interesting property of many important Chinese fields is that they are associated with non-marine basins, in particular the Songliao basin where Daqing can be found [32]. The sedimentary basins in east China, where most of the giants are located, are characterized by a large number of highly fractured traps of mainly stratigraphic type [28]. This gives the oil fields great variability in reservoir distribution, porosity and permeability, creating generally complex conditions [33]. For example, Daqing, Shengli, and Dagang all have oil in a complex geological pattern of unpredictable pockets at various depths [28]. Additionally, Zhao et al. [14] discussed principal forming conditions of large oil fields in China.

Daqing, Shengli, Huabei, Liaohe and Dagang may be seen as the most important giants and all of them are located in the north-east of China. Daqing is located in the Songliao basin, while the others are found in the Bohai basin. Hu et al. [34] gave a summary of the Songliao basin, while Gu et al. [35] reviewed the Tarim Basin and Yang and Xu [36] overviewed the Bohai basin. In addition, the Sichuan Basin, the Junggar Basin, the Qaidam Basin, and the Ordos Basin, have been discussed by others [37-40].

2.2 Production overview

Chinese oil production is chiefly done by large state-owned oil companies. The largest is China National Oil Company (CNPC), parent company of the public-listed PetroChina, which are the largest reserve holder and domestic oil producer. Sinopec, the public arm of the state-owned China Petrochemical Company, is the second largest petroleum company in China and is involved in everything from refining and petrochemicals to pipelines and oil/gas production and exploration. China National Offshore Oil Company (CNOOC) is another state-owned company and the third largest player in the petroleum sector.

A brief historical overview of oil production technology in China has been made by Liu [41]. Chow [28] explained how China adopted a short-sighted policy of forcing oil production at the expense of exploration and development in the 1970s. This resulted in extensive use of water injection. Daqing for instance, was subjected to water injection directly from the start and excessive flooding lead to increase water cut and premature abandonment of many wells as well as reduction of soil temperature [28]. This overuse of water injection helped to enhance production but has been estimated to reduce ultimate recovery [28]. The water cut is over 80% for most fields and studies on additional enhancement oil recovery have been carried out for more than 10 years now [31].

A rapid development in the study of the enhanced oil recovery (EOR) technology has occurred since the late 1970s [33], and will likely be vital for future domestic oil production. Generally complicated geological conditions, resulting in water channelling, fingering oil migration, and complicated pore structure of the rocks, limits the power of natural water flooding and have forced widespread the reliance on water injection and EOR methods are pursued [31]. For example, microorganisms are employed for obtaining oil-releasing substances in the Daqing field [42], while surfactants and polymer flooding are extensively used at the Shengli oil field [43, 44] along with special structure drilling techniques [45]. The use of horizontal drilling has also been chiefly applied to Chinese giant fields [46], as well as high frequency vibration recovery enhancement and thermal recovery technologies [47]. The necessity and feasibility of development of many mature fields in China have been compiled by Hu [48].

3. Modelling and analysis

Decline curves were originally introduced by Arps [49] and strived to obtain expressions with mathematical tractability that could be utilized in a simple and straightforward manner. Additionally, decline curve analysis is independent of the size and shape of the reservoir or the actual drive-mechanism [50], thus circumventing requirements on detailed reservoir data. Furthermore, decline curves are more than just an empirical model of field behaviour since they also represent physical solutions to reservoir flow equations in various cases [9]. A more comprehensive overview of decline curves and the methodology used in this analysis can be found in Höök et al. [16].

The exponential and hyperbolic decline curves, mathematical expressions capable of describing the change in production rate over time according to Arps [49], will be utilized here to analyze and make a number of outlooks for the Chinese giants. It should be explicitly noted that the exponential decline curve is a special case of the general hyperbolic decline. This is the explanation of why the two curves look virtually the same in some situations. Some of the Chinese giants (Daqing, Huabei, Liaohe, Shengli and Zhongyuan) are already in decline. The historical production data after the peak year is fitted with decline curves and used for projecting future production. The resulting outlooks should be regarded as optimistic, as production collapses caused by sudden events, economic or geological, cannot be included.

In total, we believe that four fields, Changqing, Dagang, Tarim and Xinjiang, have not peaked. The future production of these fields cannot be forecast by decline curves directly, so we chose to use a depletion rate analysis approach instead. This means that the depletion rate behaviour and its future trajectory are studied. Anticipated ultimate reserves are needed for these fields in order to calculate the depletion rate of the remaining reserves (URR estimates have been taken from Robelius [11] and others). The plateau phase is assumed to end when the typical depletion rate at peak value for giant oil fields on land is reached, that is, a forecasting-by-analogy approach based on typical behaviour obtained from a large statistical population of giant oil fields [9]. Once the plateau phase is over, the decline is assumed to be approximately as fast as the other giant oil fields of comparable size and character, whose typical decline rates are known from historical data.

3.1 Post-peak Chinese giants

The largest of the Chinese giant fields are generally in the post-peak stage. The most important giant field, Daqing, has been in a steady decline since 1999, despite attempts to mitigate and stabilize production. The decline of Daqing has followed an exponential curve with 3.4% annual decline ever since the onset of decline and this is expected to continue in the future (Figure 3).

Daqing has been sequentially developed since 1960s. By 1981, 23.5% of the original oil in place (OOIP) had been extracted and water cut had reached over 60%, due to the dominance of water flooding as the production method [51]. In 2004, the water cut reached 88.9% and 36.8% of the OOIP (or 75.6% of the recoverable reserves) had been recovered [52]. Daqing is essentially in the late stage of the high water-cut development phase and tertiary recovery methods must be applied. In other words, the challenge to sustain production is becoming increasingly more difficult. In addition to extensive water flooding, Daqing has also been subjected to various EOR projects and trials, including microbial techniques [42, 53], and polymer/surfactant injection [54].

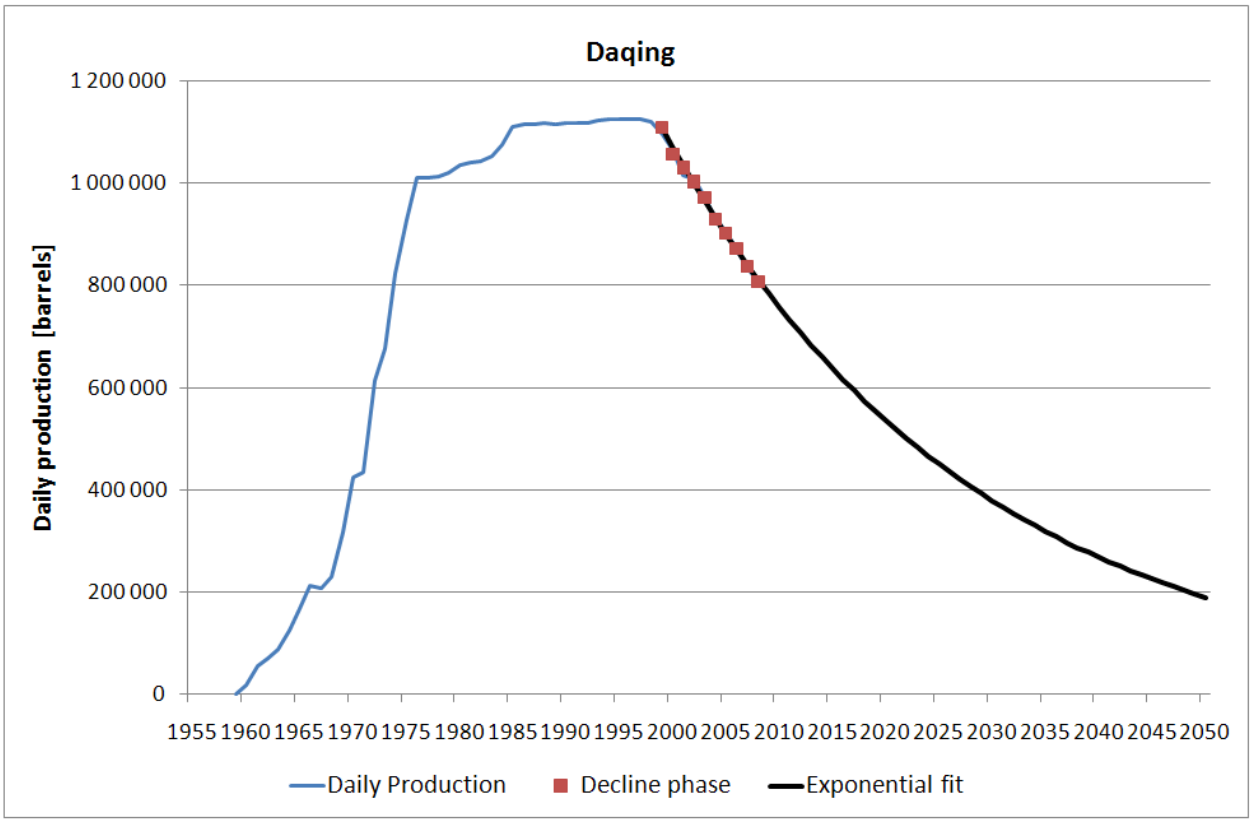

Figure 3: *Production outlook for the Daqing oil field. The hyperbolic case is the same as the exponential case and is omitted. Daqing will remain an important oil producer for many decades, but is expected to be delivering around 200 000 b/d in 40 years.*

Huabei is also one of the world's important giants and played a vital part in the rise of Chinese oil production in 1970s [28]. However, the output peaked at 350 000 b/d in 1979 and began to decline (Figure 4). In 1990s, the descent was halted and seems to have stabilized at slightly below 100 000 b/d. The Renqui reservoir, belonging to the Huabei complex, has shown a dramatic production crash in 1986-2000 according to Laherrere [25], but this seems to have been offset by new additions. Huabei has also shown signs of land subsidence [55], possibly assisting recovery because of reservoir compaction. Huabei is probably also a good example of how a single decline curve cannot fully depict the historical behavior and how a concerto of curves should be used for better agreement. The decline curve fit yields an average decline rate of roughly 8%, which reasonably may be seen again as soon as the temporary production increases cease to offset the underlying depletion-driven decline.

Liaohe ranks among the largest of the Chinese giants and saw a massive increase in production from the early 1970s to the 1990s. However, the field peaked in 1995 and has been in decline ever since (Figure 5). It has also been subjected to combined alkaline/surfactant/polymer (ASP) flooding after the Chinese government put emphasis on such measures in the 7th, 8th and 9th five-year plans ranging from 1985 to 2000 [56]. Trial tests with CO_2 injections are also being pursued at this field [57]. This far, none of the measures seems to have had much impact and their future effects remain to be seen. If the historical trend continues, production from Liaohe would be only 100 000 b/d by 2050.

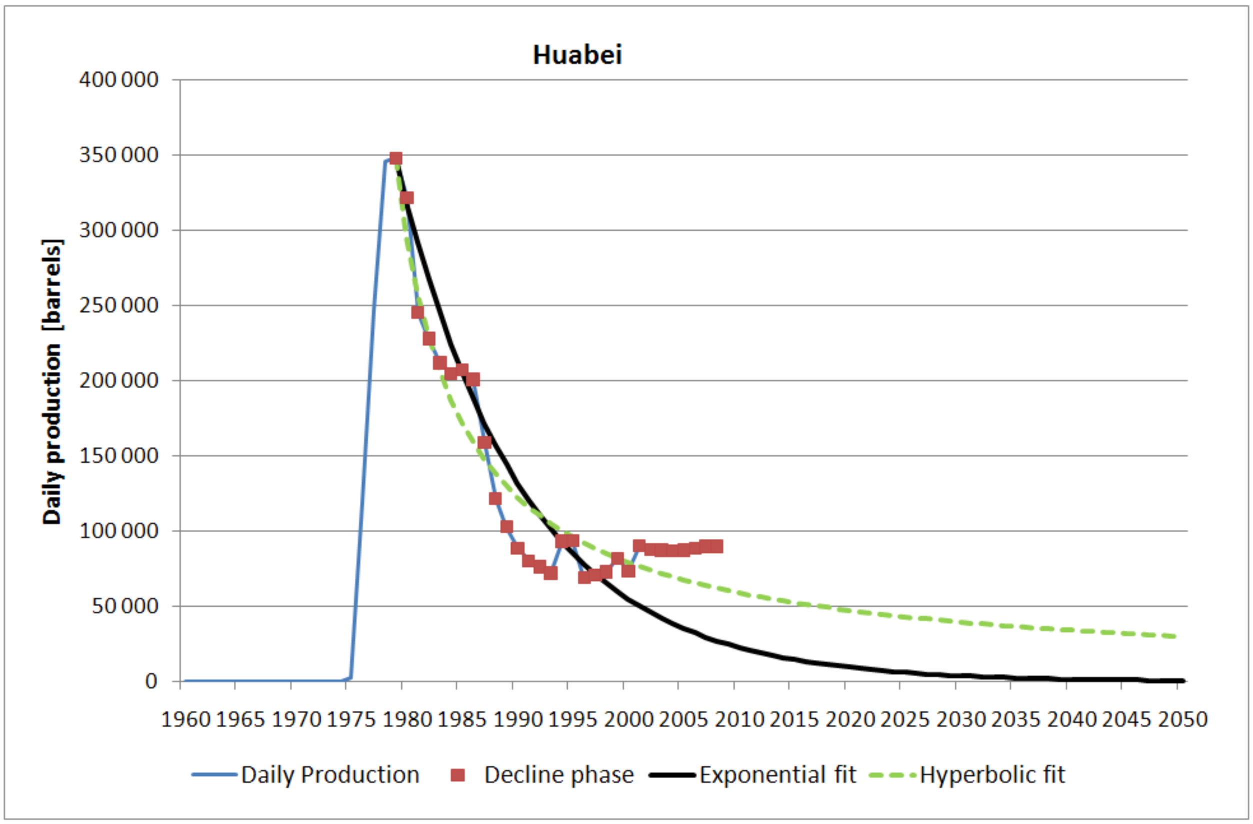

Figure 4: *Production outlook for the Huabei oil field. The field seems to have flattened out at slightly below 100 000 b/d due to redevelopment and new production enhancement methods.*

Shengli is a giant with recoverable reserves of around 10 Gb. A short period of stagnation was seen in 1975-1985, before production started to increase again (Figure 6). The field peaked in 1993 at a production of 650 000 b/d, and now the formation is characterized by high water cut, massive water channelling, and inefficient oil recovery due to complex geology and serious heterogeneities [58]. For the moment, significant redevelopment and EOR measures are being pursued and have temporarily halted the decline. The measures include nitrogen foam [58], surfactant/polymer injection [59, 60], and microbial activation [61]. How long the declining trend can be reversed remains an open question.

Zhongyuan is a relatively small giant that peaked in early 1990s with a daily production of 145 000 b/d. It has followed both exponential or hyperbolic decline curves reasonably well ever since. The Zhongyuan field, its marginal oil areas and how those can be brought into production are discussed by Dai et al. [62]. Any major revival of the field seems unlikely and additional measures will largely be able to dampen decline to some extent.

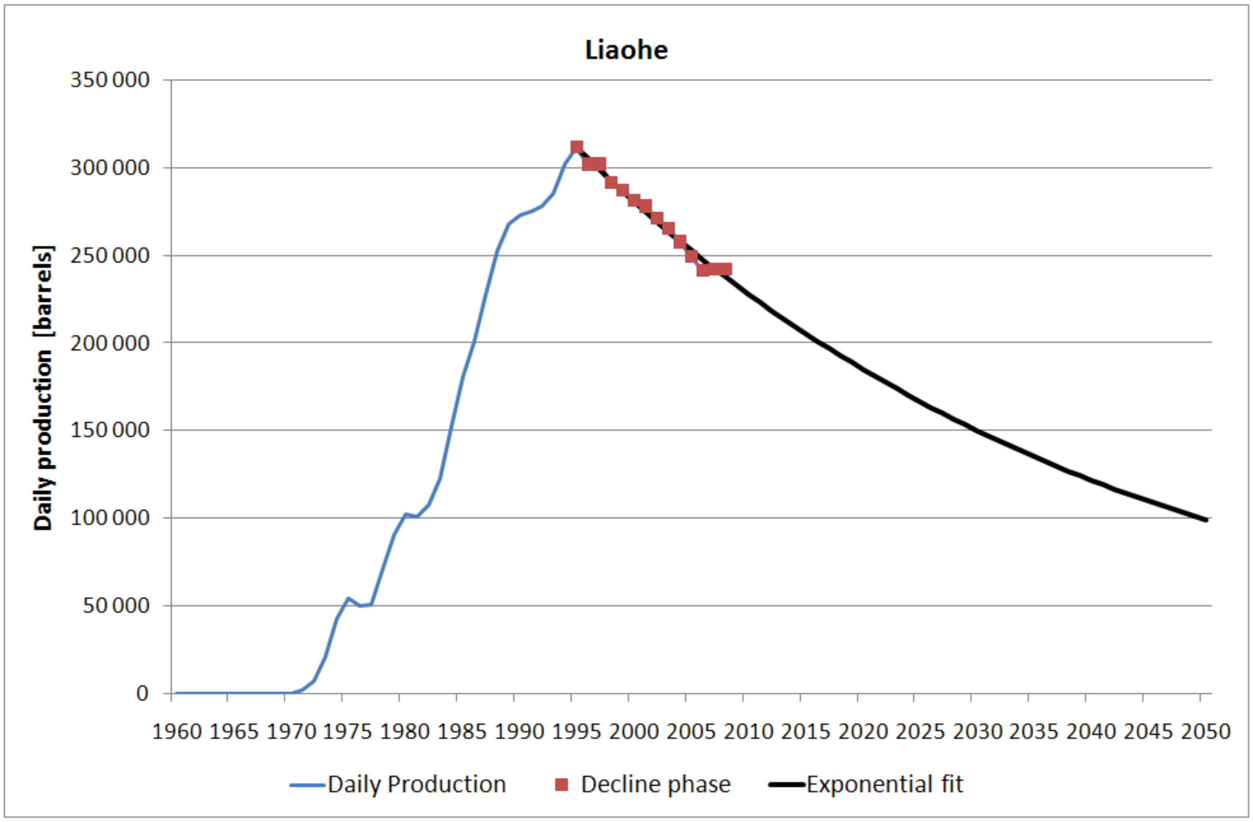

Figure 5: *Production outlook for the Liaohe oil field. The hyperbolic case equals the exponential case and is omitted. Provided that nothing unexpected happens, this field will follow a steady 2% decline in the future.*

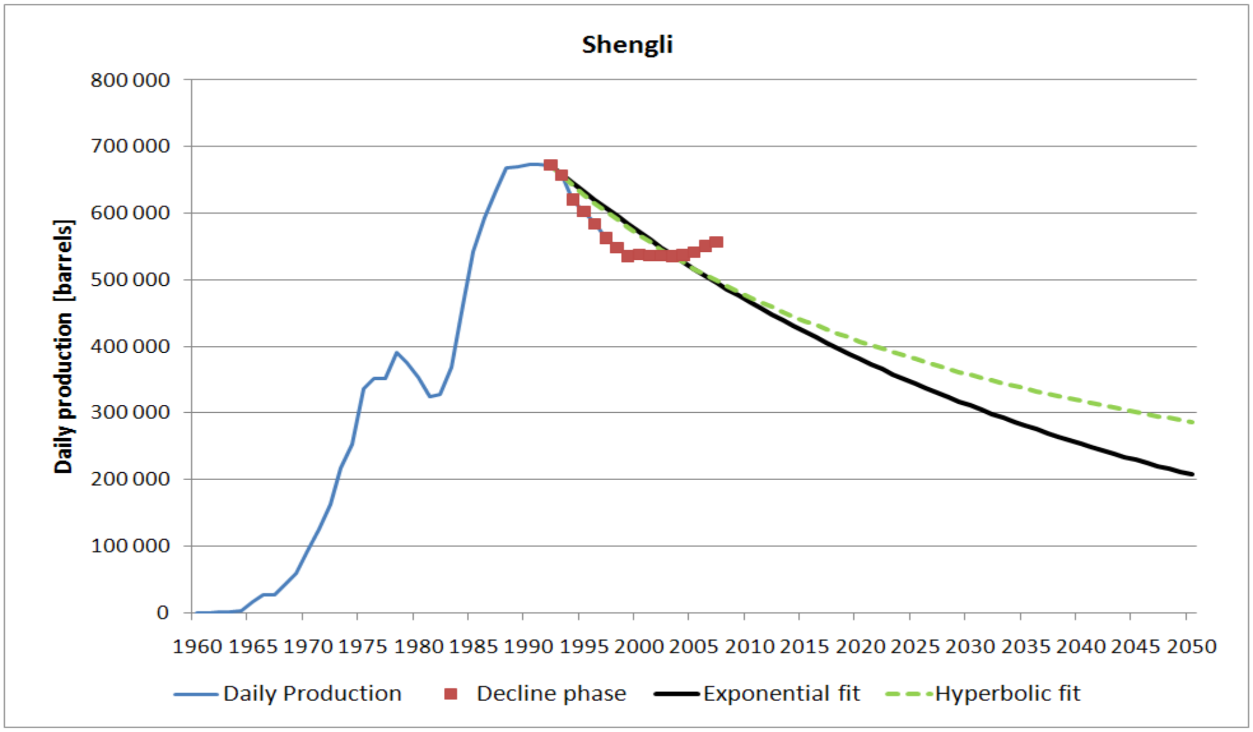

Figure 6: *Production outlook for the Shengli oil field. In recent years, redevelopment and EOR measures have been able to offset the decline and even cause a slight increase, but this is likely just temporary and a significant decrease in output can be expected over the next decades.*

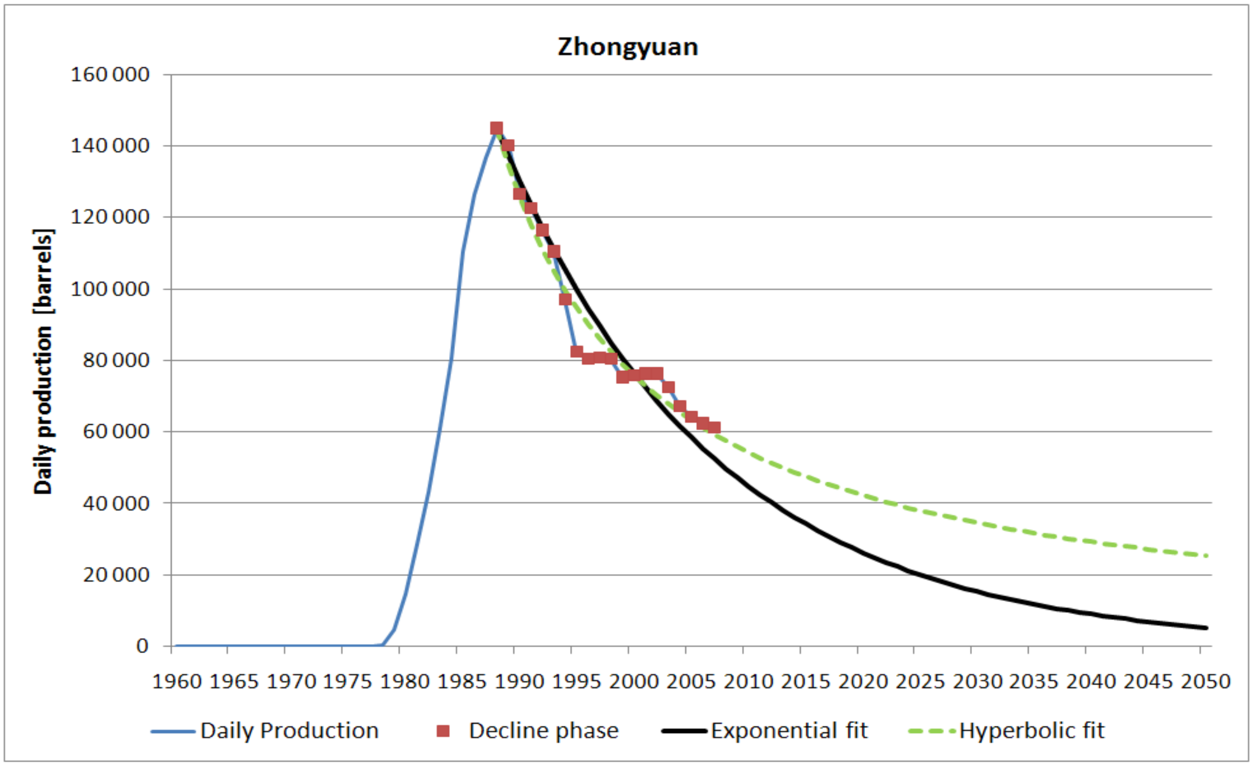

Figure 7: *Production outlook for the Zhongyuan oil field. This field agrees well with both exponential and hyperbolic decline curves, even though the hyperbolic fit is better.*

3.2 Pre-peak Chinese giants

Changqing, Dagang, Tarim, and Xinjiang have all seen increasing production since they came on stream. In fact, increased production from the pre-peak giants has offset the decline from the post-peak giants (Figure 8). Most of the production increase has been from Changqing, followed by Xinjiang and Tarim, while Dagang has seen relatively steady production since the mid-1970s. Consequently, the onset of decline in the pre-peak giant fields will have a major influence on the future domestic oil production in China.

The future behaviour of the pre-peak giants might be estimated by studying the depletion rate of the remaining reserves, provided that our URR estimates are reasonable. Previous studies of giant oil fields have investigated the typical values of the depletion rate at the onset of decline and found it to be occurring in a narrow band [9]. The importance of depletion rate of remaining reserves and its influence on reservoir flows and overall production has been discussed by Höök [63]. Jakobsson et al. [19] named this methodology "*maximum depletion rate modelling*" and did a broad overview. In practice, this means that the depletion rate of remaining reserves is allowed to reach a maximum value, found from empirical studies of other fields. Once that maximum value is reached, the depletion rate remains constant which corresponds to an exponential decline curve as shown by Jakobsson et al. [19]. In contrast, the general hyperbolic case has a decreasing depletion rate with time [63].

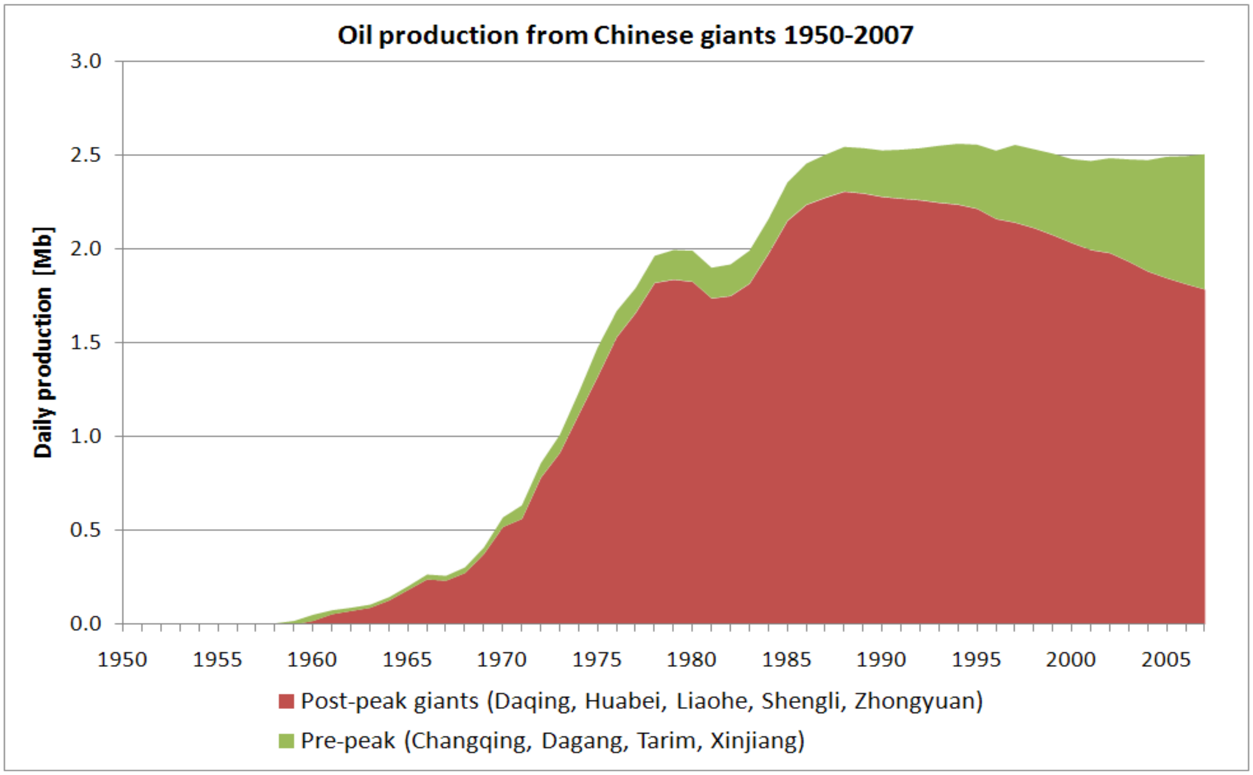

Figure 8: *Historical production of the Chinese giant oil fields. The pre-peak fields have been able to offset decline in the post-peak fields since 1990s, but this cannot continue forever and will cease as soon as the production increase in the pre-peak giants halts.*

Changqing, classified as a low-permeability reservoir [41], has seen a massive ramp-up of production from roughly 30 000 b/d in 1990 to over 250 000 b/d in 2008 (Figure 9). Much of this rise can be attributed to advanced water flooding measures [64]. At some point, the increase must cease and this is indicated by the behaviour of the depletion rate of remaining reserves.

Current depletion rate of remaining reserves at the Changqing field is 7.1%, based on an URR of 2.2 Gb. This around the typical depletion rate at peak value (7.2%) for 58 other giant fields of approximately equal size, all taken from our giant oilfield database This implies that Changqing’s production increase will stop soon and be turned into decline. The depletion rate also indicates that a reasonable average future decline rate would be around 8% [9].

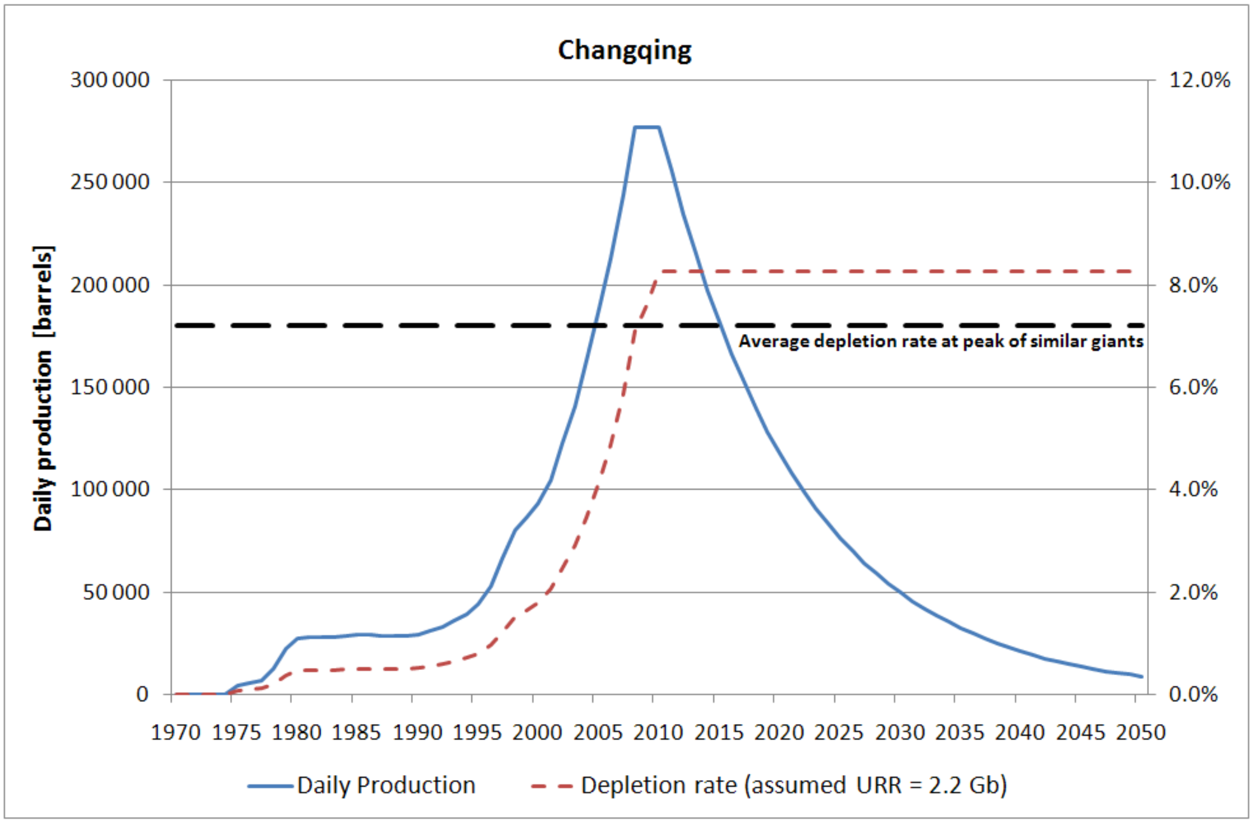

Figure 9: *Production profile and depletion rate behavior of Changqing. The rapid production increase has resulted in a steep increase in the depletion rate of remaining reserves.*

Similar reasoning can be applied to Dagang (Figure 10) and this implies that the plateau phase is about to end relatively soon, followed by a decline phase with an average annual decrease of roughly 10%. Possibly, Dagang reached its peak in 2006 although it is too early to determine with significant certainty.

Tarim (Figure 11) is estimated to have ultimate reserves of 0.9 Gb, can also be modelled in the same way from its depletion rate behaviour. This indicates that the field is about to quit the build-up phase and soon enter the decline phase. The probability of increasing production is becoming smaller, given the relatively narrow distribution of reasonably depletion rates for giant oil fields [9].

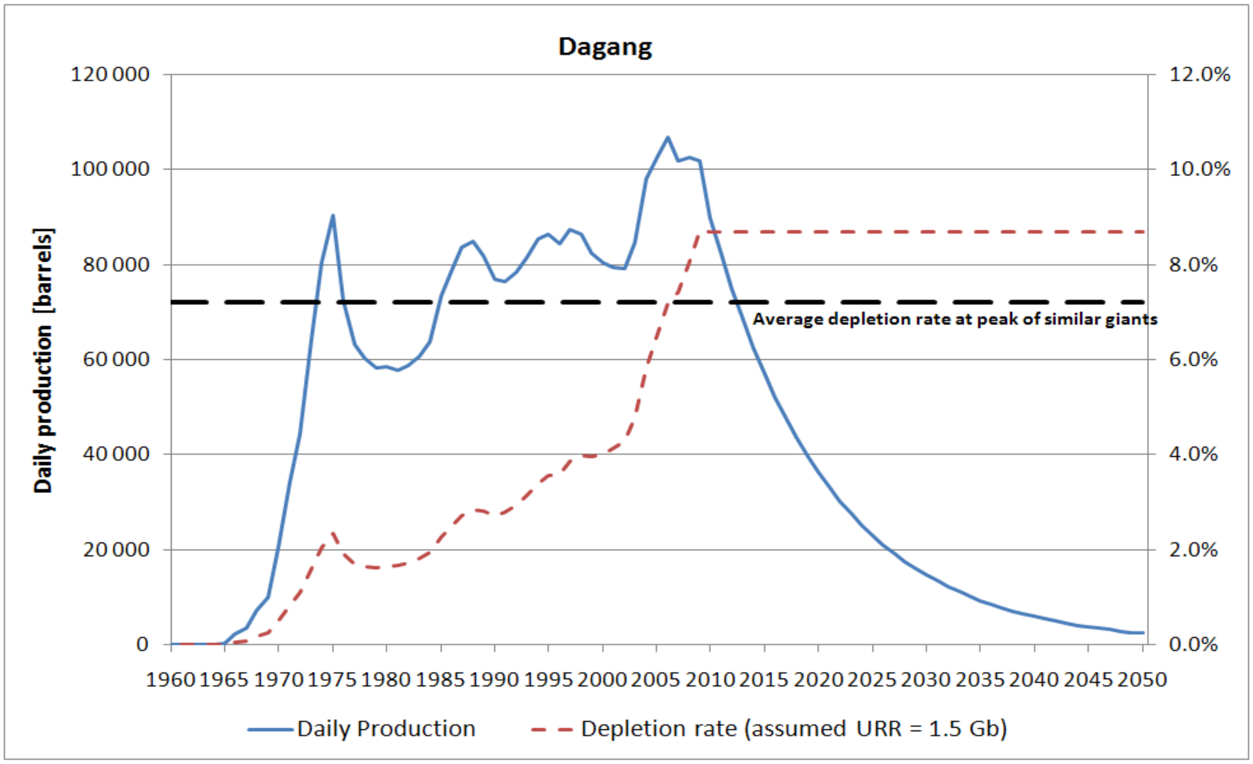

Figure 10: *Production profile and depletion rate behaviour of Dagang. A steep increase in depletion rate has occurred in 2000s.*

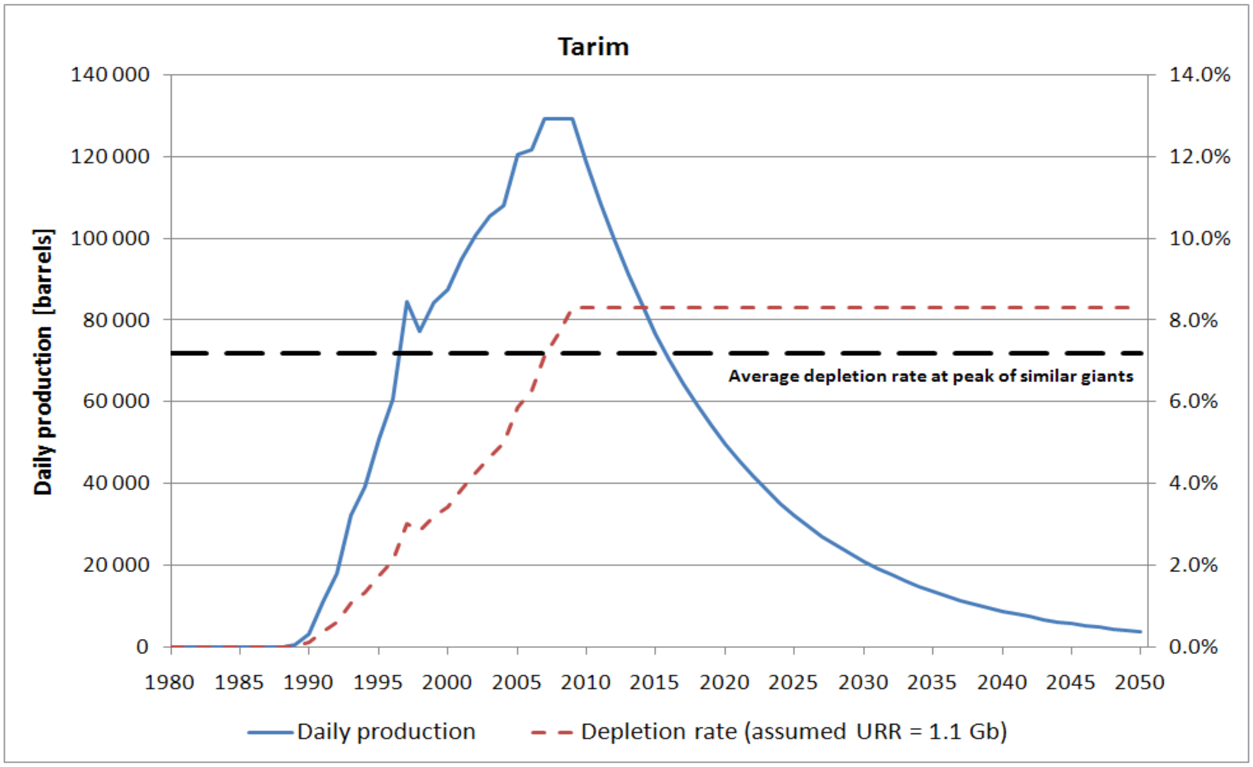

Figure 11: *Production profile and depletion rate behaviour of Tarim. The rapid production increase is followed by the steep increase in depletion rate.*

Xinjiang (Figure 12) is enormous compared to the other pre-peak giants and has been steadily increasing production since 1970s. Its URR has been estimated to 5.6 Gb [11]. The future production of this field and its onset of decline can be estimated by using analogies with similar fields worldwide, using our world giant oil field database and the narrow distribution of typical depletion rate values at the onset of decline [9, 63].

Sarir, Karanj, Minas, East Texas and Liaohe are giant fields of comparable size in terms of recoverable reserves and they all reached a production peak or left the plateau phase at depletion rates of around 3%. It is not reasonable to expect that Xinjiang will differ widely from this typical behaviour and this leads us to the conclusion that Xinjiang is about to reach a peak somewhere in the following decade, or possibly decades, provided that our URR estimate is reasonably accurate. A realistic future decline rate would be around 3.5%, also based on similarities with other fields and the strong correlation between depletion rate at peak and future average decline rate [9].

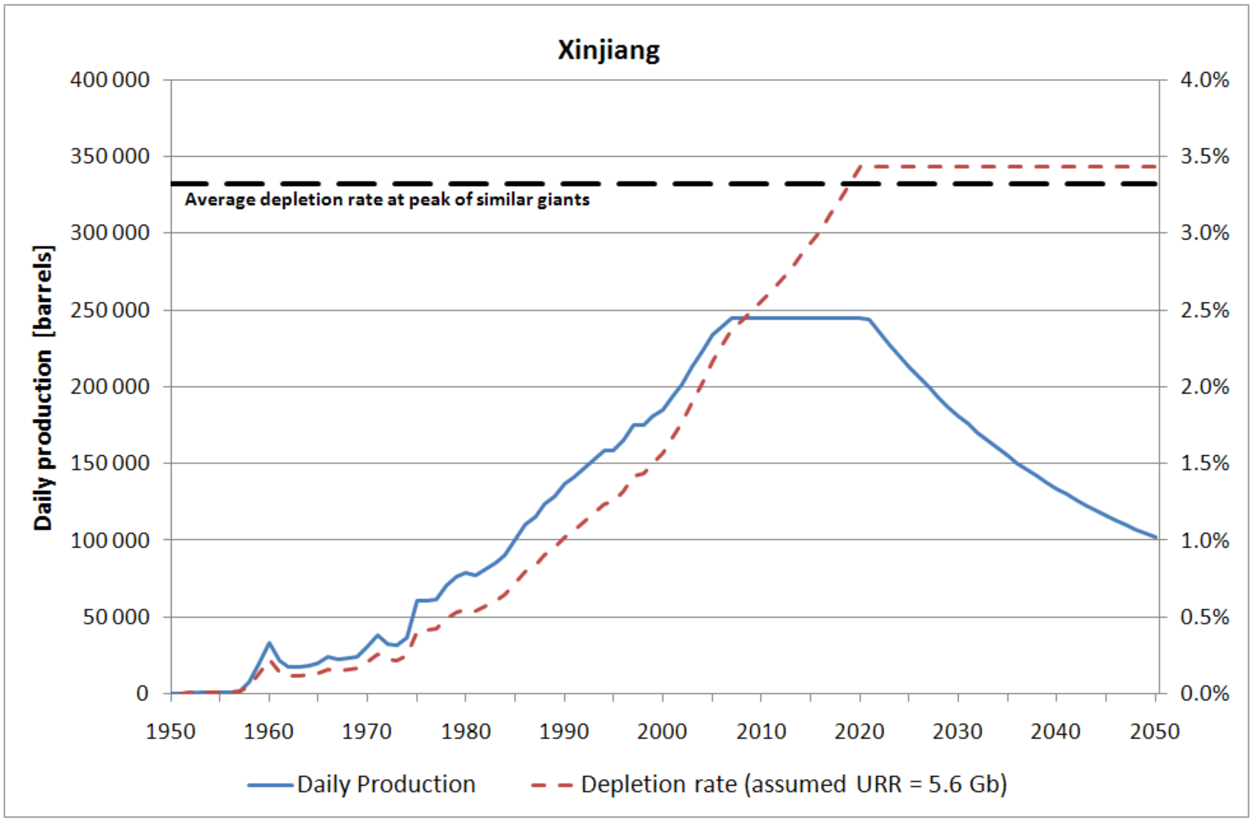

Figure 12: *Production profile and depletion rate behaviour of Xinjiang. The rapid production increase is followed by the steep increase in depletion rate.*

In summary, we believe that each of the pre-peak giants is close to reaching the onset of decline if they exhibit behaviour similar to the many hundreds of other giant oil fields worldwide. An exact peak year is hard to estimate, but from the narrow distribution of reasonable depletion rates for giant oil fields, we can conclude that the onset of decline can be expected to occur relatively soon, likely within a few years, for the pre-peak Chinese giant fields.

3.3 Technology and future decline rates

Secondary and tertiary production techniques can boost extraction rates by creating better drainage of the oil in place, maintaining reservoir pressure, or even reducing the viscosity [65]. Such measures have been used extensively throughout history and are being aggressively pursued at present. This brings about another problem for the future, namely how extraction technology masks increasing scarcity. Compelling evidence shows that such measures only increase or maintain production levels temporarily at the expense of steeper subsequent decline rates in a general case.

Both the Forties field in the UK North Sea and the Yates field in the US have been studied in detail by Gowdy and Julia [66]. Their finding was that investment in technology only temporarily raised or maintained production and that the result was steeper future decline rates. The analysis also showed that actual details on field level are important and that the common belief that technology always will mitigate shortage is untrue. EOR may just accelerate depletion of existing reserves *or* it may improve depletion rate and capture significant additional reserves.

The conclusions of Gowdy and Julia [66] were later extended and generalized for the world's giant oil fields by Höök et al. [9]. Studies of how typical giant field behaviour had evolved over time indicate that prolonged plateau phases and increased depletion, made possible by new technologies and secondary and tertiary measures, resulted in generally higher decline rates. The spectacular collapse of the giant Cantarell field, which had been subject to extensive nitrogen injection, may be seen as an extreme example of what can happen when decline finally sets in. Additional discussions on average decline rates and comparisons with other studies have been made by Höök et al. [10]. In essence, the strong correlation between depletion rate and decline rate [9], verifies the well-known but seemingly ironic nature of oil extraction: "*the better you do the job; the sooner it ends.*"

Based on this reasoning, we state that the analysis of the Chinese post-peak giant fields may be optimistic and that significantly steeper decline rates are likely to occur once the temporary gains from EOR measures wears off. A definite and certain estimate of how much higher decline rates is impossible to give at this time, but the mere possibility calls for further investigations, preparation, and responsible planning from the affected parties.

3.4 Future outlook

This analysis assumes that China's post-peak giants will continue to develop according to the decline curve fits (Figure 3-7). The Huabei field (Figure 4) is an inherently bad fit, but we expect it to be compensated by overestimations for other fields. This methodology is identical to the approach used in previous studies [10, 15-16].

Based on the depletion rate modelling, we estimate that the most pre-peak fields will peak in the imminent future (Changqing in 2010, Dagang and Tarim in 2009) while Xinjiang can increase its output to 300 000 b/d before reaching the onset of decline in 2020 (Figures 9, 10, 11 and 12). In other words, the decline from post-peak giants will not be offset as an increasing number of the non-peaked giants enter the onset of decline. Assumed future decline rates are 9% for Changqing and Tarim, 8% for Dagang, and 4% for Xinjiang.

The integral picture for all Chinese giants can be seen in Figure 13, and shows how a massive decrease in domestic oil production can be expected in the near future. Some characteristic parameters are compiled in Table 2. As soon as the production increases from the pre-peak fields ceases, the real decline will set in and become apparent. After 2010, almost 2

Mb/d of production capacity will be lost due to maturing fields and inherent decline. The lost production capacity will have to be replaced with new capacity or additional oil imports, or both.

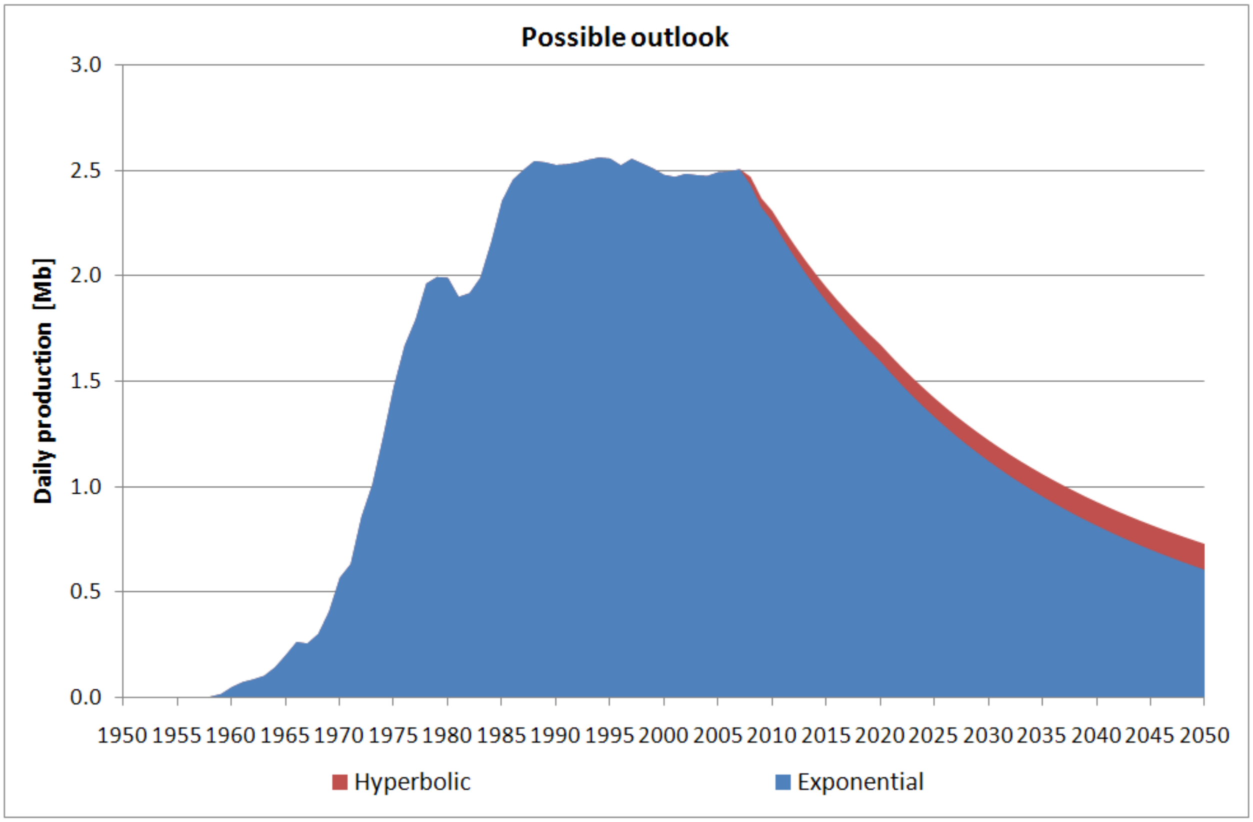

Figure 13: *Possible outlook for the domestic oil production from Chinese giant oil fields in both the exponential and hyperbolic case. The average annual decrease is around 3% and will be a major challenge to offset with new production, given the sheer production dominance of the giant fields.*

Table 2. *Characteristic parameters of the Chinese giant fields. The decline rate is given for the best fit of the exponential or hyperbolic decline curves.*

Field names	URR [Gb]	Peak year	Decline rate [%]	Cum. prod by 2050 [Gb]
Post-peak giants				
Daqing	24.1	1999	3.2	21.3
Huabei	2.2	1979	8.9	2.2
Liaohe	5.0	1995	2.1	5.1
Shengli	15.8	1992	2.0	12.5
Zhongyuan	1.3	1988	7.6	1.5
Pre-peak giants			*Assumed decline*	
Changqing	2.2	2010	8.3	2.1
Dagang	1.5	2009	8.7	1.6
Tarim	1.1	2009	8.3	1.1
Xinjiang	5.5	2020	3.4	5.1

3.5 Other fields

China also has a number of smaller oil fields and petroleum provinces. In total, these account for around 1 Mb/d or 30% of the domestic production capacity. Most of them are located on land, even though there are some offshore fields in the Bohai Bay and other coastal areas around China. Many of these fields are very small, but some of them produce significant amounts of oil (Figure 13). Even among these fields, the dominance of a just a few fields can be seen. Jilin can be classified as giant, but due to poor data we have chosen to exclude it from the giant group and keep them among the other fields.

With better data and a more detailed study of each field, we suspect that many of the non-giants fields are also near the onset of decline or show to have significant challenges associated with production increases, due to maturity or limited remaining undeveloped reserves. Needless to say, none of these other fields can realistically increase their future production to offset the decline in the giant fields. The number of smaller fields needed to just offset a single giant is huge (See [11] for illustration of this) and we do not foresee how China can maintain its domestic oil production without bringing new giants on stream.

The number of additional new fields required to offset the expected decline from the giants (Figure 13) would be enormous and not achievable in any realistic case as we see it. The solution to the problem imposed by the declining giants cannot be found in other domestic fields.

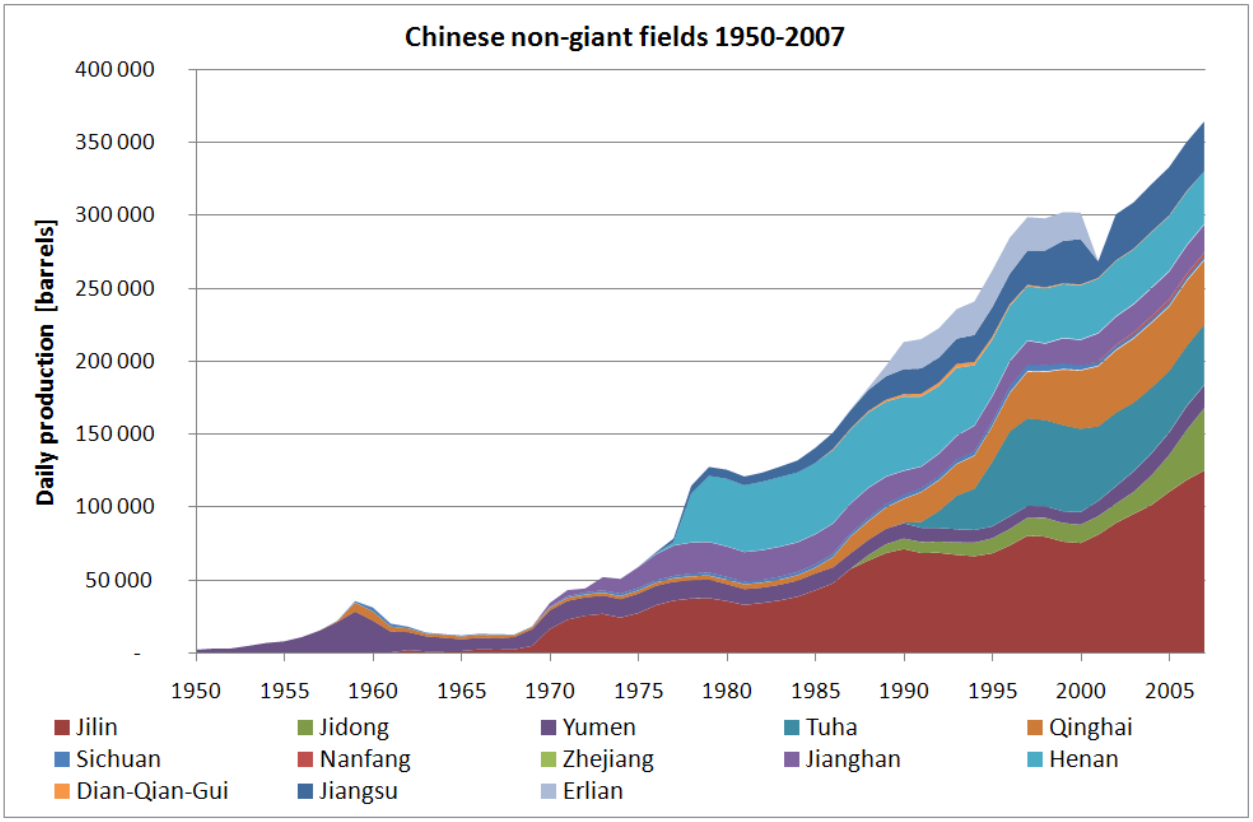

Figure 14: *Historical production of some Chinese non-giant fields.*

4. Implications for future Chinese oil supply

Based on our study of the giant fields, we conclude that future domestic oil production in China faces a significant challenge. The enormous dependence on giants for domestic production (Figure 1), as well as the magnitude of a giant compared to a smaller field, will make it very problematic to offset the decreasing production in the giant fields with new domestic sources. There seems to be limited opportunities of uncovering additional new giants in mainland China [27], and this will make it even harder to compensate for the declining giants.

It appears likely that the giant fields will remain the largest and most dominant part of the domestic oil production in China; however, it is questionable whether other petroleum sources can offset the declining giants. If not, the peak of Chinese oil production will arrive around 2010 with some uncertainty related to the peaking of the pre-peak giants. For this reason, our general expectation of the future production trajectory is largely similar to that of Campbell and Heapes [67], even though they are using a widely different forecasting methodology not based on a bottom-up approach from field level.

The reserve-to-production rate, i.e. the inverse of the depletion rate of remaining reserves, is low for China [68], indicating a rapid depletion of China’s oil reserves. Given the strong correlation between depletion rate and decline [9], it is necessary to ask whether this rapid depletion is desirable as it leads to rapid decline.

The expected decrease in production from the giants is significant (Figure 12), and will inherently alter picture of future Chinese oil supply. Over the next decade and into the foreseeable future, a major shortfall of domestic oil production will occur, caused primarily by the maturing and declining giants. This predicament calls for wisdom in both planning and policymaking, along with responsible countermeasures in order to ensure continued growth and well-being of China and its people.

Additional discussions on peak oil in China have been provided by Pang et al. [68] and Feng et al. [69]. It is important to remember that peak oil do not mean the end of growth and development, rather it is a development theory that dictates that the growth of any finite resource cannot be sustained indefinitely [70]. Continued petroleum-driven growth will naturally not last longer than the availability of petroleum. Therefore, responsible planning and proper handling of the energy issue are essential for ensuring continued Chinese development.

4.1 Possible countermeasures

Pang [71] proposed four possible countermeasures that could be utilized to take the edge off the problems caused by peaking giants and the coming production peak in domestic oil production. Similar countermeasures and methods for tackling energy security challenges have also been proposed by Hughes [72].

First, continued exploration and development of domestic oil fields are essential for maintaining production and to dampen the decline of the giant fields in the future. Dreams of continued increase in domestic oil production are seemingly unfounded in the longer perspective, even though a few years of slight increase or maintained production levels can be expected to occur. Managing decline and alleviating the reduced output of the Chinese giant fields as much as possible must be an integral part of any reasonable plan for Chinese oil supply. These types of countermeasures include additional exploration, improved recovery as well as utilizing new technologies and unconventional oil formations. The importance of technology is also mentioned briefly by Feng et al. [69].

Secondly, it was proposed that alternative energy sources or replacements should be developed. These include synthetic liquid fuels, wind turbines, nuclear energy, electric vehicles and other measures of similar type. China is already forcefully pursuing new energy sources, but the present plans might have to be revised in the light of changed situations and peak oil. For example, the immense tonnage of coal required for coal liquefaction makes it questionable whether coal-derived synthetic fuels can be a viable alternative for providing the necessary volumes of liquid fuels [73]. Alternative energy pursuits should also be undertaken to reduce the environmental impact, which is an important goal in itself apart from improving the Chinese energy security.

Thirdly, increased oil import and strategic alliances with future suppliers is a reasonable mitigation method too. Oil import requires that someone is able to export. Therefore, the potential countries that can supply China in the future will become quite limited. Selecting suitable suppliers and engaging in reasonable long-term cooperation and contracts can prove to be an imperative way of ensuring access to the necessary oil imports in a future world where oil becomes increasingly scarce and the number of oil exporters diminishes. Feng et al. [69] also points to the importance of forging new relationships.

Lastly, energy consumption and demand reductions were identified as a possible countermeasure with significant energy saving potential. Improvement of energy efficiency in the heavy industry as well as other sectors is targeted in the 11^{th} five-year plan, spanning from 2006-2010, but future plans should pursue energy efficiency even more forcefully given the huge potential for energy consumption reductions. Rebound effects must also be considered and properly handled. This category also includes lifestyle changes and the need to adopt a more sustainable existence than a Western consumption-based way of life.

5. Conclusions

The Chinese petroleum industry has managed to keep many of their giants on a production plateau for many decades. The achievements in Daqing are impressive, resulting in stable and sustained production over many decades. However, nothing can change the eventual onset of decline in oil fields and many of the Chinese giants have already passed their peak production levels (Figures 2, 3, 4, 5, and 6). In addition, the other giants seem to be near their maximum production levels and about to enter the decline phase in the foreseeable time. The result is that a considerable drop in the oil production from the Chinese giants can be expected over the next decades (Figure 12).

There is also a possibility that our projection is optimistic, as prolonged plateau phases and utilization of secondary/tertiary recovery methods have been shown to come at the expense of a steeper future decline [9-10, 66]. Whether the production collapses or deviates significantly from the historical trend in Daqing and other field remains to be seen, but should it do so, the consequences would be dramatic. In essence, this can be seen as a policy question and whether a prolonged plateau with a rapid decline is preferable compared to a shorter plateau with a gentler decline.

There is an increasing demand for oil in China with the continuous and steady growth of its economy, in the latest decade the average economic growth rate is 9.5% and oil consumption growth rate is 6.5%. However, the average oil production growth rate was only 1.5% during the latest decade. For Chinese policymakers, it is worth paying attention to the problem of whether oil production in new oilfields or small oilfields can effectively make up for the decline in oil production of the giant oilfields. With more and more Chinese giant oil fields passing their peak of production, the conflict between demand and production will become more apparent. With stagnant or decreasing domestic production and increasing demand, the call on imported crude would be significant. Continued reliance on oil will force China into greater import dependence, and even more rapidly once domestic oil production begins to falter. Rising trends for imported crude oil and oil products should be a warning sign for policy makers that want to avoid becoming too dependent on foreign oil supplies.

Finally, it is welcome news that China's National Energy Administration issued its "*Development plan of New Energy Industry*" in 2009. The plan calls for an investment of more than three trillion Yuan in new energy industries between 2009 and 2020. China should lessen the dependence on conventional fossil energy, although it is difficult. Long-term energy supply and energy security must ultimately be sought from other non-fossil energy sources and in new, more efficient ways of utilizing the energy [70].

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