Analysis of Energy Return on Investment of China’s Oil and Gas Production

Zhaoyang Kong1, Xiucheng Dong2,*, and Qingzhe Jiang2,*, b
1School of Environment and State Key Joint Laboratory of Environment Simulation and Pollution Control, Tsinghua University, Beijing 100084, P.R. China; 2School of International Trade and Economics, University of International Business and Economics, Beijing 100029, China.

*Corresponding authors. E-mail: adongxiucheng@cup.edu.cn; bjiangqz@uibe.edu.cn

Abstract. China ranks No.1 and No.3 respectively in global oil and gas consumption. Examination of viability of oil and gas resources could provide useful information in gauging economic vulnerability of future oil and gas supply in China. Energy Return on Investment (EROI) is an important index to characterize the viability of a natural resource from an energy viewpoint. This paper calculates EROI for oil and gas exploration (EROI OGE) and EROI for light oil products (EROI LOP) in China. The results show that the EROI OGE decreased from approximately 16.4 in 1985 to 8.4 in 2003, and then increased to 12.2 in 2012. The EROI OGE in recent years are due to the increasing of gas production. As a trade-off between the decrease of oil extraction efficiency and the increase of oil processing efficiency, the EROI LOP fluctuated around 4. The results suggest that China should develop the natural gas industry and improve the oil processing efficiency vigorously.

1. Introduction
Nearly 60% of the world’s energy consumption is meet by oil and gas, and their availability has a critical impact on economies of many countries [1-2]. China is the largest energy consumer in the world, and its energy consumption has increased from 5.7×10^8 tce (tonnes of coal equivalent) in 1978 to 43×10^8 tce in 2015 [3]. In China, oil and gas provide approximately 24% of its total energy consumption [4]. As a result of its limited domestic production capacity, however, China has to import more and more oil and gas from others counties. In the past 20 years, China’s oil-import dependency has increased from 9.8% in 1996 to 60.6 in 2015. In addition, China’s gas-import dependency grows also rapidly and is projected to reach over 40% by 2030 [5]. The high imported oil and gas dependency poses a risk to energy security. If China seek to induce import dependency, it must develop domestic oil and gas resources vigorously. Therefore, it is necessary and important to calculate the viability of China’s domestic oil and gas resources. EROI is a useful approach for estimating the viability of an energy source from an energy viewpoint [6]. This paper calculates EROI for oil and gas exploration (EROI OGE) and EROI for light oil products (EROI LOP) in China.

2. EROI Methodology
The general equation for EROI is as follows:
The numerator is the sum of all energy produced, and the denominator is the sum of the energy inputs. Before calculating the EROI, it is necessary to choose the suitable system boundary, which is perhaps the most important decision in an EROI analysis [7]. The system boundary of this paper is shown in Figure 1. The energy outputs of EROI_{OGE} is oil and natural gas. The energy inputs include the energy consumption in extraction. Here, the energy outputs of EROI_{LOP} are light oil products including gasoline, kerosene, and diesel. To calculate the EROI_{LOP}, we must consider not only the energy consumed in oil extraction but also the energy required for oil transportation and processing.

Figure 1. The system boundaries for EROI_{OGE} and EROI_{LOP}

The formula for EROI_{OGE} is as follows:
\[
EROI_{OGE} = \frac{E_{OGE}}{E_{r,0&G}}
\]  
(2)

Where \( E_{OGE} \) refers to total energy outputs of oil and gas extraction. EROI_{LOP} is expressed as follows:
\[
EROI_{LOP} = \frac{E_{LOP}}{E_{e,oil} + E_{t,oil} + E_{p,oil}}
\]  
(3)

Where, \( E_{e,oil} \), \( E_{t,oil} \) and \( E_{p,oil} \) refer to the total energy input of oil extraction, transportation and processing, respectively.

In calculating the EROI_{LOP}, we find that the amount of oil extracted are not equal to the amount of oil processed, as will be shown in Section 3.2. However, to calculate the EROI_{LOP}, we must take into account equal volumes. Safronov and Sokolov (2014) [4] also encountered this problem in calculating the EROI_{LOP} for Russian oil companies. Thus, Safronov and Sokolov (2014) proceeded as follows (Figure 2):
1. Equalize mounts by notionally increasing or decreasing oil extraction;
2. Proportionally change the energy inputs for oil extraction;
3. Calculate the EROI_{LOP}.

In this scheme, the authors make an important assumption, that is, the average energy inputs for oil extraction (or oil processing) did not change as the production scale changed. However, this assumption is usually not true, and in fact, the average energy inputs for oil extraction (or oil processing) do change with a changed production scale. In oil processing, for example, changes in scale have important implications for energy efficiency [8-10]. In fact, based on the method of Safronov and Sokolov (2014) [4], we could calculate the EROI_{LOP} by adjusting Equation (3) to
exclude the assumption. First, we simultaneously divided the numerator and denominator by the amount of oil processing ($M_p$):

$$\text{EROI}_{LOP} = \frac{E_{LOP}}{E_{e,oil} / M_p + E_{t,oil} / M_t + E_{p,oil} / M_p}$$

The calculation of the EROI$_{LOP}$ requires $M_p$ to be equal to the volumes of oil extraction ($M_e$) and oil transportation ($M_t$), so we obtain the following equation:

$$\text{EROI}_{LOP} = \frac{E_{LOP}/M_p}{E_{e,oil,per} + E_{t,oil,per} + E_{p,oil,per}}$$

Where, $E_{LOP,per}$ refers to the light oil production per tonne of oil processing, and $E_{e,oil,per}$, $E_{t,oil,per}$, and $E_{p,oil,per}$ refer to the energy input per tonne of oil extracted, oil transportation and oil processing, respectively.

The calculation of the EROI$_{LOP}$ requires $M_p$ to be equal to the volumes of oil extraction ($M_e$) and oil transportation ($M_t$), so we obtain the following equation:

$$\text{EROI}_{LOP} = \frac{E_{LOP}/M_p}{E_{e,oil,per} + E_{t,oil,per} + E_{p,oil,per}}$$

Where, $E_{LOP,per}$ refers to the light oil production per tonne of oil processing, and $E_{e,oil,per}$, $E_{t,oil,per}$, and $E_{p,oil,per}$ refer to the energy input per tonne of oil extracted, oil transportation and oil processing, respectively.

![Figure 2. Scheme for calculating the EROI$_{LOP}$](image)

The energy input of oil extraction is part of the energy input of light oil production. However, the cost of oil and gas is mixed together, so we have to assume that $E_{e,oil,per}$ is equal to $E_{e,O&G,per}$ (the energy input per tonne of oil and gas extracted). Thus, Equation (5) is adjusted as follows:

$$E_{LOP,per} = \frac{E_{LOP,per}}{E_{e,O&G,per} + E_{t,oil,per} + E_{p,oil,per}}$$

As $E_{ROI_{O&G}} = 1/E_{e,O&G,per}$, Equation (6) is modified as follows:

$$\text{EROI}_{LOP} = \frac{E_{LOP,per}}{1 / E_{ROI_{O&G}} + E_{t,oil,per} + E_{p,oil,per}}$$

Thus, it is much easier for us to calculate the EROI$_{LOP}$ using Equation (6) or (7).

The energy outputs and inputs for China’s oil and gas extraction are derived from National Bureau of Statistics of China [3]. In China, oil transportation relies on pipelines, and we assume that the average distance from oilfield to oil processing plant is approximately 1000 km. The unit energy consumption by oil pipeline transport is approximately 0.3 MJ/ton-km [11]. Because it is unavailable to obtain the accurate data of refining energy consumption in different refineries, we use the average refining energy consumption of Sinopec for substitution [12-13].

3. Results and discussion
The EROI\textsubscript{OGE} and EROI\textsubscript{LOP} in China are shown in Figure 3. It is clear that, as a result of the depletion of oil reserves, oil production needs more energy inputs. In addition, the growth in energy inputs in turn leads to a decrease in the EROI\textsubscript{OGE} in 1985-2003. However, after 2003, the EROI\textsubscript{OGE} increased from 8.4 to 12.2, which may result from the increasing gas production with relatively high EROI. As a result of the interaction between the decrease of oil extraction efficiency and the increase of oil processing efficiency, the EROI\textsubscript{LOP} fluctuated about 4.

Figure 3. The EROI\textsubscript{OGE} and EROI\textsubscript{LOP} in China

Hu et al. (2013) [14] showed that China’s EROI\textsubscript{OGE} fluctuated from 12 to 14:1 in the mid-1990s and decreased to 10:1 in the period from 2007-2010 (Figure 4). The EROI results of this paper are similar to those of Hu et al. Hu et al. (2013) [14] further predicted that China’s EROI\textsubscript{OGE} will continue to decline in 2011-2020 and will drop to 9.6:1 by 2020. The result of this prediction is different from the result of this paper. According to the actual data, the EROI\textsubscript{OGE} calculated in this paper rises in 2011-2013. We argue that China’s EROI\textsubscript{OGE} will continue to rise in the short term. The reason is that China’s natural gas development is relatively late and its EROI is currently in the rising stage. EROI trends of an energy resource are impacted by two main factors [15]. One is technological component. With the progress of energy production, the mining technology will be gradually mature and the energy inputs

Figure 4. The EROI\textsubscript{OGE} values of this study and Hu et al.’s study
used in the extraction process will decrease. However, technological progress has theoretical limits (Figure 5a). The other is physical resource component. The energy resource that offer the best returns is exploited first. Attention then turns to resources with lower returns as production continues. This mode of exploitation leads to a gradual increase in energy input per unit output (Figure 5b). Given the above two components, the EROI of an energy source will first increase and then decrease (Figure 5c).

Assuming that the EROI trends for oil and natural gas are shown in Figures 6a and 6b, respectively, and the natural gas development stage is later than oil, the EROI of oil and gas may be shown in Figure 6c. Its trend is to rise first, then fall, then rise again, and finally fall. Now, China’s oil and gas development is in accordance with stage 4 (t3 to t4) in Figure 6c, which is an ascending stage rather than the descending stage proposed by Hu et al.

**Figure 5.** EROI trends in technical constraints and resource constraints

**Figure 6.** Illustration of EROI trends for oil and gas
4. Conclusion
This paper calculated the EROI for oil and gas exploration (EROI\textsubscript{OGE}) and EROI for light oil products (EROI\textsubscript{LOP}) in China. The results show that the EROI\textsubscript{OGE} in China decreased from 19.1 in 1986 to 9.6 in 2003, and recovered to 15.7 in 2013. The increase of EROI\textsubscript{OGE} is due the increasing of gas production with relatively high energy return. According to the analysis in Section 4, in the short term, the increase of gas production will further improve the EROI\textsubscript{OGE}. In the future, some measures should be taken by the government to increase gas production such as rationalizing the domestic gas pricing mechanisms. The EROI\textsubscript{LOP} is much lower than EROI\textsubscript{OGE} and fluctuated around 4. To increase the EROI\textsubscript{LOP}, some measures could be taken to improve the oil processing efficiency such as increasing the R\&D investment.

Acknowledgements
This work was supported by the National Natural Science Foundation of China (71722003, 71273277, No. 71690244), the Philosophy and Social Sciences Major Research Project of the Ministry of Education (No.11JZD048), the National Key R\&D Program (2016YFC0208901), and China Postdoctoral Science Foundation (2017M620809).

References
[1] BP Statistical Review of World Energy 2017. Available online: http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (accessed 21 January 2017).
[2] Munasinghe, M. The sustainomics trans-disciplinary meta-framework for making development more sustainable. Int. J. Sust. Dev. 2002, 5, 125-182.
[3] National Bureau of Statistics of China. China Statistic Yearbook 1989-2013. China Statistics Press: Beijing, China, 2014. [In Chinese].
[4] Safronov, A.; Sokolov, A. Preliminary calculation of the EROI for the production of crude oil and light oil products in Russia. Sustainability 2014, 6, 5801-5819.
[5] Kong, Z.; Dong, X.; Zhou, Z. Seasonal imbalances in natural gas imports in major northeast Asian countries: variations, reasons, outlooks and countermeasures. Sustainability 2015, 7, 1690-1711.
[6] Gagnon, N.; Hall, C.A.S.; Brinker, L. A preliminary investigation of energy return on energy investment for global oil and gas production. Energies 2009, 2, 490-503.
[7] Cleveland, C.J.; O’Connor, P.A. Energy return on investment (EROI) of oil shale. Sustainability 2011, 3, 2307-2322.
[8] Huang, Z.H.; Liu, L.L. Sacle economy and cost analysis: from the perspective of the relationship between refining size and cost. Chemical Techno-Economics 2002, 3, 28-31. [In Chinese]
[9] Zhang, G.S. Study on economy of scale of refinery and process units. Petrol. Refinery Eng. 2007, 37, 58-62. [In Chinese].
[10] Lin, B.; Xie, X. Energy conservation potential in China’s petroleum refining industry: evidence and policy implications. Energy Convers. Manag. 2015, 91, 377-386
[11] Ou, X.; Xiaoyu, Y.; Zhang, X. Life-cycle energy consumption and greenhouse gas emissions for electricity generation and supply in China. Appl. Energy 2011, 88, 289-297
[12] Sinopec. Sinopec Statistic Yearbook 2001-2013. China Petrochemical Press: Beijing, 2014
[13] Sinopec, Annual Reports. Available online: http://www.sinopecgroup.com/group/gsjy/gsbg/ (accessed 20 August 2014).
[14] Hu, Y.; Hall, C.A.S.; Wang, J.; Feng, L.; Poisson, A. Energy return on investment (EROI) of China’s conventional fossil fuels: historical and future trends. Energy 2013, 54, 352-364
[15] Dale M, Krumdieck S, Bodger P. A Dynamic Function for Energy Return on Investment. Sustainability 2011, 3, 1972-1985.