Energy 113 (2016) 586–596

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

An oil production forecast for China considering economic limits

Ke Wang [a], Lianyong Feng [a], Jianliang Wang [a], Yi Xiong [a], Gail E. Tverberg [b, *]

[a] School of Business Administration, China University of Petroleum, Beijing, China
[b] Our Finite World, 1246 Shiloh Trail East NW, Kennesaw, GA 30144, USA

ARTICLE INFO

Article history:
Received 5 December 2015
Received in revised form
21 March 2016
Accepted 10 July 2016

Keywords:
Conventional oil
Unconventional oil
Production forecast
Peak oil
Low oil price

ABSTRACT

In recent years, it has become apparent that oil prices may not rise endlessly. Unconventional oil is likely to be especially affected by low prices because it tends to be high-priced to extract. To estimate the impact prices might have on future Chinese oil production, we develop a model in which only future unconventional oil production is affected by price. We analyze three price scenarios: Stays Low, Best Estimate, and Ever-Rising Prices. In these scenarios, remaining Ultimate Recoverable Resources (URR) are estimated to be 10%, 50%, and 90% of remaining Technically Recoverable Resources, respectively. Since oil price can be expected to affect the shape of the extraction curve, we spread estimated URR to year using models that do not assume that future production will ultimately produce a symmetric Hubbert-type curve (Multi-Cycle Generalized Weng Model and Stochastic Resource-Constrained Growth Model). In the Best Estimate Scenario, China's oil production is expected to reach a maximum of 226.79 million tons in 2020. In the Ever-Rising Prices Scenario, China's maximum oil production occurs in 2023. In the Stays Low Scenario, maximum production has already been reached.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

China is the world's largest oil consumer and the world's fourth largest oil producer [1]. One issue that has arisen, especially since mid-2014, is the issue of low prices and their potential impact on China's future production. The goal of this paper is to provide a range of estimates of future oil production under selected price scenarios, to better understand the impact that low oil prices might have on future production. We also discuss some reasons why oil prices should not be expected to continue to rise endlessly.

In order to accomplish this, we analyze conventional and unconventional oil separately, since unconventional oil tends to be high-priced to extract, and thus is likely to be affected by low oil prices to a greater extent than conventional oil. Furthermore, conventional oil tends to be extracted first because it is cheapest and easiest to extract. As a result, the oil resources that remain contain a disproportionate share of unconventional oil.

A number of other researchers have developed estimates of China's future oil production [2–4]. None has considered the conventional/unconventional split and the impact of price on these estimates.

2. Oil prices and expected quantity extracted

2.1. How economic limits affect oil extraction

Often estimates of future oil production are based on estimates of technically recoverable resources (TRR), given today's technology. In some cases, particularly climate analyses, estimates are based on Oil in Place (OIP), assuming that technology will gradually improve, allowing an increasing proportion of the OIP to be extracted.

There is an economic question that needs to be considered as well. Often, the assumption is made that oil prices will keep rising, allowing all of the oil to be extracted that technology permits. We know that the cost of producing oil will keep rising because we extract the cheapest to produce oil first, leaving the more expensive-to-produce oil for later. The question, which many have never considered, is, “Will the p rice which the marketplace offers for oil continue to rise as quickly as the cost of producing oil? Or will the price of oil lag behind, and production be cut off as a result of the lagging price?”

The IEA in its Figure 1.4 of World Energy Outlook 2015 (WEO 2015) assumes that oil prices can rise to $300 per barrel by 2100 [5]. Even this price may not act to extract all TRR, since some oil may be in very small deposits or ones that are very deep and away from needed resources. Some TRR is located under cities, necessitating

* Corresponding author.
E-mail address: GailTverberg@comcast.net (G.E. Tverberg).

http://dx.doi.org/10.1016/j.energy.2016.07.051
0360-5442/© 2016 Elsevier Ltd. All rights reserved.

moving large numbers of people to access the resource. Such a move would be very expensive, quite possibly more than $300 per barrel. Fresh water is often needed for extraction, but is not available locally. In theory, it could be trucked long distances, or it could be obtained by desalinating seawater and installing pipelines so that this desalinated water could be pumped uphill to where it is needed. While technically feasible, the cost is likely to be prohibitive.

The world recently has struggled for roughly 24 months with low oil prices. A similar problem happened in the second half of 2008 and in 2009. We can no longer simply assume that prices will rise with rising cost of extraction. If nothing else, if oil prices rise to $300 per barrel or higher, substitutes such as coal to liquids will become competitive, and thus can be expected to hold oil prices down.

Physicist François Roddier has given a thermodynamic explanation of the difficulty we are encountering. Roddier describes all of human society as a dissipative structure that self-organizes to maximize its use of energy [6,7]. With this understanding of the role of energy (not just oil), the growing use of energy is essential to the growth of the economy; a reduction in the growth in energy consumption can be expected to lead to slowing economic growth. This view is supported by the fact that there is a high correlation between world Gross Domestic Product (GDP) and world energy consumption since 1975, as illustrated in Fig. 1. In fact, there seems to be a strong relationship between energy consumption and economic growth, going back as far as 1820 (Fig. 2). The fact that GDP is growing more rapidly than the use of energy on Fig. 2 would suggest that other factors, such as improved technology and energy efficiency, may also be contributing to GDP growth.

The rising cost of producing energy products (including oil) is a sign that diminishing returns are affecting the system. Companies that had previously extracted conventional oil at relatively low cost are forced to move on to higher-cost unconventional oil. As production costs rise more quickly than the inflation rate, more resources are transferred into the energy-production sector of the economy, and away from the production of other goods and services. If this pattern continues, the growth of the economy can be expected to slow. With slowing economic growth, demand for energy products, including oil, seems likely to fall. Instead of ever-rising prices, we may encounter recession and low or falling oil prices, such as we have been seeing recently. These low prices may eventually lead to the end of oil production.

2.2. Selection of oil price scenarios

Clearly, different observers have different ideas regarding how oil prices may change in the future. We have chosen to look at three different oil price scenarios. In our Best Estimate Scenario, we assume that approximately 50% of remaining TRR[1] for unconventional oil will ultimately be recoverable. The way we might expect this to happen is if future oil prices are somewhat in the range of IEA's "Low Price Scenario" and "450 Scenario" in IEA's WEO 2015 [5], as shown on Fig. 3. In this scenario, a typical price between now and 2100 might be in the $100 to $125 per barrel range.

Our second scenario is called the "Ever-Rising Prices Scenario." In this scenario, we expect that 90% of remaining TRR for oil will be recovered. This scenario is expected to be in the range of IEA's "Current Policies Scenario" shown on Fig. 3. In this scenario, prices will keep rising as needed to keep up with higher extraction costs. Thus, prices may rise as high as $270 or $300 per barrel by 2100. Over time the view of TRR may rise, because high prices encourage the development of new resources and new techniques.

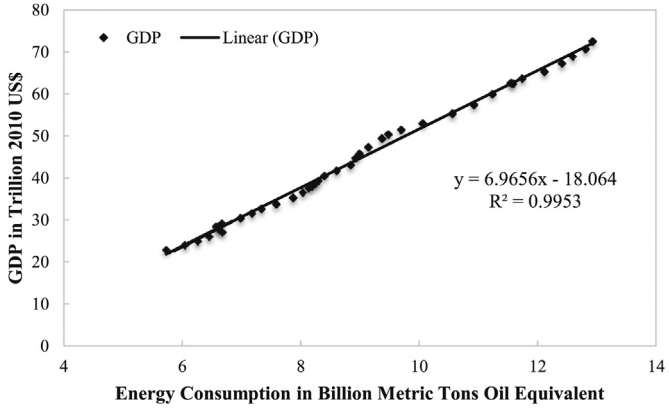

Fig. 1. World GDP compared to Energy Consumption 1975 to 2014. Data sources: [1,8].

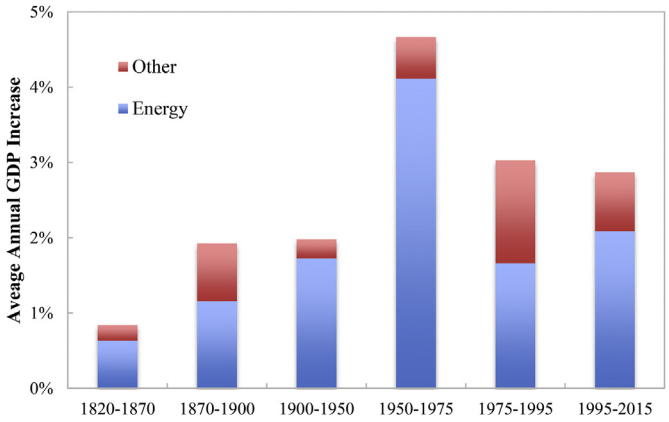

Fig. 2. Average GDP growth rate, divided between increases in energy consumption and other influences, such as technology and efficiency improvements. Data sources: [1,8–10].

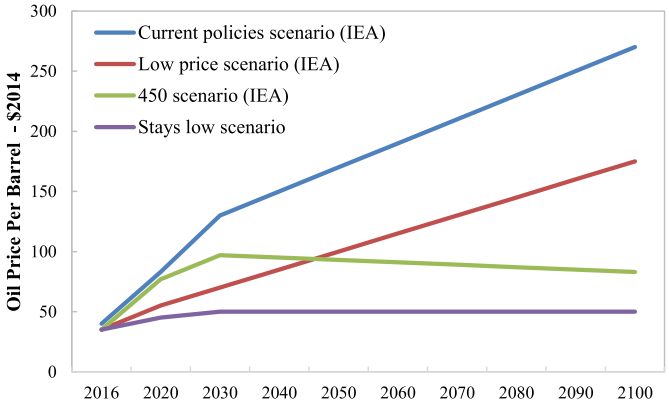

Fig. 3. Oil price scenarios of interest. The first three scenarios listed are based on scenarios from IEA WEO 2015 [5]. Values for dates through 2040 are as given by IEA. Values after 2040 are estimated assuming that prices will follow the same linear change pattern after 2040 as IEA indicates will occur between 2030 and 2040. The Stays Low Scenario is a creation of the authors. It assumes that oil prices will remain at or below $50 per barrel indefinitely.

[1] Definitions to TRR diverge among different agencies. In order to make it clear in this paper, we use "TRR" to indicate total amount of technically recoverable resources that exist underground before the production starts, while we use "remaining TRR" to indicate resources yet to be extracted technically. The same explanation applies to "URR" and "remaining URR" used in this paper.

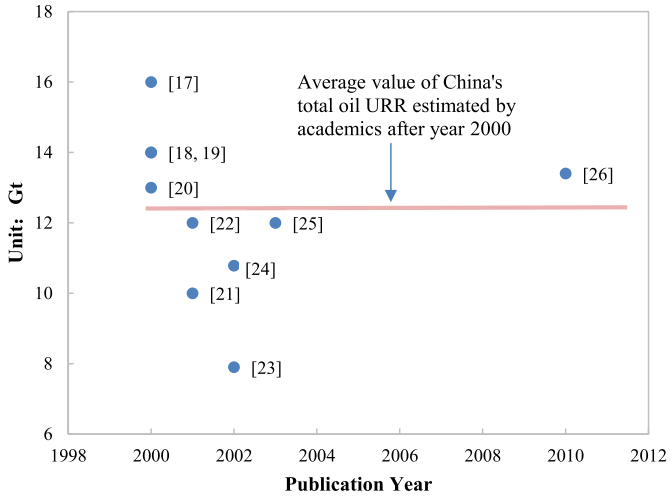

Fig. 4. Summary of research results regarding China's total oil URR (conventional + unconventional) Note: Numbers beside the blue points reflect references to published reports [17–26]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In our third scenario, "Stays Low Scenario," we expect that 10% of remaining TRR will be extracted. Prices are expected to remain at or below $50 per barrel, indefinitely.

We apply the selected relativities of remaining URR to remaining TRR for unconventional oil production only. Conventional oil production is forecast without adjustment, since its cost of production is much lower, and thus less likely to be affected by low prices.

Most of our calculations and exhibits are on a Best Estimate basis. We discuss the indications of the Stays Low Scenario and the Ever-Rising Prices Scenario in Section 5.3 and show expected future extraction amounts on Fig. 12.

3. Resources and production

3.1. URR of China's oil

Ultimate Recoverable Resources (URR) is an estimate of the total resources that will ever be produced. This amount tends to change over time, depending on technology available and economic conditions, particularly oil price [1,11]. In general, the higher the price, the more advanced the technology that can be profitably used and the larger the amount of oil that can be profitably extracted. The selection of URR is very important to the peak production forecast, since its selection affects the amount distributed to year by modeling techniques.

For conventional oil, we estimate URR based on the work of others, because low oil prices are expected not to have a material impact on these amounts. For unconventional oil, we estimate remaining URR as a percentage of remaining TRR. These ratios vary by scenario: Best Estimate, 50%; Ever-Rising Prices, 90%; and Stays Low, 10%.

3.1.1. URR of China's conventional oil

There are two difficulties in dealing with published information regarding expected URR of China's conventional resources: (a) Often, estimates are for a combination of conventional and unconventional resources, and (b) estimates by China's official agencies tend to be high compared to those from other sources.

As an example, the following are URR estimates by China's official agencies. The "New Round Evaluation of Domestic Oil and Gas Resources," published by China's Ministry of Land and Resources (CMLR) in 2005, shows China's conventional oil URR as 21.2 billion tons [12]; the number was raised to 23.3 billion tons in the "Dynamic evaluation of oil and gas resources in China" published in 2010 [13]. It was again raised in the "Dynamic evaluation of oil and gas resources in China" published in 2015, this time to 26.8 billion tons [14].

There are several reasons for an optimistic bias in these

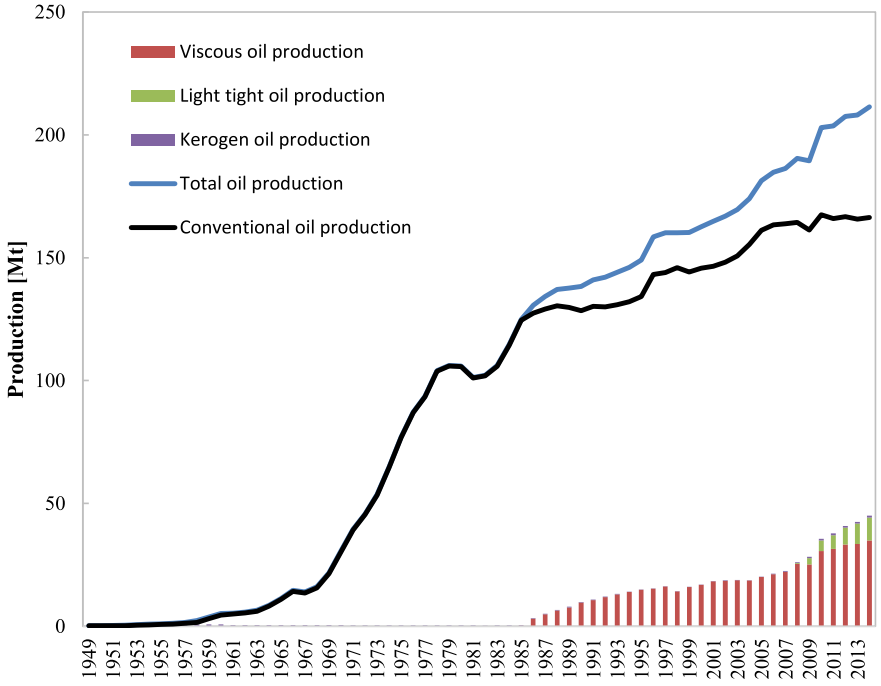

Fig. 5. China's historical oil production by type of oil. Note: unconventional oil shown in stacked bar chart at bottom.

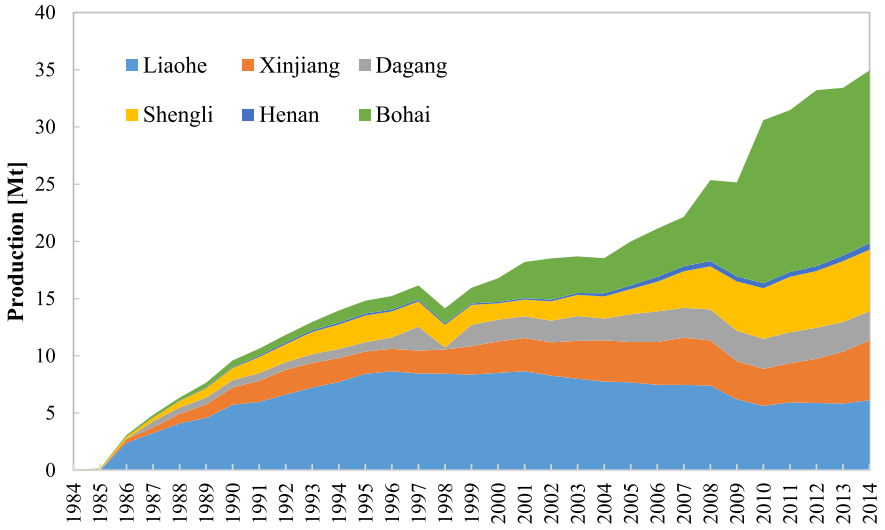

Fig. 6. Historical production of China's viscous oil.

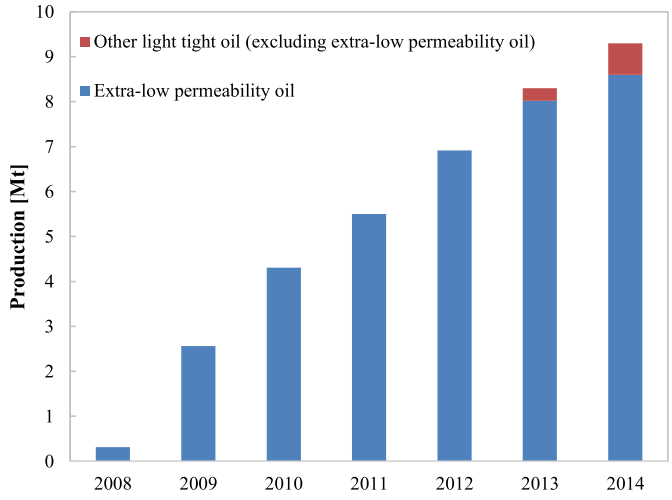

Fig. 7. Historical production of China's light tight oil (separated between extra-low permeability oil and other).

estimates. One reason is confusion between conventional and unconventional oil; the officially published conventional oil URR, if calculated in accordance with international standards, includes some unconventional oil [15]. Also, official estimates consider only technological limitations, but ignore the possibility that prices cannot rise high enough to enable extraction. A third issue is possible over-optimism in estimating future technology advancements. Finally, a high bias may be creeping in, if field production managers who need to meet production targets are making some of the estimates [16]. For these reasons, we expect that China's true conventional oil URR will be smaller than the amounts published in official reports.

URR estimates from academia (which are also on a combined conventional/unconventional basis) average only about half as much as estimates from the official agency. The dispersion of these estimates can be observed on Fig. 4. The average academic URR estimate made in years 2000–2015 is 12.31 billion tons.

Among the many academic researchers, only Mohr et al. [27] provide URR estimates of China's conventional oil and unconventional oil separately. According to Mohr et al., China's conventional

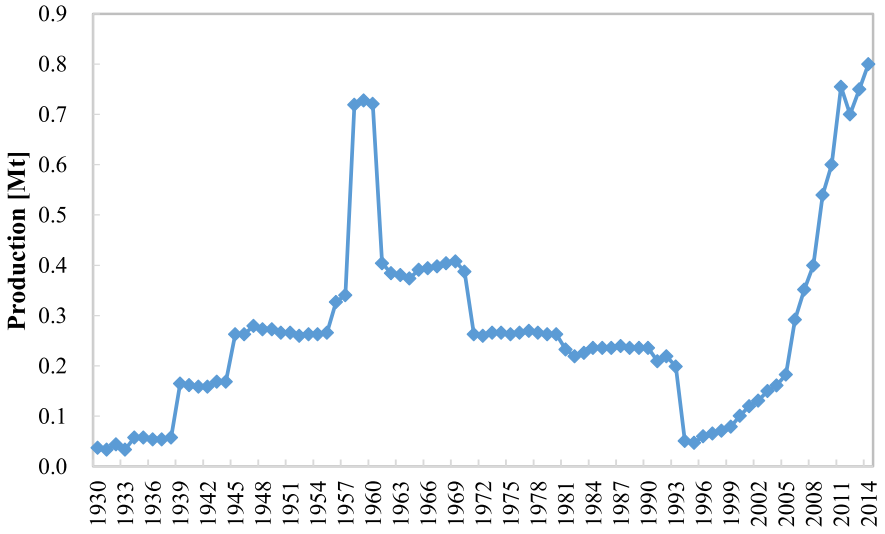

Fig. 8. Historical production of China's kerogen oil.

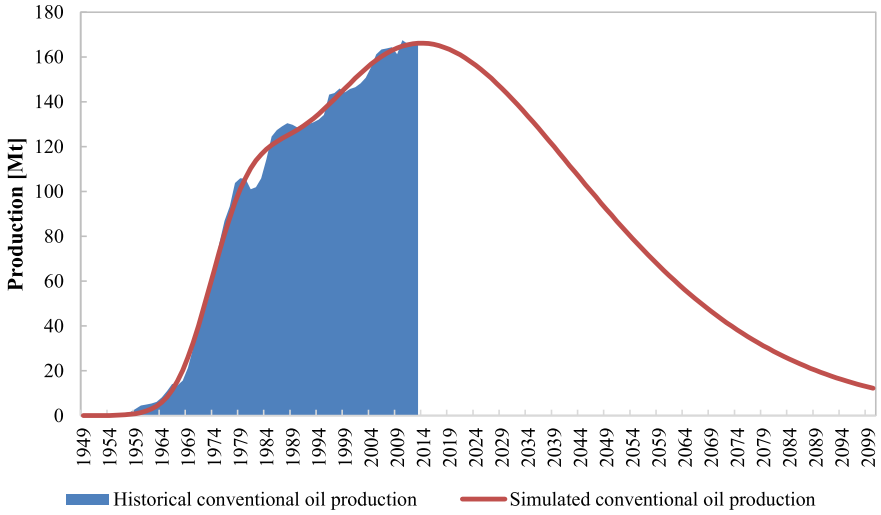

Fig. 9. Forecast of China's conventional oil production.

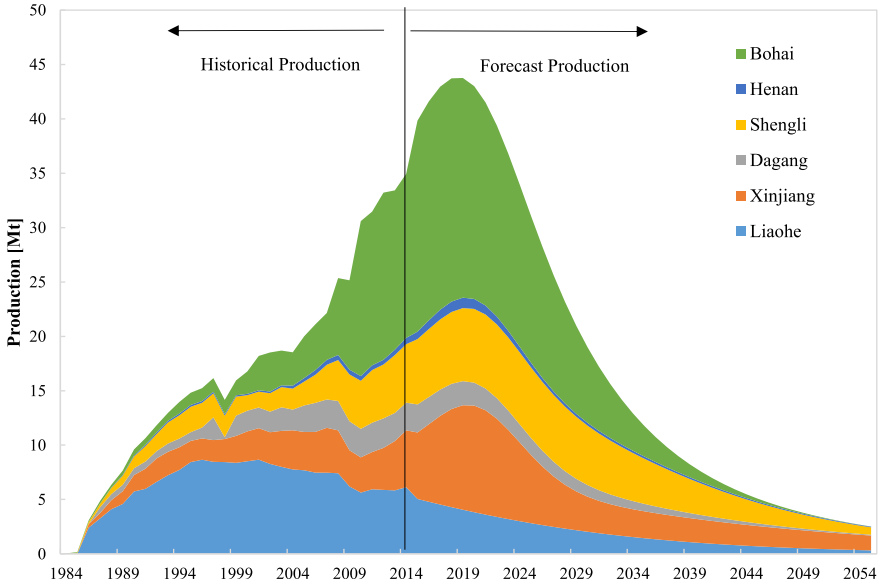

Fig. 10. Best Estimate forecast of China's viscous oil production.

oil URR is 12.80 billion tons under the “Low Scenario” and 14.37 billion tons under the “Best Guess Scenario.”

In this paper, we have chosen an estimate of 12.80 billion tons as our URR estimate for conventional oil. Arguably, this estimate is a high estimate, since the average estimate of all academic researchers is only 12.31 billion tons for the sum of conventional and unconventional oil. This selection is equal to Mohr's “Low Scenario” estimate for China's conventional oil.

3.1.2. URR of China's unconventional oil

The four types of unconventional oil we have chosen to analyze are viscous oil, light tight oil, kerogen oil, and oil sands. Our choice of categories is very similar to those of the International Energy Agency (IEA) in its “World Energy Outlook 2012”: extra-heavy oil, light tight oil, kerogen oil, and oil sands [28]. The major difference in our choice of categories is the use of “viscous oil,” instead of extra-heavy oil, because this term has traditionally been used in China to characterize heavy and extra-heavy oil. The use of the term viscous oil may result in our definition including some oil that would be characterized as “heavy oil” elsewhere. This does not appear to be a major issue; other scholars have used a similar approach [29,30].

We use a combination of two techniques to estimate the URR for viscous oil, as shown in Table 1. One of these techniques is based on the sum of production to date and 50% of the remaining TRR estimated by international and domestic researchers [31–36], because this analysis is being used in determining the Best Estimate level of production. The other technique, Hubbert Linearization (HL), is a curve fitting approach that is widely used when a long history of historical production is available [37,38]. Recent patterns are based on periods when oil prices were typically in our Best Estimate Range, rather than at the other two price extremes.

Our Best Estimate total URR for China's major six viscous oilfields, considering the indications of two methods and the relative maturity of each field's extraction, is 1.724 million tons (Table 1).

In China, the term “light tight oil” has become widely used only very recently [39,40]. It is used to describe extra-low permeability oil, similar to the oil extracted from the US Bakken oil formation.

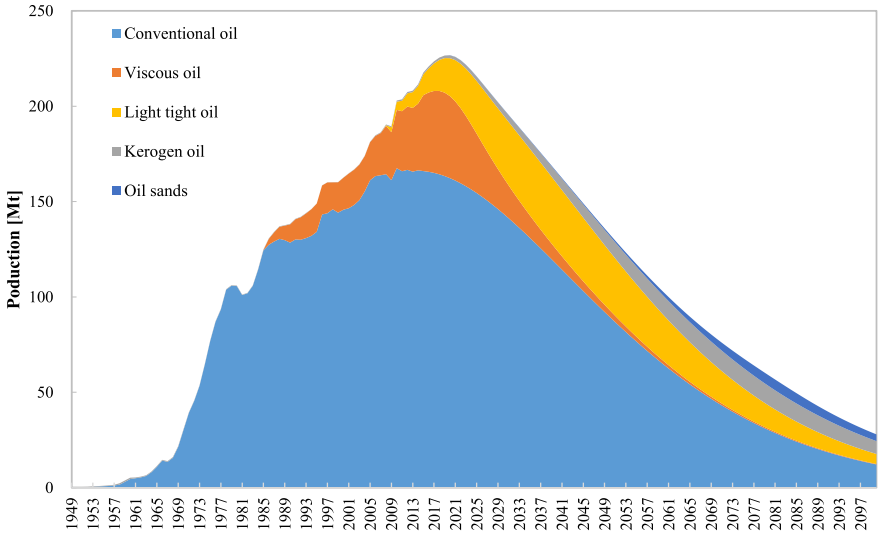

Fig. 11. Forecast of China's total oil production under Best Estimate Scenario. Note: production amounts for 2014 and prior are historical data; production amounts after 2014 are simulated data.

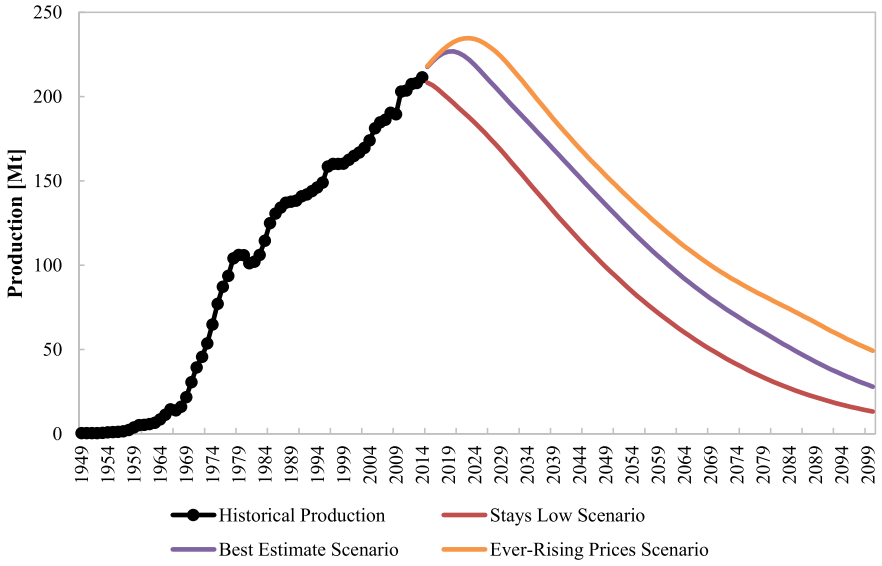

Fig. 12. Sensitivity analysis of China's oil production forecasts to different price scenarios.

Table 1
URR of China's major viscous oilfields (billion tons).

Field	Liaohe	Xinjiang	Dagang	Shengli	Henan	Bohai	Total
TRR × 50%	0.425	0.429	0.137	0.256	0.020	0.459	1.724
TRR source	[31]	[32]	[33]	[34]	[35]	[36]	
HL	0.242	0.120	0.077	0.223	0.020	0.312	0.994
% Weight to HL	80%	50%	50%	50%	50%	30%	
Selected URR	0.278	0.275	0.107	0.240	0.020	0.415	1.334

While there are slight differences in similar groupings used historically in China, these are not expected to materially impact our analysis [41–43].

Several estimates of light tight oil resources are available. Our review of indications from Chinese scholars shows a TRR range of 4.3–10 billion tons, averaging 7.15 billion tons [42,44–46]. An analysis by the German Federal Institute for Geosciences and Natural Resources shows TRR to be 0.427 billion tons [47]. McGlade's 2012 review of estimates by other authors shows a TRR range of 0.273–8.458 billion tons, with an average value of 3.82 billion tons [48]; according to EIA/ARI [49] and IEA WEO2013 [50], TRR is 4.393 billion tons. We have selected a Best Estimate URR of 1.974 billion tons, which is 50% of the average of these amounts.[2]

There are also several estimates of China's kerogen oil resources. The first authoritative estimate was issued in a 2006 report by Chinese authority CMLR, indicating discovered TRR of China's kerogen oil of 1.46 billion tons [51]. The German Federal Institute for Geosciences and Natural Resources (BGR) [47] indicates TRR of 0.639 billion tons. The World Energy Council (WEC) [52] indicates proved resources of 1.344 billion tons. We assume proved resources reflect financial considerations so are equivalent to URR. This paper

[2] Since production to date of China's light tight oil, kerogen oil and oil sands are very tiny (or non-existent) compared with their remaining resource amount, we regard their TRRs/URRs as equal to their remaining TRRs/URRs.

uses the average of 50% of CMLR published discovered TRR, 50% of BGR published TRR, and 100% of WEC published proven resources, or 0.798 billion tons, as the Best Estimate URR of China's kerogen oil.

There is a wide range of estimates available for China's oil sands resources. CMLR's official estimate in a 2006 report is 2.26 billion tons [53]. Geologist Chengzao Jia[3] has noted that China's oil sands resources are of poor quality, low continuity and are quite difficult to extract [54]. The German authority BGR [55] estimates TRR to be only 25 million tons, while Mohr and Evans [56] estimate the URR to be only 4 million tons. In this paper, we choose the average of 50% of the official published TRR, 50% of BGR published TRR, and 100% of Mohr's published URR, or 0.382 billion tons as the URR of China's oil sands.

Table 2 summarizes our selected Best Estimate URRs for the four types of unconventional oil.

3.2. China's historical oil production

3.2.1. Historical production of China's unconventional oil

Historically, China's largest source of unconventional oil production has come from viscous oil, shown in Fig. 6. China's viscous oil is mainly located in six oilfields: Liaohe, Xinjiang, Dagang, Shengli, Henan and Bohai [57].

China's second-largest source of unconventional oil is light tight oil, shown in Fig. 7. According to published reports of CNPC, China's extra-low permeability oil production comes mainly from Changqing Oilfield; large-scale production began in the year 2008 and increased to over 8 million tons in 2013 [58]. China also has a very small amount of other light tight oil that is in a pilot stage of development, based on prior research [59] and discussions with the person[4] in charge at CNPC. Only two years of data are available for it.

China's kerogen oil extraction has been in operation since 1930, but the scale of production is very small (Fig. 8). Its production follows a multi-cyclical pattern, with one growth cycle from 1930 to 1959, followed by declining production from 1959 to 1994. Another period of growth began after 1994 [29].

To date, there has been no oil sands production.

3.2.2. Historical production of China's conventional oil

An estimate of China's conventional oil is obtained by subtracting estimated unconventional oil production from total oil production, as illustrated in Fig. 5. China's unconventional production began growing significantly in 1984, and reached 45.04 million tons in 2014. China's total oil production in 2014 was 211.43 million tons, implying that conventional oil production amounted to 166.39 million tons, or 78.7% of China's total oil production.

Since 1984, China's conventional oil has grown by an average of 1.26% per year. With the inclusion of unconventional oil, its total oil production has grown by an average of 2.06% per year during the same period.

4. Selected forecasting methods

4.1. Multi-Cycle Generalized Weng Model

Many methods are available for forecasting the year-by-year production of estimated URR, including the Generalized Weng model [60], the Hubbert Model [61], the HCZ Model [62] and the System Dynamics Model [63]. None of these models handles the possibility that oil production will have more than one cycle (peak and decline), a situation that is becoming increasingly common for oil fields. In addition, the widely used Hubbert Model and its variants are rooted in the questionable simplifying assumption that production of oil fields should be in symmetrical patterns. If the reason for reduced consumption is lower oil prices, this assumption is especially questionable.

Based on the above considerations, we chose to use the Multi-Cycle Generalized Weng Model, developed by Feng et al. for the types of oil for which historical production data for at least a few years is available (that is, conventional oil, viscous oil, light tight oil, and kerogen oil). Such a model can handle the possibility that oil production would display multiple production cycles [64] and can show asymmetric and flatter peak production (the longer peak plateau), which are common characteristics for China's oil fields [65]. This model was shown by Wang et al. to provide a suitable method for simulating the production of China's fossil fuels [65], and has been used to forecast China's conventional gas production [66].

The Single-cycle Generalized Weng Model can be represented by the equations below:

$$Q = at^{b}e^{-\frac{t}{c}} \tag{1}$$

$$N_R = ac^{b+1}\Gamma(b+1) \tag{2}$$

$$Q_{max} = a\left(\frac{bc}{2.718}\right)^{b} \tag{3}$$

$$t_m = bc \tag{4}$$

In these equations, Q stands for the annual production; Q_{max} stands for the peak production; N_R stands for the ultimate recoverable resource; t stands for the time of development; t_m stands for the peak year; a, b, c are all constants in the forecast model; $\Gamma(b+1)$ stands for the Gamma Function, where $\Gamma(b+1) = b!$ if b is a positive integer.

To handle the multi-peak situation, Feng et al. developed a modification of the Generalized Weng Model that adds together the production of several forecasting cycles [64]. The basic equation for this model is the following:

$$Q = \sum_{i=1}^{k} Q_i = \sum_{i=1}^{k} \left[Q_{max}\left(\frac{et}{t_m}\right)^{b} e^{-\left(\frac{bt}{t_m}\right)} \right]_i \tag{5}$$

A more comprehensive description of the Multi-cycle Generalized Weng Model can be found in Feng et al. [64] or Wang et al. [65].

4.2. Stochastic Resource-Constrained Growth Model

For the oil sands, no historical data exists. To model future production, we have chosen to use the Stochastic Resource-Constrained Growth Model, developed by Ward et al. [67]. This method was developed for forecasting production of a resource such as unconventional oil or gas when little historical production data is available.

Table 2
URR of China's unconventional oil used in this paper.

	Viscous oil	Light tight oil	Kerogen oil	Oil sands
URR (billion tons)	1.724	1.974	0.798	0.382

[3] Former General Geologist of China National Petroleum Corporation (CNPC).

[4] Director Kong, Department of Exploration and Development, CNPC (Interview time: 2015/05/16).

This approach involves simulating future production with a family of growth curves starting from a given value of initial production. The group of growth curves is distinguished by different production growth rates. In the simulation, growth rates are assigned randomly within a selected value range, to approximate future production uncertainties.

In this approach, production q(t) is allowed to grow exponentially according to the specified initial growth rate *r*, but is progressively curtailed as the overall quantity of the extracted resource approaches the recoverable resource quantity URR remaining at time $t = 0$. The model is given by:

$$q(t) = q_0 e^{krt}(1 - \frac{Q(t)}{URR}) \quad (6)$$

In this model, Q(t) is the cumulative production at time *t* (and $Q = 0$ when $t = 0$), q(t) is the production rate at $t = 0$, and *k* is an exponent scaling factor. *k* is used to force the model to yield exponential growth conforming to the specified growth rate *r* for at least the duration of the first time step (t_1), and is determined by:

$$k \approx \frac{\ln[(1+r)^{t_1}/(1 - \left(\frac{q_0(1+(1+r)^{t_1})t_1}{2URR}\right))]}{rt_1} \quad (7)$$

A more comprehensive description can be found in Ward et al. [67].

5. Results

5.1. Production forecast for China's conventional oil

Fig. 9 shows expected future conventional oil production, based on the Multi-cycle Generalized Weng Model, together with the selected URR for conventional oil of 12.8 billion tons. As noted previously, China's conventional oil production has already begun declining, with peak production of 167.51 million tons in 2010.

5.2. Production forecast for China's unconventional oil

Based on our model, the largest contributor in the near term to unconventional oil production is viscous oil, with peak production of 43.76 million tons in 2019. Its expected pattern of future extraction is shown in Fig. 10. China's light tight oil is expected to reach peak production of 35.15 million tons in 2037. Based on our model, production of kerogen oil will keep growing in the mid to long term and reach peak production of 10.71 million tons in 2070.

Oil sands production, as noted in Section 4, is forecast using the "Stochastic Resource-Constrained Growth Model." This model requires assumptions with respect to its initial production year, initial production amount, and future production growth rate. Based on expert interviews, this paper assumes the initial production year will be 2020, the initial annual production will be 100 thousand tons, and the growth rate in future production will be in the range of 1%–12%. The upper limit of 12% is chosen based on the average annual growth rate of Canadian oil sands production (1968–2014), since Canadian oil sands resources are of better quality than Chinese oil sands resources. The simulation result shows that the oil sands production will grow gradually and will reach peak production of 5.67 million tons in 2081, without a large impact on China's total oil supply.

Fig. 11 shows modeled expected future oil production, divided among conventional oil and the four kinds of unconventional oil. Based on our analysis, at the Best Estimate level, China's total oil production can be expected to reach a peak in 2020, with peak production of 226.79 million tons. This peak, including unconventional oil, is only 10 years after the peak in conventional oil.

5.3. Oil price sensitivity analysis

All of the estimates provided elsewhere in this report have been based on the assumptions of our Best Estimate Scenario. As a sensitivity analysis, we show two additional scenarios—our Stays Low Scenario, in which oil prices stay at $50 per barrel or less, and our Ever-Rising Prices Scenario, in which oil price will keep increasing as extraction costs increase, perhaps reaching $300 per barrel by 2100. When we make the calculations on this basis, our estimate for future production of conventional oil is unchanged, since we have assumed that it is not affected by very low prices.

Our sensitivity analysis model shows that in the Stays Low Scenario, China's oil production can be expected to reach a maximum value of 211.43 million tons in 2014; in the Ever-Rising Prices Scenario, China's total oil production will peak at 234.63 million tons in 2023. Of course, we also know that actual 2015 production was higher than 2014 production. What the model is telling us is that under the Stays Low Scenario, we can never expect oil production to exceed that of 2015.

6. Discussion

6.1. Impact of disputed conventional/unconventional production

Exactly which oil should be considered conventional, and which should be considered unconventional, is not entirely clear. Our selection of oil to be treated as unconventional leaves out some types of disputed production. If these had been included as unconventional, the proportion of unconventional oil would be even higher.

One type of disputed oil production involves the part of Daqing Oilfield extracted by unconventional methods. In order to keep its annual production above 40 million tons, Daqing Oilfield has been using more advanced Enhanced Oil Recovery (EOR) methods in recent years, because gas drive and water drive EOR methods have become less effective [16]. The primary advanced method used is polymer flooding; at times, it is even using the ASP flooding method. Both polymer flooding and ASP flooding are well known for their high cost and large environmental impact. Because of the high cost and adverse environmental impacts of these EOR techniques, it could be argued that oil produced using these methods should be categorized as unconventional oil. According to Fig. 13, the use of these methods began in 1996, and in 2014, they accounted for over 35% of Daqing's total production.

We noted in Part 3.2.1 that part of the oil produced in Changqing Oilfield is considered as light tight oil. In that analysis, we assumed that only extra-low permeability oil should be considered light tight oil. This cut-off includes only about one-third of the oil from Changqing. If the cut-off were raised to permeability of less than 1 mD [57], which is similar to the permeability of the Bakken, then about 80% of the oil from Changqing would be considered unconventional, based on CNCP information. There is no fixed Chinese standard for distinguishing low permeability oil, very-low permeability oil and extra-low permeability oil, and the reservoir characteristics, accumulation mechanisms, and development methods are all significantly different from conventional oil [15]. Because of these issues, perhaps this oil should also be categorized as unconventional oil.

We noted in Part 3.2.2 that according to the definitions we used, unconventional oil amounted to 45.04 million tons in 2014, out of total oil production of 211.43 million tons. Daqing extraction using advanced EOR methods amounted to 14.06 million tons in 2014,

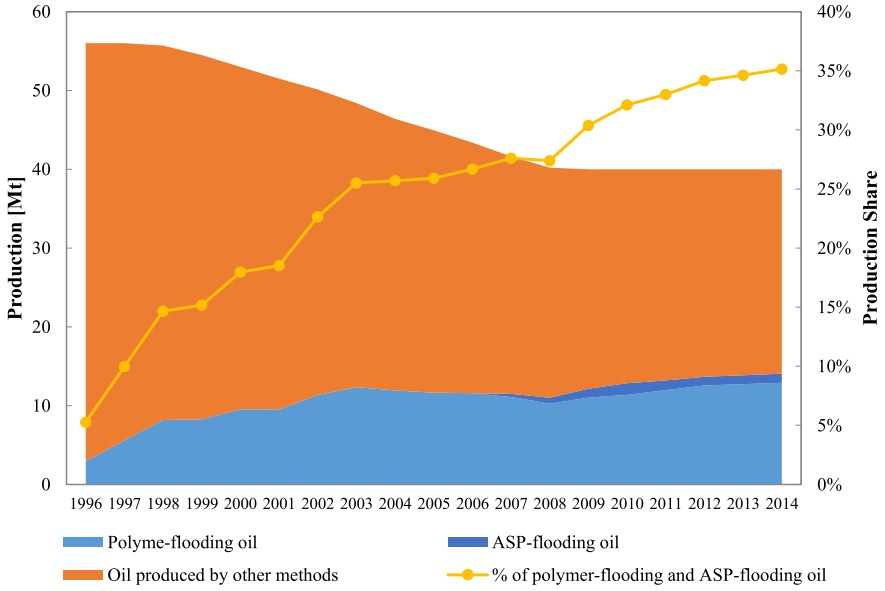

Fig. 13. Oil production of Daqing Oilfield.

and the Changqing extraction that should perhaps be included with unconventional amounted to 10.74 million tons. Thus, if we define unconventional oil more broadly, we increase the amount of unconventional oil extracted in 2014 by about 55%. With this broader definition of unconventional, the peak year of China's conventional oil is brought even earlier, to 2006.

Shifting part of the oil production from conventional to unconventional would also have an impact on expected total future production and the shape of the decline curve. Our Best Estimate analysis without adjustment indicates total production will reach a peak in 2020. With this adjustment, this date is shifted to 2018, because URR is estimated to be equal to 50% of TRR (instead of 100% of TRR) for resources shifted from conventional to unconventional.

Furthermore, for both the Best Estimate and the Stays Low scenarios, the shape of the decline curve after the peak is reached on Fig. 12 is steeper, because remaining TRR is adjusted by relativities of 50% and 10% instead of 100%. There would be virtually no impact on the expected production under the Ever-Rising Prices Scenario, since it uses a relativity of 90%, which is close to the 100% relativity used for conventional.

6.2. Remaining time until decline begins

Under the Best Estimate Scenario, China will reach its peak in oil production in 2020, which is only four years away, and under the Stays Low Scenario, the peak already appears to have taken place. In either case, there is very little time to prepare for it.

Even under the Ever-Rising Prices Scenario, China's oil production, including unconventional, is expected to reach a peak in 2023 and decline thereafter. The basic problem is that conventional oil production is already declining, and unconventional oil production cannot be expected to make up for the decline in conventional oil production.

6.3. Parallels to the rest of the world

The situation that China is reaching is not very different from the situation the world is reaching. Oil production is increasingly from high-priced unconventional sources. If oil prices permanently fall below $50 per barrel, a large share of unconventional oil producers around the world is likely to find that their oil production is too expensive for world markets. They, too, will find further extraction unprofitable, and may choose to reduce production until prices rise again. If prices stay below $50 per barrel, the time for increasing production will never come.

Without the “ballast” of rising unconventional oil production, total world oil production may begin to fall if prices remain under $50 per barrel.

7. Conclusions

If oil price were not an issue at all, the oil information of primary interest would be OIP. Prices could be expected to rise arbitrarily high, and technology would be expected to gradually improve so that eventually nearly all of the OIP could be extracted.

In this analysis, we consider a range of scenarios that are not as extreme as basing our analysis on OIP. Instead, we look at a range of scenarios that are defined as percentages, ranging from 10% to 90% of today's estimate of remaining TRR. Based on this analysis, we find that in the Best Estimate Scenario (50% of remaining TRR), China's oil production is expected to reach a peak in 2020 at 226.79 million tons of oil production. This consists of 71.56% of conventional oil and 28.44% of unconventional oil. Under our Stays Low Scenario (10% of remaining TRR), China's oil production has most likely already reached its peak. Under the Ever-Rising Prices Scenario (90% of remaining TRR), China's total oil production is expected to peak at 234.63 million tons in 2023.

With these forecasts, China can expect that its oil production will begin to decline in the next few years, even if prices do rise to higher levels. Even at the highest price scenario, peak production is expected in 2023. If prices remain below $50 per barrel, we expect China's production will begin declining very soon, likely in 2016.

The world situation is likely somewhat parallel to China's, especially if prices remain under $50 per barrel. It is difficult to extract unconventional oil profitably with prices at such a low level. Unconventional oil is becoming a larger share of total oil supply elsewhere, including United States' oil from shale and Canada's oil sands. If prices stay low, it would not be surprising if world oil production declines, because unconventional oil remains unprofitable.

It might be helpful if researchers determining TRR of oil fields could associate with each analysis the amount that is technically recoverable at various price levels, such as $50, $100, $200, and $300 per barrel. This may be difficult to do in practice, because there are many components of required prices including the cost of capital, likely tax levels, and costs associated with a particular field, such as the cost of moving a city with a large population in order to get to the resource.

The assumption that forecasters nearly everywhere make is that we can always have as large a quantity of resources of each desired type as we want, because prices will rise to an adequate level to enable extraction, or substitutes will be found. If the assumption of ever-rising prices isn't really true, perhaps we need to scale back our view of what will be possible in the future. In fact, perhaps the "Peak Oilers" will prove to be right, after all. The main difference is that the peak in oil production will come through low prices, rather than the high oil prices everyone was expecting.

Acknowledgments

This study has been supported by the Science Foundation of China University of Petroleum, Beijing (No. 2462014YJRC024), Humanities and Social Sciences Fund of China's Ministry of Education (Grant No. 15YJC630121), National Natural Science Foundation of China (Grant No. 71373285; Grant No. 71303258; Grant No. 71503264) and the Major Program of the National Social Science Found of China (Grant No. 13&ZD159).

References

[1] BP. BP Statistical Review of World Energy 2015. June 2015. http://www.bp.com/statisticalreview.
[2] Wang J, Feng L, Mohr S, Tverberg GE, Höök M. China's unconventional oil: A review of its resources and outlook for long-term production,. Energy 2015;82:31–42.
[3] Tao Zaipu, Li Mingyu. System dynamics model of Hubbert peak for China's oil. Energy Policy 2007;35(4):2281–6.
[4] Feng LY, Li JC, Zhao QF, Pang XQ, Tang X. Forecast and analysis of China's oil supply and demand based on the peak oil model. Oil Gas J January 14th, 2008: 43–7.
[5] International Energy Agency (IEA). World Energy Outlook 2015. 2015. http://www.worldenergyoutlook.org/.
[6] Roddier F. Thermodynamique de l'évolution: Un essai de thermo-bio-sociologie. Paris: Editions parole; 2012 [in French)].
[7] Tverberg GE. The physics of energy and the economy. OurFiniteWorld.com; Feb. 8, 2016.
[8] USDA Economic Research Service. Real GDP (2010 Dollars) – Updated 9/18/2015. http://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx.
[9] Smil V. Energy transitions: History, requirements, and prospects, Appendix A. 2010. Santa Barbra, CA.
[10] The Maddison-Project, http://www.ggdc.net/maddison/maddison-project/home.htm, 2013 version.
[11] Mohr SH. Projection of world fossil fuel production with supply and demand inter-actions. Newcastle: The University of Newcastle; 2010 [PhD thesis].
[12] China's Ministry of Land and Resources. Research center for oil and gas resources strategy. New round evaluation of domestic oil and gas resources. Beijing: China Earth Press; 2005 [in Chinese].
[13] China's Ministry of Land and Resources. Research center for oil and gas resources strategy. National petroleum resource assessment 2010. Beijing: China Earth Press; 2010 [in Chinese].
[14] China's Ministry of Land and Resources. Research center for oil and gas resources strategy. National petroleum resource assessment 2013. Beijing: China Earth Press; 2015 [in Chinese].
[15] Zhao JZ. Conception, classification and resource potential of unconventional hydrocarbons. Nat Gas Geosci 2012;23(3):393–406 [in Chinese].
[16] Wang JL, Feng LY, Tverberg GE. Chinese latest long-term oil production planning: is it achievable? Geopolit Energy 2013;35(11–12):12–7.
[17] Zhai GM. China's petroleum industry will keep developing in the 21st century. Oil Forum 2000;4 [in Chinese].
[18] Kang YJ. Analysis to China's oil and gas exploration and resource prospects. Beijing: China Petroleum Society; 2000. p. 66–70 [in Chinese].
[19] Shen P, Zhao WZ, Dou LR. Oil resource prospects and reserve forecast in China in next decade. Acta Petrolei Sinica 2000;21(4):1–6 [in Chinese].
[20] Qiu ZJ, Xu W. Prospects and outlook for China's oil and gas exploration. Pet Explor 2000;5(1):5–8 [in Chinese].
[21] Chen YQ. Forecast of the future potential recoverable resources of China's petroleum. Xinjiang Petrol Geol 2001;1 [in Chinese].
[22] Chen YQ. Forecast of ultimate recoverable resources of China's petroleum. Oil Forum 2001;5 [in Chinese].
[23] Yu QT. Forecast of oil production and recoverable resources for China and America. Xinjiang Petrol Geol 2002;3 [in Chinese].
[24] Gao RQ, Chen YQ, Bi HB. Research on the forecast of China's oil recoverable resource[KW3]. Acta Petrolei Sinica 2002;23(5):44–7 [in Chinese].
[25] Chen YQ. Forecast of China's future oil production and ultimate recoverable reserves. Oil Forum 2003;1 [in Chinese].
[26] Tang X, Zhang BS, Deng HM, Feng LY. Forecast analysis of China's oil production based on system dynamics. Syst Eng Theory Pract 2010;30(2):207–12 [in Chinese].
[27] Mohr SH, Wang J, Ellem G, Ward J, Giurcoc D. Projection of world fossil fuels by country. Fuel 2015;141:120–35.
[28] International Energy Agency (IEA). World Energy Outlook 2012. 2012. http://www.worldenergyoutlook.org/.
[29] Sun ZD, Jia CZ, Li XF. Exploration and development of unconventional oil and gas. Beijing: Petroleum Industry Press; 2011 [in Chinese].
[30] Liu CL, Che CB, Yang HL. Evaluation methods for conventional and unconventional oil and gas resources and their application. Beijing: Geology Publishing House; 2012 [in Chinese].
[31] Zhang FL, Zhao HY. Steam injection development technology for viscous oil in Liaohe oil field [M]. Beijing: Petroleum Industry Press; 2007 [in Chinese].
[32] Baidu Encyclopedia. Sep 8, 2015. http://baike.baidu.com/view/1204810.htm.
[33] Zhou JJ, Wu JS, Guo LP, Liu L, Wu YQ. Cold mining technology for the viscous oil and extra-viscous oil reservoir in Dagang oil field. Petrol Drill Tech 2004;32(2):56–8 [in Chinese].
[34] Tang PZ. Research on enhancing viscous oil development efficiency with petroleum sulfonate. Shandong University; 2007.
[35] Wu GS, Gao XT, Wang JQ, Song JH, Zhang Y, Zhang HH. Development strategy for the viscous oil in Henan oil field. J Jianghan Petrol Inst 2004;26(4):139–41 [in Chinese].
[36] Chen B. Science and technology innovation and practice in Bohai oil field during procedure of increasing oil production to 30 million tons [M]. Beijing: China Petrochemical Press; 2011 [in Chinese].
[37] Mohr SH, Evans GM. Shale gas changes N. American gas production projections. Oil Gas J 2010;108(27):60.
[38] Mohr SH, Evans GM. Combined Generalized Hubbert-Bass model approach to include disruptions when predicting future oil production. Nat Resour 2010;1(01):28.
[39] Jia CZ, Zou CN, Li JZ, Li DH, Zheng M. Standard, categorize, characteristics and resource perspective of China's tight oil. Acta Petrolei Sinica 2012;33(3):343–50 [in Chinese].
[40] Li DP, Luo DQ, Liu YF. Development of low permeability sandstone oilfield. Beijing: Petroleum Industry Press; 1997 [in Chinese].
[41] Zhao JZ, Wu SB, Wu FL. Classification and evaluation standard of low permeability reservoir—take Ordos Basin for example. Lithol Reserv 2007;3 [in Chinese].
[42] Zou CN, Zhu RK, Wu ST, Yang Z, Tao SZ, Yuan XJ, et al. Types, characteristics, genesis and prospects of conventional and unconventional hydrocarbon accumulations: taking tight oil and tight gas in China as an instance. Acta Petrolei Sinica 2012;33(2):173–87 [in Chinese].
[43] USGS. Assessment of undiscovered oil resources in the Devonian-Mississippian Bakken formation. Williston Basin Province, Montana and North Dakota: USGS Fact Sheet; 2008.
[44] Zou CN, Zhang GS, Yang Z, Tao SZ, Hou LH, Zhu RK, et al. Concepts, characteristics, potential and technology of unconventional hydrocarbons: on unconventional petroleum geology. Petrol Explor Dev 2013;40(4):413–28.
[45] Jia CZ, Zheng M, Zhang YF. Unconventional hydrocarbon resources in China and the prospect of exploration and development. Petrol Explor Dev 2012a;39(2):, 139–146.
[46] Zou CN, Yang Z, Cui JW, Zhu RK, Hou LH, Tao SZ, et al. Formation mechanism, geological characteristics and development strategy of nonmarine shale oil in China. Petrol Explor Dev 2013;40(1):15–27.
[47] German Federal Institute for Geosciences and Natural Resources (BGR). Energy resources 2009: reserves, resources, availability-crude oil, natural gas, coal, nuclear fuels, geothermal energy. Hannover: BGR; 2009.
[48] McGlade CE. A review of the uncertainties in estimates of global oil resources. Energy 2012;47(1):262–70.
[49] U.S. Energy Information Administration. Technically recoverable shale oil and shale gas resources: an assessment of 137 shale formations in 41 countries outside the United States. June 2013. Washington, DC.
[50] International Energy Agency (IEA). World Energy Outlook 2013. 2013. http://www.worldenergyoutlook.org/.
[51] China's Ministry of Land and Resources. New round of oil and gas resources assessment report——Evaluation report of domestic oil shale resource. Beijing: China Earth Press; 2006 [in Chinese].
[52] World Energy Council (WEC). World energy resources: 2013 survey. October 2013.
[53] China's Ministry of Land and Resources. New round of oil and gas resources assessment report——Evaluation report of domestic oil sands resource. Beijing: China Earth Press; 2006 [in Chinese].
[54] Jia CZ, Zheng M, Zhang YF. China's unconventional oil and gas resources and

the prospect of their exploration and development. Petrol Explor Dev 2012;2 [in Chinese].
[55] German Federal Institute of Geology and Natural Resources (BGR). Energy study 2012: reserves, resources and availability of Energy resources. Hannover: BGR; 2012.
[56] Mohr SH, Evans GM. Long term prediction of unconventional oil production. Energy Policy 2010;38(1):265–76.
[57] Jin F. Developing and utilization prospect of unconventional oil resources. Petrol Chem 2007;6:48–54 [in Chinese].
[58] China National Petroleum Corporation (CNPC). Changqing met with low permeability. January 22, 2014. http://news.cnpc.com.cn/epaper/sysb/20140122/0091863004.htm.
[59] Yang H, Li SX, Liu XY. Characteristics and resource potential of tight oil and shale oil in Ordos Basin. Acta Petrolei Sinica 2013;1 [in Chinese].
[60] Chen YQ. Derivation of the Weng forecast model and its application. Nat Gas Ind 1996;16(2):22–6 [in Chinese].
[61] Feng LY, Li JC, Pang XQ. China's oil reserve forecast and analysis based on peak oil models. Energy Policy 2008;36(11):4149–53.
[62] Hu JG, Chen YQ, Zhang SZ. New models to forecast production of oil and gas fields. Acta Petrolei Sinica 1995;16(1):79–86 [in Chinese].
[63] Tang X, Zhang B, Höök M, Feng L. Forecast of oil reserves and production in Daqing oilfield of China. Energy 2010;35(7):3097–102.
[64] Feng LY, Wang JL, Zhao L. Construction and application of a multicycle model in the prediction of natural gas production. Nat Gas Ind 2010;30(7):114–6 [in Chinese].
[65] Wang JL, Feng LY, Zhao L, Snowden S, Wang X. A comparison of two typical multi-cyclic models used to forecast the world's conventional oil production. Energy Policy 2011;39(12):7616–21.
[66] Wang JL, Feng LY, Zhao L, Snowden S. China's natural gas: resources, production and its impacts. Energy Policy 2013;55:690–8.
[67] Ward JD, Mohr SH, Myers BR, Nel WP. High estimates of supply constrained emissions scenarios for long-term climate risk assessment. Energy Policy 2012;51:598–604.