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Domestic oil and gas or imported oil and gas – An energy return on investment perspective

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ABSTRACT

Both domestic oil and gas and imported oil and gas are essential to meet the enormous energy demand in China, which is incurred by its rapid economic growth. However, which is better than another? To address this issue, an energy return on investment (EROI) analysis, which is a useful method to evaluate the physical performance of an energy process, is applied. Besides, the EROIs time series of offshore domestic oil and gas and onshore domestic oil and gas are calculated, and the causes of the change tendency of EROIs time series are studied. The EROIs of imported oil and gas from different import countries are also calculated, laying the foundation for optimization of the import structure from an EROI perspective. Moreover, environmental inputs, which cause the externality of an energy process, are also studied. The results show that the EROIs of the entire domestic oil and gas fluctuate between 8.5 and 12, and the EROIs of the imported oil and gas lie in the range between 2.9 and 9.5. We conclude that: 1) The EROIs of domestic oil and gas is higher than those of imported oil and gas, indicating that domestic oil and gas has a higher physical efficiency than imported oil and gas. 2) The change tendency of EROIs is influenced by the extractions of natural gas. Moreover, the EROIs of imported oil and gas are additionally related to oil and gas prices. 3) From an EROI perspective, LNG and pipeline gas are better than imported crude oil. Australia, Kazakhstan, and the USA should be prioritized for China to import LNG, pipeline gas, and crude oil respectively. 4) Environmental inputs reduce the EROIs. Therefore more caution should be paid on the reduction of environmental inputs.

1. Introduction

Oil and gas (OG) play a pivotal role in the modern industry, and OG demand is closely related to economic development. China has seen rapid growth in the economy since the reform and openness. Meanwhile, the demand for OG in China has increased significantly due to the rapid economic growth (see Fig. 1). To satisfy the substantial growth, China has begun to push the development of its domestic OG industry and to import OG from other producers. However, the gap between domestic production and consumption will become larger in the future. BP estimates that the imported OG volume will double its size and reach 836 million tons oil equivalent (MTOE) in 2035 (BP, 2015), indicating that the average annual growth rate is approximate 5.5%.

Abbreviations: A_{IG}, aggregate volume of imported gas; A_{IO}, aggregate volume of imported oil; CNOOC, China National Offshore Oil Corporation; CNPC, China National Petroleum Corporation; DDA, dismantlement and site restoration allowance; DEF_i, DOG emission factor of emission *i*; DOG, domestic oil and gas; E_{DOG}, entire DOG energy outputs; E_{OFDOG}, offshore DOG energy outputs; E_{ONDOG}, onshore DOG energy outputs; $E_{P(IG)}$, unit price of the imported gas; $E_{P(IO)}$, unit price of the imported oil; $E_{P(oil)}$, price per barrel of oil; $E_{U(IG)}$, unit energy output of the imported gas; $E_{U(IO)}$, unit energy output of the imported oil; $E_{U(oil)}$, unit energy content of oil; E_T, total energy; E_d, direct inputs of the entire DOG; E_{eint}, energy intensity of the entire economy; E_{id}, Indirect inputs of the entire DOG; E_{iint}, Energy intensity of industrial sector; E_o, DOG energy outputs; ECF_i, external cost factor of emission *i*; EE, exploration expenses; EF_i, emission factor of emission i related to IOG; EJ, exajoule; ENV_{DOG}, environmental inputs of the entire DOG; ENV_{IOG}, environmental inputs; ENV_{OFDOG}, environmental inputs of offshore DOG; ENV_{ONDOG}, environmental inputs of onshore DOG; EROI, energy return on investment; $EROI_{CO}$, EROI of crude oil; $EROI_{DOG}$, EROI of the entire DOG; $EROI_{DOG,env}$, EROI with environmental inputs of the entire DOG; $EROI_{IO}$, EROI of imported oil; $EROI_{IG}$, EROI of imported gas; $EROI_{IOG}$, EROI of IOG; $EROI_{IOG,env}$, EROI with environmental inputs of IOG; $EROI_{LNG}$, EROI of LNG; $EROI_{NG}$, EROI of natural gas; $EROI_{OFDOG}$, EROI of offshore DOG; $EROI_{OFDOG,env}$, EROI with environmental inputs of offshore DOG; $EROI_{ONDOG}$, EROI of onshore DOG; $EROI_{ONDOG,env}$, EROI with environmental inputs of onshore DOG; $EROI_{PG}$, EROI of pipeline gas; $EROI_{stnd}$, standard EROI; $EROI_{1,env}$, standard EROI with environmental inputs; GDP, gross domestic production; IOG, imported oil and gas; LNG, liquefied natural gas; M_{id}, monetary indirect costs of the entire DOG; M_{OFDOG}, monetary inputs of offshore DOG; OE, operating expenses; OG, oil and gas; PJ, petajoule; SINOPEC, China Petroleum & Chemical Corporation

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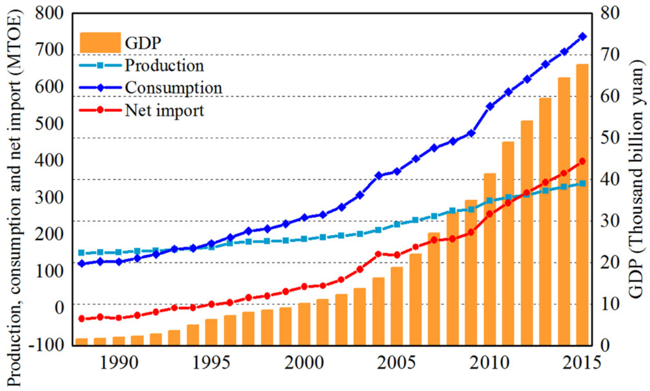

Fig. 1. GDP, oil and gas productions, and consumptions in China.

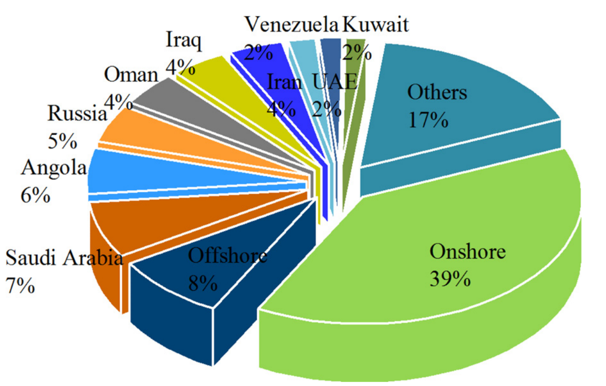

Fig. 2. Domestic production and key suppliers of oil and gas resources for China in 2014.

There are two ways to bridge the gap, namely domestic OG (DOG) and imported OG (IOG). The DOG is always a vital supply source for China. Although China does not belong to oil-rich countries, there are still some potentials - the proven OG reserves in China were 2.5 billion tons and 3.8 trillion cubic meters respectively in 2015 (BP, 2016). IOG serves as another important supply source for China and accounts for a significant proportion in the supply mix. Domestic productions and key suppliers of IOG for China in 2014 are shown in Fig. 2.

China needs more OG to support its economic development, and care more about the energy surplus and physical efficiency of OG supply. Therefore, several interesting questions arise: from a physical efficiency perspective, which way to obtain the OG resources is better for China, DOG or IOG? How do the physical efficiencies of different energy supply processes (namely the entire DOG, the onshore DOG, the offshore DOG, and IOG) change over time, and what causes the change tendency? Which oil-exporting countries are excellent choices for China? Besides, as environmental issues receive great attention globally, and more energy inputs are required to eliminate the pollutions, environmental issues can be regarded as energy inputs of an energy supply process and have considerable impacts on EROI. Thus, another question is proposed: What will happen to EROIs when environmental inputs are considered?

An energy return on investment (EROI) analysis is proposed to address such questions from the perspective of net energy analysis. EROI is the ratio of the aggregate produced energy to the aggregate consumed energy in an energy supply process (Hall et al., 1979). It is different from economic indicators because it measures the energetic physical performance. Therefore, it is a useful and straightforward indicator which reflects the net energy surplus to the society (Gupta and Hall, 2011; Murphy et al., 2011). The concept originated from ecology (Hall, 1972), and was first formally proposed by Hall et al. (1979). Later on, several important papers were published in Science and other journals by Hall, Cleveland, Kaufmann and others (Cleveland et al., 1984; Hall et al., 1986; Hall and Cleveland, 1981). Few studies were carried out after that. However, studies on EROI have sprung up again after 2005.

Two basic methodologies are applied in the EROI analysis, i.e. the bottom-up and the top-down. The choice of the methodologies is determined by the system boundaries and data restriction (Murphy et al., 2011). For bottom-up methodology, process analysis is a typical and standardized method - it divides an energy supply process into several procedures and estimates the EROI by summing up the inputs and outputs of each procedure. Life cycle assessment (LCA) belongs to process analysis, (Murphy et al., 2016) suggest that all researchers should apply LCA when calculating EROI, which makes the comparison between different energy technologies consistent. However, LCA is limited by data availability. As for top-down methodology, the economic input-output analysis is a typical method, in which inputs and outputs are derived from economic data. The dynamic function is another example of top-down methodology (Dale et al., 2011a). Recently, a hybrid methodology combining process analysis and economic input-output analysis is proposed recently to overcome data restriction (Murphy et al., 2011).

The mainstream protocol in EROI analysis is proposed by Murphy et al. (2011). Before that, studies on EROI were divergent because there was no consensus about the system boundaries. A two-dimensional framework was presented by Murphy et al. (2011) to confine the system boundaries. Apart from this protocol, several other protocols were proposed (Arvesen and Hertwich, 2015; Atlason and Unnthorsson, 2014; Brandt et al., 2013a, b; Brandt and Dale, 2011; Chen et al., 2017; Dale et al., 2011a; Feng et al., 2018a, b; Hall et al., 2009; Henshaw et al., 2011; Kessides and Wade, 2011; Zhang and Colosi, 2013). Most of these protocols are similar to Murphy's or are based on Murphy's, despite the frameworks proposed by Dale et al. (2011a) and Henshaw et al. (2011). However, these two frameworks focus on the physical principles, which leads to the neglect of economic properties of the energy carriers.

EROI analysis is applied in three areas: 1) To measure the performance of different energy systems, which is the most common application. Energetic physical performance of different energy supply processes are evaluated by EROIs analysis, including oil and gas (Brandt, 2011; Brandt et al., 2015; Cleveland, 2005; Court and Fizaine, 2017; Dale et al., 2011b; Feng et al., 2018a, b; Freise, 2011; Gagnon et al., 2009; Gately, 2007; Grandell et al., 2011; Guilford et al., 2011; Hall et al., 2014; Hu et al., 2011; Hu et al., 2013; Kong et al., 2016; Moerschbaecher and Day, 2011; Nogovitsyn and Sokolov, 2014; Poisson and Hall, 2013; Safronov and Sokolov, 2014; Xu et al., 2014), coal (Court and Fizaine, 2017; Feng et al., 2018a, b; Hall et al., 2014; Hu et al., 2013), shale oil and gas (Cleveland and O Connor, 2011; Sell et al., 2011; Wang et al., 2017a, b; Yaritani and Matsushima, 2014), oil sand (Brandt et al., 2013a, b; Wang et al., 2017), power generation (including wind and solar power generation) (Dupont et al., 2018; Huang et al., 2017; Kittner et al., 2016; Kunz et al., 2014; Leccisi et al., 2016; Neumeyer and Goldston, 2016; Raugei et al., 2012; Raugei and Leccisi, 2016; Swenson, 2016; Weißbach et al., 2013), coal to liquid and gas (Kong et al., 2015; Kong et al., 2016), jet fuel (Trivedi et al., 2015), energy production sector (Brand-Correa et al., 2017; Feng et al., 2018a, b), and biofuel (Beal et al., 2012; Font De Mora et al., 2012; Pechsiri et al., 2016). 2) To compare the impacts of technology and depletion. Technology will enhance the EROI by promoting the efficiency. However, depletion will decrease the EROI. Their impacts are examined by several scholars (Brandt, 2011; Brandt et al., 2013a, b; Cleveland, 2005; Gagnon et al., 2009; Gately, 2007; Grandell et al., 2011; Guilford et al., 2011; Hall et al., 2014; Hu et al., 2011; Nogovitsyn and Sokolov, 2014; Poisson and Hall, 2013; Safronov and Sokolov, 2014; Sell et al., 2011). 3) To study the relationship between economy and EROI. Recently, the relationship between oil price, economic performance, and EROI receives more attention (Aucott and