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A systematic method of evaluation of the Chinese natural gas supply security

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HIGHLIGHTS

- Ecological network analysis is adopted to evaluate natural gas supply security.
- A network model of natural gas supply system in China is established.
- The contributions of different compartments to supply security are ranked.
- The relationships among different compartments in the network are analyzed.
- Suggestions based on scenario analysis are given to improve supply security.

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ABSTRACT

As a relatively clean energy, natural gas will be increasingly in demand to meet short-term low-carbon targets. The gap between the demand and supply of natural gas will be increasingly scrutinized, which highlights the significance of natural gas supply security. Considering the extensive connections among various aspects related to natural gas supply and the complex interactions behind these connections, ecological network analysis was applied to simulate the natural gas supply system in China and systematically measure its overall security level. Network Information Analysis, Structural Analysis, and Utility Analysis were conducted. It is found that the Chinese natural gas supply security increased during 2000–2011. In terms of the influence of different compartments on the whole natural gas supply system, in order from the largest to smallest influence they are: supply sources, consumption sector, refining, and reserve sectors. And the relationships among compartments became stronger in the later stage than that in the earlier stage of the study period. Suggestions on improving China's natural gas supply security were proposed based on the results and further scenario analysis. The network model developed herein is a new perspective for natural gas supply security assessment, which can be used as guidance for policy making.

1. Introduction

Natural gas (NG), as a cleaner fossil energy source than coal and oil especially during its consumption [1], is now commonly believed helpful to offer solutions for improving air quality and adapting to global climate change. Considering volatile oil prices, an unstable international oil market, and the great potential of NG exploitation [2], the demand for and concerns of NG are increasingly raised in the global energy markets. In 2013, global NG consumption grew by 1.1% while the NG production only grew by 0.8% [3]. This caused the dependency on NG imports. It is reported that the amount of global NG imports reached 997.2 billion m^3 in 2014 among which North America imported 128.5 billion m^3, Europe imported 414 billion m^3 and Asia Pacific imported 300.5 billion m^3 [3]. And, as estimated by the International Energy Agency, by 2030, 25% of the world's energy needs will be covered by NG, while the global NG consumption will be double the 2008 level by then [4]. These facts and projections lead to policy makers to become increasingly serious regarding the potential threat to the global NG security.

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As a representative of rapid economic development around the world, China's NG consumption will increase to 260 billion m^3 in 2015 with an annual growth rate of 18.99% during 2011–2015 [5], when compared with that of 109 billion m^3 in 2010 [6]. And it is even predicted that China's NG consumption will continuously rise and exceed 350 billion m^3 by 2020 [7–9]. On the other hand, the NG production is limited and cannot satisfy the increasing consumption demands. It is predicted that the total amount of China's NG production in 2015 and 2020 will reach 134 billion and 197 billion m^3, respectively [10]. Furthermore, Lin and Wang [11,12] predict that China's NG production will peak around the 2020s, after which the gas production will decline rapidly. Such a gap between the consumption and production of NG leads to the dependence of China's natural gas supply (NGS) on imports, with the foreign dependency degree of 21.56% in 2011 [13]. And, this dependency will reach nearly 50% in 2015, which induces strong concerns about the China's natural gas supply security (NGSS), which is evaluated and regulated in this paper.

A number of studies have evaluated and analyzed NGSS, which can be mainly classified into three streams: (1) analyzing the influence of one specific factor on the NGSS, (2) analyzing the overall status of NGSS in specific regions, and (3) proposing measures to improve NGSS based on analyzing the dynamics of NGSS. In terms of the first stream, both external factors (supranational or supra-regional) and internal factors (national or regional) were considered to investigate their influences on the NGSS in specific countries and regions. The considered external factors mainly include external supply sources [1,14–19] and international gas price [20,21], while the internal factors include the households' willingness to pay for safeguarding NGSS [22], liberalization (e.g., legal governance and market regulation) [23], NG production [24], NG consumption [13], and civil unrest [25].

Although much more attention has been paid to the first stream, analysis of the overall status of NGSS will provide more comprehensive information for improving the level of regional NGSS than analysis of the influence of a signal factor on the NGSS, which is essential for holistic policy making. Both qualitative and quantitative methods have been applied to analyze the overall status of NGSS. The qualitative studies analyzed the status quo of NG consumption, summarized the problems faced by the NGSS, and proposed measures to improve the NGSS such as strengthening energy politics and diplomacy, diversifying NGS sources, and improving NG storage facilities [26–29]. In terms of quantitative methods, an indicator-based assessment [30–36] and model-based analysis [37–41] were conducted. By comparison, model-based analysis would be better for evaluating the overall status of NGSS, since it is difficult to quantify comprehensively the overall security by using an individual indicator or synthesizing different but interactive indicators. However, the existent models such as the dynamic model for simulating the indigenous NG industry [37], and the simulation model for describing the gas supply chain [39] are unable to consider and reflect the real and complex relationships among different sectors within the NGS system, which will reduce the effect on the actual policy making.

Besides evaluating NGSS, there are also some studies focusing on the political, strategic, and operational decisions to improve NGSS. Geng et al. [42] analyzed the evolution characteristics of the international natural gas trade structure and gave suggestions for natural gas trading countries to adopt feasible and targeted trade strategies. Higashi [43] analyzed the evolution of China's natural gas market and Wood [44] analyzed the global and regional LNG trade over the past 20 years, based on which strategic suggestions were put forward to maintain the stability of NG system. Siddig and Grethe [45] supported Israeli decision makers by investigating the effects of reduced gas imports from Egypt and the evolvement of domestic gas production as an alternative. Üster and Dilaveroğlu developed a decision support tool to aid decision makers in optimizing NG transmission networks with minimal total investment and operating costs [46]. Because the various sectors related to the NGS are not integrated in a holistic system with complicated interactions, it is difficult to predict comprehensively the possible change of the NGS system after implementing certain policies. This implies that the impact of the proposed policies on the overall NGSS is unpredictable, which will may cause risk for NGSS.

Focusing on these issues, this paper aims to (1) comprehensively evaluate NGSS when integrating various components in a system, and (2) give suggestions to improve NGSS based on analyzing the characteristics of the NGS system and quantitatively measuring the impacts of different means on the NGS system. Therefore, ecological network analysis (ENA), a general systems-oriented analytical tool which connects all of the objects within a system and measures their relationships [47], is selected as the approach to simulate systematically the NGS system and to measure the overall security. By integrating the complex relationships among different components within the system as well as that between the system and the surroundings, ENA can quantitatively analyze the direction of various ecological flows and the interactions among them in a network system, and reveal the integrity and complexity of ecosystem behaviors [48]. Moreover, it is possible to identify the key components and pathways for the NGSS by analyzing the structure of the NGS system and the relationships among different components. Subsequently, corresponding measures can be selected to improve NGSS and the effect can be ensured to a certain extent by projecting the impacts of different measures on the NGS system.

2. Methods and data

2.1. Definition of NGSS

It is well acknowledged that the term "energy security" is polysemous [49], whose definition is usually related to the site, purpose, and period of a given study [50]. Among the various definitions of energy security which usually includes the security of both energy supply and energy use, the most widely used one is described as "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns" by IEA [51]. Focusing on the NGS system which connects all related compartments (e.g., NG production sector and different external supply sources) within a network, the NGSS is defined as an adequate supply of NG to allow the NG network to operate stably and sustainably even with certain disturbances. And, the overall level of NGSS can be measured by the ENA-based sustainability indicators.

2.2. Ecological network analysis of NGSS

2.2.1. Construction of the ENA model

According to the basic processes of ENA [52,53], assessment of NGSS mainly includes the six steps shown in Fig. 1.

Specifically, the Chinese NGS system has fewer import sources and a shorter import history, compared with the Chinese crude oil supply system [54]. It induced a more detailed network model where 18 compartments are divided in the NGS system (see Fig. 2), including (1) the NG production sector, (2) refining sector, (3) consumption sector, (4) reserve sector, (5) transit sector, (6) Turkmenistan, (7) Qatar, (8) Australia, (9) Indonesia, (10) Malaysia, (11) Yemen, (12) Russian Federation, (13) Nigeria, (14) Egypt, (15) Trinidad & Tobago, (16) Oman, (17) Algeria, and (18) Other Countries with less export of NG into China than the