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Global pattern of the international fossil fuel trade: The evolution of communities

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ABSTRACT

In the international trade of fossil fuel, countries are clustering into communities. The evolution of the communities can reflect the underlying trade pattern. This paper provides a new perspective in analyzing the global pattern of international fossil fuel trade by quantitatively analyze the evolution of the communities. Emergy transformity are used to unify the three different fuels into the same unit seJ. This paper creates network models of fossil fuel as well as coal, crude oil, and natural gas and detected the clustering of the countries by an algorithm. Three types of Normalized Mutual Information are designed to measure characteristics of the evolution of the communities. A matrix is also designed to show the flows between each two communities.

This study finds that the natural gas trade network is the most partitioned and the most stable. In 2013, natural gas exceeded crude oil had the highest similarity with the integrated fossil fuel trade pattern. 2012 was a turning point. The trade blocs and organizations play important roles. However, their effects are limited. The geographical factor is reinforced and the roles of the USA and Russia are becoming more important. Clusters containing Asia Pacific countries are less stable.

1. Introduction

Coal, crude oil and natural gas are the most important types of energy in modern society. Because of the uneven distribution of production and consumption, these three fossil fuels flow between countries by international trade [1]. A better understanding of the evolution of the global pattern of the international trade of fossil fuel is important to policy makers. In the international trade of fossil fuel, countries are clustering into communities (or clusters) [2]. Some countries are closely related while others are loosely related. Trade blocs such as European Union (EU), North American Free Trade Agreement (NAFTA), and organizations such as Organization of Petroleum Exporting Countries (OPEC) are well-known communities formed by trade agreements and/or political strategies. However, do the relationships among countries follow the same pattern in the real world? A detailed quantitative analysis of the clustering of the countries is needed to reveal the true pattern of the fossil fuel trade. This study introduces a new perspective to quantitatively analyze the evolution of communities in the international trade of fossil fuels by complex network analysis and emergy theory, and provides a series of indexes and methods to portray the dynamic evolution of the global pattern which can be useful references to the policy makers.

There are two questions need to be answered before we carry out the study. First, how to modelling the global pattern of international trade? Most of the previous studies are based on traditional international trade theories and models. For example, Halkos et al. designed a visual framework to display multi-region and multi-sector classical models, and it can illustrate the interactions among interregional and intersectoral economic activities [3]. Bernhofen took a set of conceivable outcomes as the primitive and

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predicted the pattern of international trade in the neoclassical model [4]. Yang et al. studied the country risk and potential oil exports in the international oil trade [5]. Feijoo et al. studied the impact of cross-border trade between North American and Mexico by natural gas model [6]. These studies provided some methods to analyze international trade pattern. However, these studies are carried out in the perspective of country-to-county, region-to-region, or sector-to-sector. Actually, international trade is a dynamic system with numerous countries and complicated relationships. There needs a systematic model to reflect the global pattern of international trade.

Complex Network Method is an effective way to modelling complicated systems. In previous studies on trade networks, researchers found that the international trade network is typically divided into communities according to geography or GDP rather than by regional-trade agreements [8]. Furthermore, in previous studies on energy trade network Ji et al. applied a global oil trade core network to analyze the overall features, regional characteristics, and stability of the oil trade [9]. Some researchers studied the competition relationship between countries in the international crude oil trade network [10], and the trading-based relationship [11]. Estimating potential trade links in the international crude oil trade by link prediction approach [12]. There was also network analysis on international trade of natural gas [13].

Community analysis of Complex Network Method can be used to reveal the global pattern of international trade. It has the advantage of finding clusters in numerous nodes and interactive links [7]. Whether or not two countries are in the same community is not only determined by the tightness of the relationships between the two of them, but also affected by the other countries that have relationships with them [2]. In previous studies, the authors applied weighted and unweighted complex network models to study the evolution of communities in the international oil trade [19]. Normalized Mutual Information (NMI) was used to measure the global pattern of the trade communities. NMI indicates the similarity of two results of partitions obtained in the network [20]. Previous study is only an application of the original index. In this study, three types of NMI are designed to go a step further in quantitatively measuring the global pattern of the international fossil fuel trade network.

The studies on international trade network of energy we mentioned above are based on single commodity. However, international trade of fossil fuel is an integrated system with the main commodities of coal, crude oil and natural gas. There comes the second question. How to construct an integrated network model of coal, crude oil and natural gas? This study introduces a way to construct a complex network model of the integrated fossil fuel trade based on Emergy Theory. As we all know, the main commodities of fossil energy are with different forms and units. Money can be used to measure the trade volume, however the price and exchange rate are fluctuating continuously [14] which will affect the results. Energy can be used to measure the ability to cause work and exergy can be used to measure the maximum useful work [15], however these two methods cannot reflect the “cost” of the energy, namely how much energy is needed in order to produce a certain amount of fossil energy. This study introduces the concept of Emergy to measure the trade quantity of coal, crude oil, and natural gas. Emergy is the ‘energy memory’ of the commodity which considering the cost of energy in the geological process, and in the processes of production and transportation in common units of the solar energy [16]. Thus, the trade quantity of coal, crude oil, and natural gas can be transformed into emergy by their transformities (in units of seJ/J) [17,18]. The sum of the three emergies can be used to measure the emergy of fossil fuel. The trade flow of fossil fuel can be represented by the emergy flow. In this study, comparing the evolution of fossil fuel trade communities with the single commodity trade communities can reveal the underlying patterns of the world energy market.

In section 2, the data sources, transformity, network model, algorithm of community detecting, and network indexes are introduced. In section 3, the total emergy, the number of communities and Modularity, the similarity between single and integrated networks, the deviation of the communities and the stability of the communities are studied. In Section 4 there are discussions about the results from two aspects: the roles of coal, crude oil and natural gas; and the evolution of the global pattern around the turning point.

2. Data and method

2.1. Data and transformity

The data of international trade of coal, crude oil and natural gas is from the website of *UN Comtrade*, which contains all export and import flows among 226 countries in the world. The trade quantities are measured by the units of kilogram. The annual trade data of all the available countries from 2000 to 2013 are included in this study. The description of the data source, the energy content of the commodities, and the transformity of coal, crude oil and natural gas are shown in Tables 1–3. The trade quantities of the three fuels are transformed into emergy and the sum of them is the emergy of fossil fuel.

2.2. International trade network model

The complex network model $G = (V, E)$ contains two elements, the nodes V and the edges E, where $V = \{v_i : i = 1, 2, \ldots, n\}$, n is the number of nodes, and $E = \{e_k : k = 1, 2, \ldots, m\}$, m is the number of edges. $w_{i,j}$ is the weight from node i to node j. The matrix of the complex network model is

$$G = (V, E) = \begin{bmatrix} 0 & w_{1,2} & \cdots & w_{1,n} \\ w_{2,1} & 0 & \cdots & w_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n,1} & w_{n,2} & \cdots & 0 \end{bmatrix} \tag{1}$$

In the network model of international fossil fuel trade, the nodes are the countries and the edges are the trade relationships. The directions of the edges are the directions of the emergy flows, and the weights of the edges are the value of emergies. For example, if

Table 1
HS Code and data descriptions.

Commodity	HS Code	Description
Coal	2701	Coal; briquettes, ovoids and similar solid fuels manufactured from coal
Crude oil	2709	Petroleum oils and oils obtained from bituminous minerals, crude
Natural gas	271111	Natural gas, liquefied (LNG)
	271121	Natural gas in gaseous state (NG)

Note: Data source is http://comtrade.un.org/.