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ENA-based evaluation of energy supply security: Comparison between the Chinese crude oil and natural gas supply systems

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ABSTRACT

Energy has become a scarce global strategic resource, and energy supply security is receiving increasing attention. A common evaluation platform is necessary to systematically understand the supply security levels of different energy sources and help make the national energy strategy. Ecological network analysis (ENA) is thus regarded as a useful common tool to systematically simulate, evaluate, and compare the supply security for different energy sources, when considering the fact that modern energy systems have formed a complex global energy network through extensive energy trading. Based on the established ENA platform, we evaluated and compared China's crude oil and natural gas supply security from 2000 to 2012. To this end, we assessed the overall security level, investigated the relationship among different compartments within the network system, determined the system's structure, and analyzed the system's properties. It was found that the Chinese crude oil supply security level was higher than that of the natural gas supply and that the crude oil supply system was more mature in terms of multiple properties. Suggestions are proposed to improve the Chinese energy supply security based on further scenario analysis, including increasing domestic energy production, controlling energy consumption, diversifying foreign supply sources, and strengthening the strategic reserve. The ENA-based common platform can be used for the systematic evaluation and improvement of energy supply security and further support national energy policymaking for both developed and developing countries, both energy importers and exporters.

1. Introduction

As an important power source for production and living, energy is the essential driving force of the world's socio-economic development. Its stable and sustainable supply is vital to global socio-economic security. However, an energy crisis is pending. It has been reported that the global oil and natural gas reserves as of the end of 2014 are only sufficient to meet 52.5 and 54.1 years of global production, respectively, according to BP's latest estimate [1]. Energy has become a scarce strategic resource, and its supply security has attracted more and more concern [2], especially when considering the potential ramifications of international politics, the economy, and diplomacy.

As one of the largest energy consumers in the world [3], China faces a remarkable threat to its energy supply security. The total energy consumption in China has been continuously increasing with urbanization and industrialization, with coal, oil, and natural gas being the dominant types of energy used. The domestic production of coal is relatively abundant, while oil and natural gas depend more and more on imports. China became a net oil importer in 1993, and the gap between supply and demand has gradually increased since then [4]. In 2013, China became the second largest oil importer in the world, accounting for 12.5% of the global share [5]. In terms of natural gas, China became a net importer in 2007 [6]. With an average growth rate of 7.6%, the international import of natural gas to China will account for a larger and larger global share. It is therefore urgent to evaluate China's crude oil and natural gas supply security and implement measures to safeguard the security level in advance, considering the increasingly large gap between the demand and domestic supply and, consequently, the increasing dependence on foreign oil and natural gas.

Many scholars and organizations have engaged in research on energy security, whose definition is polysemous regarding the objects, emphases, and dimensions in different studies [7,8]. In terms of

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research topics, the meaning of energy security differs between developed and developing countries. For developed countries, it has emphasized the need to establish an elastic energy system at an acceptable price to meet the energy demand required by socio-economic activities, human living, and national defense [9]. For developing countries, energy security has been regarded to satisfy basic human needs at the family level and per capita consumption level, and the quality was usually much lower than that in developed countries. National energy security was ensured by improving energy use efficiency, developing renewable energy, and reducing the use of fossil fuels for residential energy consumption [10–16]. With respect to emphasis, the understandings of energy security also differ. To meet the demand for energy, energy security has been defined as the ability to meet both continuous and discontinuous demand [11,17–19]. Focusing on the influence on the economy, energy security has been regarded as maintaining an effective and timely energy supply while keeping the price at a level that has no adverse impact on the economy [20–22]. Other definitions have considered the anti-interference capability, resistance to growing energy costs, and adaptability to a limited energy supply [23]. Some researchers have stated their understanding of energy security according to varying dimensions. For some, the concept includes three dimensions (i.e., availability, acceptability, and availability) [24]. Others have posited that it includes four dimensions (i.e., availability, affordability, efficiency, and environmental stewardship) [25] or even five dimensions (i.e., availability, technology development, acceptability, affordability, and sustainability, or) [19].

Depending on the definition, energy security has been evaluated and analyzed from different perspectives. Studies have focused on the economic factors [26], domestic influencing factors [27], and foreign geopolitical factors [28]. The qualitative analysis of energy security has been further developed to include quantitative methods. While some have focused on the safety of the energy supply [29], others have stressed the environment (e.g., considering the relationship between energy supply security and climate change) [30], the influence of energy price fluctuations on local energy supply and demand [31], or a combination of various factors. For instance, Streimikiene et al. quantitatively analyzed the existing problems of energy systems in the Baltic states resulting from terminal energy consumption, per capita energy consumption, energy intensity, net energy import dependence, and energy supply efficiency [32]. Gnansounou considered the energy supply and environmental impacts [33]. Frondel et al. measured energy security with respect to energy supply and imports, domestic energy production, and political economy [34].

Different indices have also been established to measure energy security, including independent and aggregation indices. Multiple independent indices have been applied together to represent the energy security situation from different perspectives (e.g., the reserve-production ratio [10,35], the diversity index [22,34,36,37], net energy import dependence [22,38], the non-carbon-intensive fuel mix [22], the policy stability index [36,39], energy prices, and the geopolitics of energy security [40]). The aggregation indices have been utilized to represent the overall level of energy security in specific study areas, e.g., the energy vulnerability index, willingness to pay [41,42], political stability in energy production areas [36], the energy sustainable development index [43–47], and even the overall energy security index [48].

All these studies are helpful for a better understanding and reasonable evaluation of energy security, where the two critical aspects of energy supply security and energy use security were usually not separated clearly. Considering its strategic significance for national security and the huge challenge, we will focus on energy supply security in this paper. In order to guarantee the national energy supply security, this paper aims to: (1) establish a common platform to systematically evaluate and compare the supply security level for different energy sources (including both renewable and unrenewable energy), and (2) propose suggestions for improving the national energy supply security level based on characteristics analysis of different energy supply systems.

With respect to the first issue, ecological network analysis (ENA), a general systematic method to integrate various interactive components in a system [49–56], is applied to construct a common evaluation platform for energy supply security, especially considering the truth that modern energy systems have formed an energy network around the world through international energy trading [57]. Compared to the previous application of ENA in specific element metabolism simulation (e.g., water [58,59] and carbon [60,61]), energy system analysis [62,63], and supply security assessment for a single energy source [44–47,64–66], the ENA-based common evaluation platform established in this paper will help a country fast obtain a clear contour of national energy supply security for different energy sources, which is valuable for establishment of national energy strategy.

Moreover, based on ENA, it is possible to measure quantitatively the direct and indirect relationships (influences) among different compartments and that between the system and the surroundings, which can further simulate the dynamics of the overall system and comprehensively analyze the features of the system [49–51]. All the aforementioned factors contribute to the second issue.

2. Methodology

2.1. Ecological network model of the energy supply system in China

A general network model must be established to simulate and analyze the supply systems for different energy sources. It mainly includes the following steps [53]:

(1) Identify the system of interest and confirm its boundary. Specifically, we pay attention to the energy (crude oil and natural gas) supply systems of China from 2000 to 2012, which includes China itself and foreign regions that import energy to China.
(2) Determine the main compartments and connections in the system and construct a conceptual network model of the energy supply systems in China (see Fig. 1). Herein, basic knowledge of energy flows and the overall situation of Chinese energy production, refining, consumption, reserves, imports, and exports should be referred to. No matter what types of energy sources are considered, the energy supply system mainly includes domestic compartments

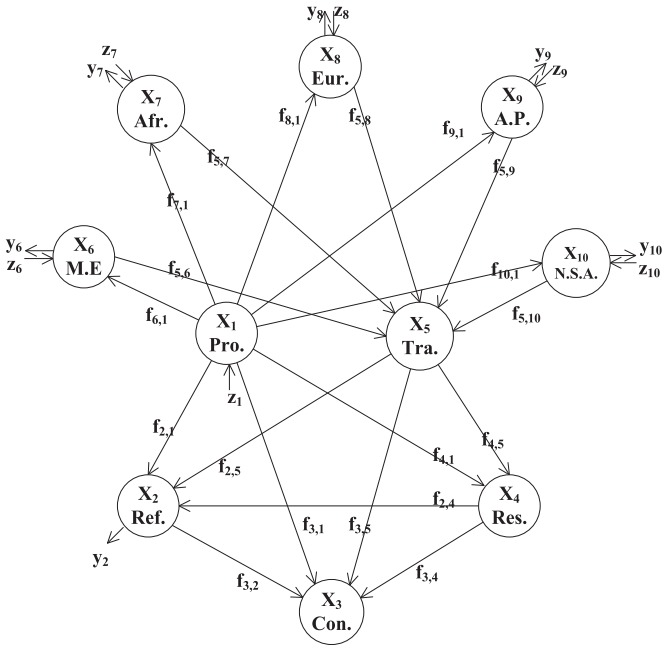

Fig. 1. Ecological network model of the energy supply system in China.