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Viewpoint

Assessment of energy security in China based on ecological network analysis: A perspective from the security of crude oil supply

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HIGHLIGHTS

- Ecological network analysis (ENA) is introduced into energy security assessment.
- A model of crude oil supply network in China is established based on ENA.
- A pyramid structure of the contributions of different compartments to energy security was found.
- Suggestions for forming a stable network are given to improve energy security.

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ABSTRACT

Energy security usually considers both the stability of energy supply and security of energy use and it is receiving increasing attention globally. Considering the strategic importance and sensitivity to international change of the crude oil supply, we decided to examine China's energy security. An original network model was established based on ecological network analysis to holistically evaluate the security of the crude oil supply in China. Using this model, we found that the security of the crude oil supply in China generally increased from 2001 to 2010. The contribution of different compartments in the network to the overall energy security resembled a pyramid structure, with supply sources at the bottom, the consumption sector at the top, and the refining and transfer sectors in the middle. North and South America made the largest contribution to the security of the crude oil supply in China. We provide suggestions to improve the security of the crude oil supply in China based on our results and further scenario analysis. The original network model provides a new perspective for energy security assessment, which can be used as a baseline to develop other models and policy.

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1. Introduction

Energy security, as an important factor affecting economic production and human life, is vital for sustainable development. It is generally acknowledged that energy security includes two aspects, i.e., the stability of energy supply (meaning that the energy supply is maintained at a stable level that can satisfy the demand of national development) and the security of energy use (meaning that energy use will not pose any threat to the environment or human survival and development) (Bielecki, 2002; Cai and Zhang, 2005; Wang, 2006; Kruyt et al., 2009; IEA (International Energy Agency), 2010; Hughes, 2012). At present, the security of energy supply is facing a huge challenge because of deregulation of the energy market, high energy prices, increasing energy demand, intensive competition for geographically concentrated resources, and the instability of international politics. China became a net oil importer in 1993 and the gap between oil supply and demand has increased since then because of the corresponding rapid socioeconomic development (Leung, 2011). According to the latest forecast by the International Energy Agency (IEA), China's dependency on oil imports will reach 62.2% in 2015 and further increase to 84.6% in 2035 (IEA (International Energy Agency), 2011). Here, we assess the security of energy supply, the more fundamental and urgent goal of energy security, which plays an important role in national economic and political security. We focus on crude oil because of its strategic importance and sensitivity to the international situation.

In recent years, numerous studies on the definition and evaluation of indicators of energy security have been reported. The term energy security is polysemous (Chester, 2010), and its definition is usually related to the site, purpose, and period of a given study (Chuang and Ma, 2013). Some studies only focused on

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resilient energy systems, stable energy supply, acceptable prices, or sustainable economic development (Bohi and Toman, 1993; Lieb-Dóczy et al., 2003; Wright, 2005; Spanjer, 2007; Lefèvre, 2010), while others also considered environmental effects (Bielecki, 2002; Cai and Zhang, 2005; Wang, 2006; Kruyt et al., 2009; IEA (International Energy Agency), 2010; Hughes, 2012; Cao and Bluth, 2012; Selvakkumaran and Limmeechokchai, 2013). Among the various definitions of energy security, the one developed by IEA (International Energy Agency) (2010) is widely used, which is defined as "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns". With regard to various indicators of energy security, different classifications can be obtained (Löschel et al., 2010). Generally, some studies assessed energy security from concrete energy-based factors such as energy availability, price affordability, energy use technologies, and efficiency (Chester, 2010; Sovacool, 2011, 2013; Sovacool and Mukherjee, 2011; Martchamadol and Kumar, 2012; Chuang and Ma, 2013). Some studies considered macroscopic energy-related factors such as social, economic, environmental, and institutional effects (Iaea, 2005; Martchamadol and Kumar, 2013). Other studies discussed the potential risks for energy security from such aspects as sovereignty, robustness, and resilience (Cherp and Jewell, 2011; Leung et al., 2014).

In terms of oil security, both qualitative analysis and quantitative evaluation have been conducted. Based on qualitative studies of oil security, measures were proposed to improve oil security including strengthening oil production, developing new energy, and improving energy efficiency (Zhou, 2004; Li and Wang, 2007; Zhao, 2007; Wang, 2008; He and Tang, 2012). Quantitative models and indicators have also been used to evaluate oil security. Gupta used an oil vulnerability index to capture the relative sensitivity of various economies towards development of the international oil market (Gupta, 2008). Le Coq and Paltseva (2009) introduced the indicators of REES (risky external energy supply) and CERE (contribution to EU risky exposure) to evaluate the short-term risks associated with the external supply of energy to the European Union member states. Greene used the oil security metrics model to measure the cost of oil dependence (Greene, 2010).

Undoubtedly, this existing body of research has contributed substantially to energy security assessment. However, there are still some issues that need to be addressed. First, a comprehensive assessment perspective and method that considers the various components related to energy supply and the relationships between them as a system is required to develop an analysis paradigm and better understand the overall situation of energy security. Second, the influences (both direct and indirect) of different components in the energy system on overall energy security need to be analyzed, which should aid effective energy regulation. In this context, here we use ecological network analysis (ENA), a powerful, general system-oriented analytical tool to connect all of the objects within a system and measure their relationships (Fath and Patten, 1999), to simulate the crude oil supply network in China and quantitatively analyze its security, which is defined as an adequate supply of crude oil to allow the crude oil network to operate stably.

2. Methods

2.1. ENA

ENA is a powerful system-oriented modeling technique used to examine the structure and flow of materials in ecosystems (Fath and Patten, 1999), that places emphasis on the transfer between compartments rather than just the characteristics of individual compartments (Ulanowicz, 1986). Inspired by the input–output analysis originated in economic system (Leontief, 1936), ENA has been proposed and gradually developed by many researchers (Hannon, 1973; Patten et al., 1976; Patten, 1978; Rutledge et al., 1976; Ulanowicz, 1986, 1997; Ulanowicz and Norden, 1990). And it has been widely applied in various fields; e.g., urban ecosystems (Zhang et al., 2009; Li and Xu, 2010; Chen and Chen, 2012), forests (Schaubroeck et al., 2012), wetlands (Mao et al., 2010; Mao and Cui, 2012), financial systems (May et al., 2008) and natural gas pipelines (Scotti and Vedres, 2012).

The definition of flows and flow analysis are always the foundation and core of ENA. In this paper, as an initial attempt to understand the security of crude oil supply in China, flow analysis – the most fundamental perspective of ENA – is applied.

As indicated in Fig. 1, the basic units of a network model include compartments and their interactions. Here, X_i represents the ith compartment, f_{ij} represents flow from compartment j to compartment i, y_j represents flow out of the network for compartment j, and z_i represents flow into compartment i from outside the network.

Nondimensional input-oriented intercompartmental flow from compartment j to compartment i (g_{ij}) is defined as:

$$g_{ij} = \frac{f_{ij}}{T_i} \tag{1}$$

where T_i is the sum of the intercompartmental and boundary inflows to compartment i. Based on the matrix $G=(g_{ij})$, the dimensionless integral flow matrix $N=(n_{ij})$ is calculated as follows:

$$N = (n_{ij}) = G^0 + G^1 + G^2 + \cdots + G^k + \cdots = (I-G)^{-1} \tag{2}$$

where I is the identity matrix, and n_{ij} represents the integral dimensionless value of g_{ij}.

We mainly use two methods based on flow analysis, ecological network information analysis (ENIA) and ecological network structure analysis (ENSA) to systematically assess the security of crude oil supply in China.

2.2. Construction of a network model for crude oil supply in China

2.2.1. Basic steps

Referring to the basic procedure of ENA (Fath et al., 2007; Zhang et al., 2009), assessment of the security of the crude oil supply in China mainly includes the following six steps:

Step 1: Identify the system of interest and place a boundary around it (Fath et al., 2007). Here, we chose the crude oil supply

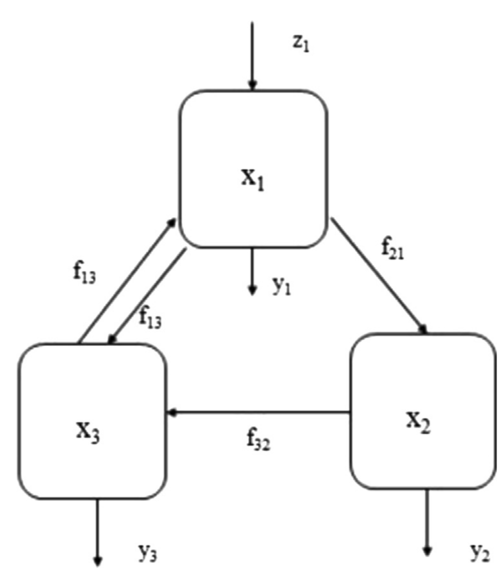

Fig. 1. A simple hypothetical network model with three compartments illustrating ecological network analysis (ENA).

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