



A dynamic analysis on global natural gas trade network



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HIGHLIGHTS

- The international natural gas trade is analyzed using complex network theory.
- Natural gas market integration is analyzed using the minimum spanning tree model.
- Both the LNG and pipeline gas trade networks display scale-free distributions.
- The markets in North America, Europe and Asia are not integrated.
- The improvement of market integration will promote the trade globalization.

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ABSTRACT

This paper analyzes the evolution characteristics of the international natural gas trade structure and the integration of the international natural gas market by using complex network theory. It is found that both the LNG and pipeline gas import and export trade networks display scale-free distributions, while the countries in the LNG trade network are linked more closely than those in the pipeline gas trade network. The markets in North America, Europe and Asia are not integrated, which indicates that a unified global natural gas market has not yet been formed. However, the degree of integration between the European and Asian markets is relative strong during 2000–2011. Finally, the integration among international natural gas markets and the inter-regional LNG trades are highly interrelated and mutually influencing.

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1. Introduction

To ensure energy supply security and address global climate change, the development of various low-carbon energy sources has been accelerated significantly in the world [18,23,27]. Especially, natural gas, a kind of relatively clean fossil energy, is widely favored by many countries and is perceived to be the bridge to a low-carbon future [1,4,22]. The world's reserves of natural gas are rich, and the exploration of natural gas has great prospects. The world's proven reserves of natural gas were 208.4 trillion cubic meters, and the reserve-production ratio was 63.6 in 2011 [3]. The IEA [12] thought that the world was entering the golden age of the use of natural gas. Due to the uneven distribution of natural gas reserves and the upward growth of natural gas demand, natural gas trading activities have become increasingly frequent, and trade volume has been growing rapidly. In 2011, 35.29% of natural gas consumption was done by the way of trade, and the average growth rate of the international natural gas trade reached 6.90%

during 2000–2011 [3]. Natural gas trade will continue to increase rapidly in the future.

Compared with the relatively flexible and free form of the oil trade, the liquidity of the natural gas trade is restricted by the market structure of the regional natural gas trade and is affected by the configuration of natural gas. (1) The pattern of the natural gas market and the pattern of natural gas trade are closely related. Due to the different price standards that the different regional markets are based on, the international natural gas market is divided into three major, distinct regional markets: North America, Europe and Asia. In North America, there is a competitive market system, and the market controls risk through cash and derivatives markets; in the European market, the price is mainly based on those of competing energy sources, such as oil, and most of the trade is based on long-term contracts; natural gas trade in the Asia-Pacific region is priced mainly through oil indexation and is also based on long-term contracts. These different kinds of price formation mechanisms make LNG prices in Europe and Asia higher than the ones in North America [25]. (2) There are two kinds of natural gas trade: pipeline gas trade and LNG trade, and each of these two trade forms has different characteristic. For a long time, due to being restricted by the

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configuration of natural gas, the natural gas trade was mainly conducted via pipeline, and the scope of trade and trade bodies were greatly hampered by this form of trade [5]. However, the emergence of LNG trade has greatly increased the flexibility and mobility of the international natural gas trade.

With the increase of LNG trade, the pattern of international natural gas trade is bound to change, and the evolution of the natural gas trade will have an important impact on gas-exporting countries and importing countries. The natural gas market is the carrier of the natural gas trade, and the relationships between the different regional markets have a significant impact on the formation of international natural gas trade patterns. Therefore, this paper began the study from the two perspectives: the volume and prices of the natural gas trade. This paper investigates the complex characteristics of natural gas trade pattern, its dynamic evolution and the relationship between the evolution of the international gas market structure and the evolution of the international gas trade in order to understand the distribution mode of the natural gas trade and the structural market characteristics of natural gas. It has very important practical significance for natural gas trading countries in terms of mastering international trade law and adjusting natural gas trade strategies in order to protect the supply security of natural gas.

The studies on international natural gas trade patterns are mainly performed via qualitative analysis, while quantitative research projects are less common. Mazighi [20] analyzed the process of international gas trade evolution from 1970 to 1997, and the results showed that a strong correlation existed between the international pipeline gas trade and the LNG trade. At the same time, it pointed out that the globalization of the LNG trade was associated with not only the increase of the share of the LNG trade but also with the increase of inter-regional LNG trade volume. Mazighi [21] discussed the driving force that made the globalized market of natural gas form and pointed out that the globalization of the natural gas trade was related to not only the growing demand for natural gas but also to the willingness of natural gas-exporting countries to sell natural gas according to short-term contracts. Arora and Cai [2] evaluated the potential global impacts of increase in U.S. natural gas exports as a result of the shale gas boom using a global economic model. It is found that world economic activity is higher through most of the simulation period and the U.S. benefits more when U.S. natural gas exports rise.

Currently, the international natural gas market is divided into three major, distinct regional markets: the North American, European and Asian markets. There are many debates regarding the globalization of the natural gas market. Some people think that the international natural gas market will remain broken up into regional markets due to the various resource endowments and geographical factors. The IEA [10] reported that the regional natural gas markets will tend to globalize with the increase in the number of natural gas-producing countries and consuming countries, as well as the advent of the LNG spot market and the formation of short-term contracts. Higashi [9] analyzed the evolution of China's natural gas market in terms of market structure, demand and supply; natural gas prices and the security of the supply and pointed out that China would become the largest pipeline gas-importing country in the Asia-Pacific region and the third largest LNG-importing country by 2015. He also pointed out that the global economic crisis had a negative impact on China's natural gas market. The IEA [11] argued that the rise of unconventional natural gas production in North America had regional and global influences and that it had considerably reduced the natural gas import volume of the United States. Wood [30] analyzed the global and regional LNG trade over the past 20 years and pointed out that the LNG market in Europe had been rapidly developing in the past decade but that Asia would be still in the dominant position regarding LNG trade.

Research on the degree of integration of natural gas markets is as follows: Siliverstovs et al. [26] analyzed the degree of integration of natural gas markets in Europe, North America and Japan from 1990 to 2004. The results showed a high level of natural gas market integration within Europe, between the European and Japanese markets and within the North American market. However, the results obtained suggested that the European market and the North American market, as well as the Japanese market and the North American market, were not integrated. Neumann et al. [24] and Neumann [25] used a Kalman filter model to study the degree of integration among the different regional natural gas markets and found that the degree of integration within the European market, as well as between the North American and European markets, was improving.

This paper has three main contributions: (1) the international pipeline gas trade network and LNG trade network are constructed using complex network theory to analyze the topological and evolutionary characteristics of international natural gas trade patterns. (2) The minimum spanning tree model of the international natural gas market is constructed to explore the market structure and the degree of integration of natural gas markets. (3) The relationship between the evolution of international natural gas market integration and the evolution of inter-regional natural gas trade is analyzed. The main findings of this paper are that both the international pipeline gas and LNG trade network display scale-free features, in which the trade position of nodes presents obvious heterogeneity. There is still a separated global natural gas market, while increasing inter-regional LNG trades will accelerate the integration of regional natural gas markets. These findings will help natural gas trading countries master the spatial distributed characteristics and understand the trade rules to optimize their trade strategies and ensure energy supply security.

The remainder of this paper is organized as follows: in Section 2, the models are constructed. In Section 3, the international natural gas trade network is analyzed. In Section 4, the relationship between the evolution of international natural gas market integration and the evolution of international natural gas trade pattern is analyzed. Section 5 provides concluding remarks.

2. Models and methods

This paper constructs the international gas trade networks in order to analyze the international natural gas trade pattern and constructs a model of the minimum spanning tree in order to analyze the degree of integration among various regional natural gas markets and further analyze the relationship between the evolution of international natural gas market integration and the evolution of international natural gas trade patterns.

2.1. The international natural gas trade network model

In this paper, the international natural gas trade network can be abstracted as a connected network $G=(V,E)$ by V and E , where $V=\{v_i:i=1,2,\dots,n\}$, $n=|V|$ is the number of nodes and $E=\{e_i:i=1,2,\dots,m\}$, $m=|E|$ is the number of edges. The nodes represent the countries, and the edges represent the fact that there are relationships between each of the countries. The data on the international LNG trade and the pipeline gas trade are extracted from BP's statistical review of world energy 2001–2012 [3]. The interval of the data is from 2000 to 2011. This paper analyzes the international natural gas trade network mainly via two aspects: the topology of the natural gas trade network and the evolutionary characteristics of natural gas trade pattern.

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