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

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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:

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$$\mathrm{EROI} = \frac{\text{Energy returned (outputs)}}{\text{Energy required (inputs)}} \tag{1}$$

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 $\mathrm{EROI_{OGE}}$ is oil and natural gas. The energy inputs include the energy consumption in extraction. Here, the energy outputs of $\mathrm{EROI_{LOP}}$ are light oil products including gasoline, kerosene, and diesel. To calculate the $\mathrm{EROI_{LOP}}$, we must consider not only the energy consumed in oil extraction but also the energy required for oil transportation and processing.

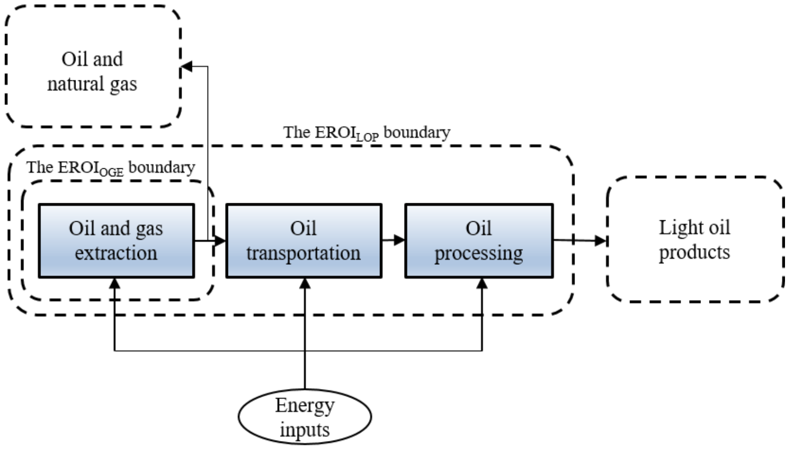

Figure 1. The system boundaries for $\mathrm{EROI_{OGE}}$ and $\mathrm{EROI_{LOP}}$

The formula for $\mathrm{EROI_{OGE}}$ is as follows:

$$EROI_{OGE} = \frac{E_{OGE}}{E_{e,O\&G}} \tag{2}$$

Where E_{OGE} refers to total energy outputs of oil and gas extraction.
$\mathrm{EROI_{LOP}}$ is expressed as follows:

$$EROI_{LOP} = \frac{E_{LOP}}{E_{e,oil} + E_{t,oil} + E_{p,oil}} \tag{3}$$

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 $\mathrm{EROI_{LOP}}$, 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 $\mathrm{EROI_{LOP}}$, we must take into account equal volumes. Safronov and Sokolov (2014) [4] also encountered this problem in calculating the $\mathrm{EROI_{LOP}}$ 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 $\mathrm{EROI_{LOP}}$.

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 $\mathrm{EROI_{LOP}}$ by adjusting Equation (3) to exclude the assumption. First, we simultaneously divided the numerator and denominator by the amount of oil processing (M_p):

$$EROI_{LOP} = \frac{E_{LOP} / M_p}{E_{e,oil} / M_p + E_{t,oil} / M_p + E_{p,oil} / M_p} \quad (4)$$

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:

$$EROI_{LOP} = \frac{E_{LOP} / M_p}{E_{e,oil} / M_e + E_{t,oil} / M_t + E_{p,oil} / M_p} = \frac{E_{LOP,per}}{E_{e,oil,per} + E_{t,oil,per} + E_{p,oil,per}} \quad (5)$$

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.

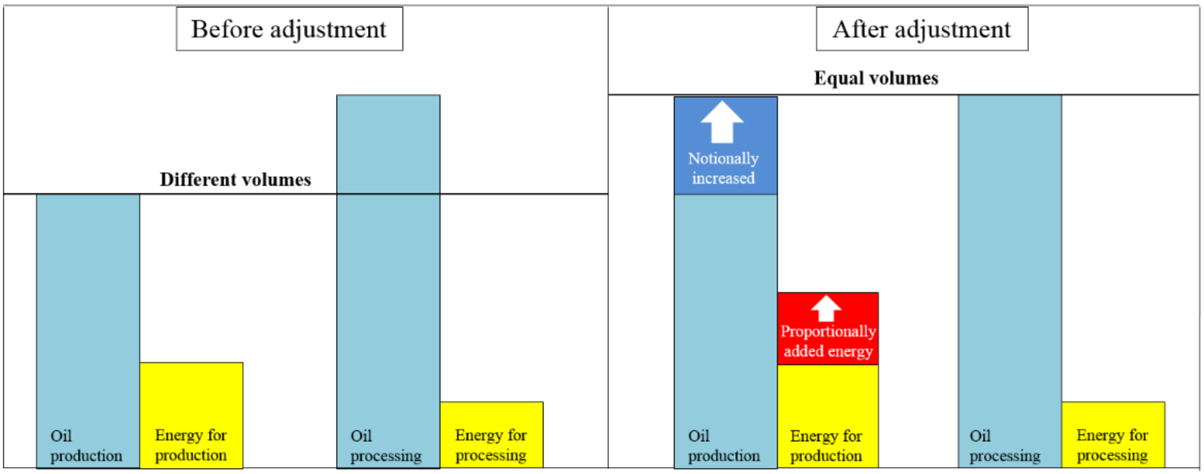

Figure 2. Scheme for calculating the $EROI_{LOP}$

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 $E_{e,O\&Gl,per}$ (the energy input per tonne of oil and gas extracted). Thus, Equation (5) is adjusted as follows:

$$EROI_{LOP} = \frac{E_{LOP,per}}{E_{e,O\&G,per} + E_{t,oil,per} + E_{p,oil,per}} \quad (6)$$

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

$$EROI_{LOP} = \frac{E_{LOP,per}}{1 / EROI_{OGE} + E_{t,oil,per} + E_{p,oil,per}} \quad (7)$$

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 $EROI_{OGE}$ and $EROI_{LOP}$ 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 $EROI_{OGE}$ in 1985-2003.However, after 2003, the $EROI_{OGE}$ 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 $EROI_{LOP}$ fluctuated about 4.

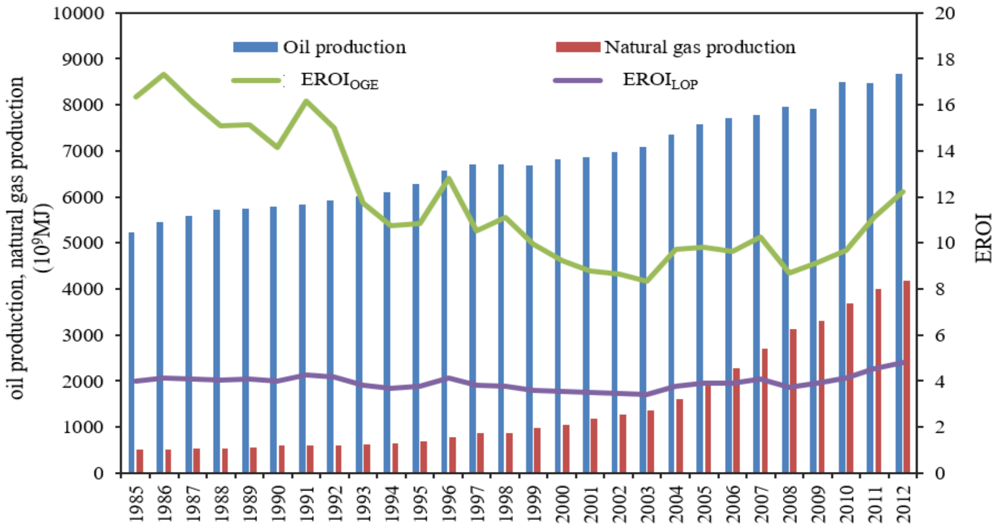

Figure 3. The $EROI_{OGE}$ and $EROI_{LOP}$ in China

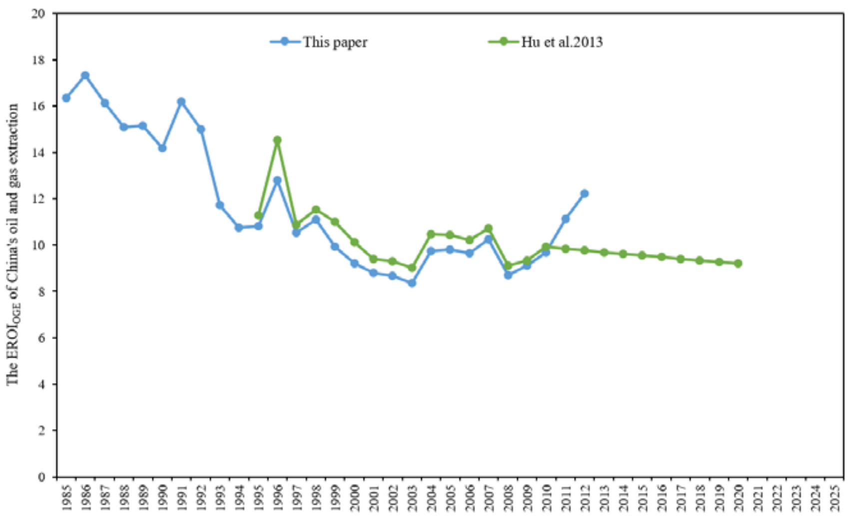

Figure 4. The $EROI_{OGE}$ values of this study and Hu *et al.*'s study

Hu et al. (2013) [14] showed that China's $EROI_{OGE}$ 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 $EROI_{OGE}$ 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 $EROI_{OGE}$ calculated in this paper rises in 2011-2013. We argue that China's $EROI_{OGE}$ 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 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 (t_3 to t_4) in Figure 6c, which is an ascending stage rather than the descending stage proposed by Hu et al.

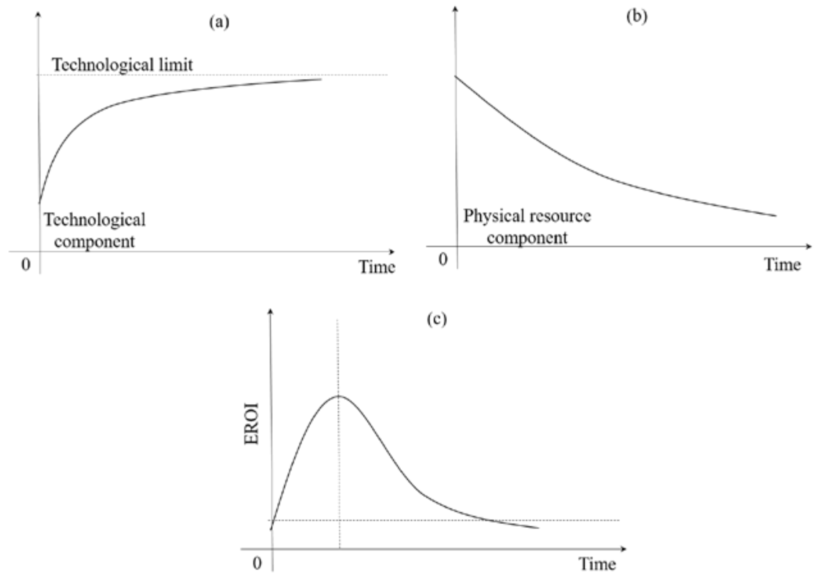

Figure 5. EROI trends in technical constraints and resource constraints

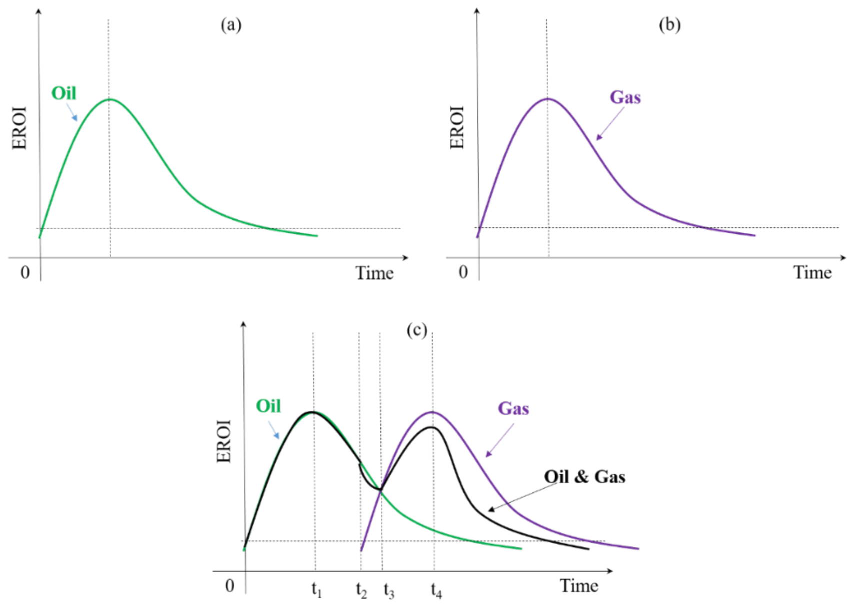

Figure 6. Illustration of EROI trends for oil and gas

4. Conclusion

This paper calculated the EROI for oil and gas exploration ($EROI_{OGE}$) and EROI for light oil products ($EROI_{LOP}$) in China. The results show that the $EROI_{OGE}$ in China decreased from 19.1 in 1986 to 9.6 in 2003, and recovered to 15.7 in 2013. The increase of $EROI_{OGE}$ 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 $EROI_{OGE}$. In the future, some measures should be taken by the government to increase gas production such as rationalizing the domestic gas pricing mechanisms. The $EROI_{LOP}$ is much lower than $EROI_{OGE}$ and fluctuated around 4. To increase the $EROI_{LOP}$, some measures could be taken to improve the oil processing efficiency such as increasing the R&D investment.

Acknowledgements

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