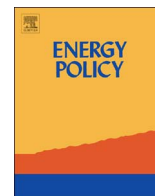




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The roles of countries in the international fossil fuel trade: An emergy and network analysis

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HIGHLIGHTS

- Trade amounts of coal, crude oil and natural gas are transformed into Emergy.
- Integrated complex network model of international fossil fuel trade is constructed.
- Geographical factor is reinforced due to the restriction of transportation cost.
- The old pattern is breaking and the new pattern is forming.
- Different countries play different roles in international fossil fuel trade network.

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ABSTRACT

A better understanding of the roles of countries in the international fossil fuel trade is crucial for trade security and policy optimization. This study aims to provide a new way to quantitatively analyze the roles of countries in the international fossil fuel trade by complex network analysis and Emergy theory. We transform the trade quantity of coal, crude oil and natural gas into emergy and the sum of the three emergies is the emergy of fossil fuel. We build up network models of fossil fuel based on the value of fossil fuel emergy. Then, the top relationships, the central position, the intermediary ability of the countries, and the roles of countries in the trade groups were used to analyze the roles of countries in the international fossil fuel trade network. We choose four countries, the USA, China, Russia and Saudi Arabia, as examples to show the analysis of roles and policy implications. We suggest that the USA and Russia should try to improve their intermediary abilities by diversifying their trade orientations and pay more attention to building up relationships with countries in different communities. China should seek for more tight relationships with other countries to improve its central position, and more pipelines connecting China, Russia, and other Middle Asia countries are needed. As for Saudi Arabia, expanding its industrial chain of crude oil is a better way to deal with the more fierce competition in the market.

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1. Introduction

Fossil fuel is the most important energy in the modern society. It flows between countries by international trade due to the uneven distribution of production and consumption. Many political affairs and economic events occurred for the sake of fossil fuel. For

an importing country, the trade security of fossil fuel is finding sufficient importing links to meet its domestic demand (Wu et al., 2009); while for an exporting country, the major concern is keeping its power in the fossil fuel market to maintain its profit (Leung and Jenkins, 2014). Thus, a better understanding of the roles of countries in the international fossil fuel trade is crucial for trade security and policy optimization (Ji and Guo, 2015; Vivoda, 2014; Zhao and Chen, 2014). This study aims to provide a new way to quantitatively analyze the roles of countries in the international fossil fuel trade by complex network analysis and emergy transformity. We choose four countries, the USA, China, Russia and

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Saudi Arabia, as examples to show the analysis of roles and policy implications.

The roles of countries in the international trade and their policies are studied by many scholars. Some studies are on the perspective of economics, for example, economic evaluation of Peru's liquefied natural gas export policy was carried out and found that Peru does not have sufficient reserves to warrant export, and the economic costs far exceed the benefits (Leung and Jenkins, 2014). The role of fluctuating modes of auto-correlation in crude oil prices (An et al., 2014b) and patterns in the fluctuation of the co-movement between crude oil futures and spot prices (An et al., 2014a) was studied. The transmission of fluctuant patterns of the forex burden based on international crude oil prices was studied (Gao et al., 2014). Some studies focused on energy security, for example, the indicators for energy security and possible benefits of climate policy include increased fuel diversity and slower depletion of fossil resources (Kruyt et al., 2009). Some studies focused on models and policies. For example, long-term energy-system developments in Africa was studied based on Integrated Assessment Models and found that an important challenge is to align the increasing investments in the energy-system with climate policy and potential revenues from international carbon trading (Lucas et al., 2015). These studies obtain abundant achievements with practical significance.

However, international trade is a huge system with numerous countries and complicated relationships. The role of a country is not only determined by its own characteristics, but also affected by the countries that have relationships with it. Complex network method has the advantage of dealing with numerous nodes and interactive links. Recently, some researchers studied the regional energy security and global oil trade patterns by complex network analysis. For example, the community structure of the international-trade multi-network was studied and found that geography-induced partitions of the cluster of countries are much more correlated with observed community structures than partitions induced by regional-trade agreements (Barigozzi et al., 2011). The countries' roles and positions in international trade was studied by complex network method and found the important positions of the EU, USA and Japan in the international trade system (Fan et al., 2014). These studies are excellent applications of complex network method on international trade.

On international trade of fossil fuel, global oil trade patterns was studied by complex network theory. The global oil export core network displays a scale-free behavior, the current global oil trade network can be divided into three trading blocs, and geopolitics and diplomatic relationships are the two main reasons for this regional oil trade structure (Ji et al., 2014). Research on the evolution of communities of countries in the international oil trade network showed that different causations of instability have different features and this should be considered by policy makers (Zhong et al., 2014). The trading-based relationships between countries in the international crude oil trade network (An et al., 2014c) was another perspective to study the roles of countries and the trade pattern. The evolution characteristics of the international natural gas trade structure was also studied by complex network theory. The integration among international natural gas markets and the inter-regional LNG trades are highly interrelated and mutually influencing (Geng et al., 2014). These studies provided insights into the research of international trade network of fossil fuel. However, as far as we know, most of the previous studies on fossil fuel trade pattern are based on single commodities, for example crude oil or natural gas. Our work is an integrated study of fossil fuel trade for a better understanding of the roles of countries in the world energy market.

According to the statistics of U.S. Energy Information Administration, the three major types of fossil fuel (crude oil, coal and

natural gas) account to 86% of the world total primary energy consumption in 2012.¹ The trade commodities of coal, crude oil and natural gas are in different forms and units. Traditionally, we use money to measure the international trade of fossil fuel. However, the trade volumes are impacted by the fluctuating prices and exchange rates. Energy can be used to measure the ability to cause work and exergy can be used to measure the maximum useful work, however these two methods cannot reflect the “energy cost” – the amount of energy that is needed in order to produce a certain amount of fossil energy. Emergy is a quality of “energy memory” considering the difference of energy quality and the embodied energy (Brown et al., 2004; Odum, 1996). Many scholars applied Emergy theory in a wide range of researches. For example, Emergy analysis was applied to the ecological impacts of small hydropower in China and found that China should rigorously investigate potential ecological problems of SHP development and proceed with caution rather than readily believing unjustified assumptions (Pang et al., 2015). The method of embodied energy and emergy analyses of a concentrating solar power (CSP) system was discussed and improved (Campbell, 2013; Zhang et al., 2012). Emergy analysis measures the values of resources, services and commodities in common units of the solar energy used to make them (Brown and Herendeen, 1996; Brown et al., 2011). Thus, we can transform the trade quantity of coal, crude oil and natural gas into emergy by their transformity (in units of seJ/J). The sum of the three emergies can be used to measure the emergy of fossil fuel. Based on the value of fossil fuel emergy, we can build up the complex network model of international fossil fuel trade. Our work provides a quantitative study of the roles of countries in the international fossil fuel trade combining Emergy theory and complex network method.

In Section 2, the data of coal, crude oil and natural gas are transformed into emergy, and the emergy proportions of the four countries are analyzed. In Section 3, the network models are constructed, and the top relationships of the four countries are studied. In Section 4, the central position and the intermediary ability of the countries are studied based on complex network indexes. In Section 5, an algorithm is introduced to detect the trade groups in the network, and the roles of countries in the trade groups are studied. Section 6 is the discussion and conclusion remarks.

2. Transform data into emergy

The data of international trade of the three commodities is from the website of *UN Comtrade*, which contains all export and import flows among 226 countries in the world. We select the annual trade data from 2000 to 2013. The description of the data source, the energy content of the commodities and the transformity are shown in Tables 1–3. We transform the trade quantities of the three fuels into emergy and the sum of them is the emergy of fossil fuel.

We choose four countries, the USA, China, Russia and Saudi Arabia, as examples to study the roles of countries in the international fossil fuel trade. The USA is the country who imports the highest value of emergy in most of the years, and China is the country whose import emergy was rocketing and became the biggest importing country in 2013 (please see Table 4). Russia has been the No. 1 exporting country of fossil fuel since 2001, and Saudi Arabia ranked No. 2 in most of the years (please see Table 5).

The total import and export value of emergy of the four countries are shown in Fig. 1, and the emergy proportion of coal,

¹ <http://www.eia.gov/totalenergy/>

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