Complex Network Approach to International Trade of Fossil Fuel

Semanur Soyyiğit Kaya, Ercan Eren

***Abstract*—**Energy has a prominent role for development of nations. Countries which have energy resources also have strategic power in the international trade of energy since it is essential for all stages of production in the economy. Thus, it is important for countries to analyze the weaknesses and strength of the system. On the other side, international trade is one of the fields that are analyzed as a complex network via network analysis. Complex network is one of the tools to analyze complex systems with heterogeneous agents and interaction between them. A complex network consists of nodes and the interactions between these nodes. Total properties which emerge as a result of these interactions are distinct from the sum of small parts (more or less) in complex systems. Thus, standard approaches to international trade are superficial to analyze these systems. Network analysis provides a new approach to analyze international trade as a network. In this network, countries constitute nodes and trade relations (export or import) constitute edges. It becomes possible to analyze international trade network in terms of high degree indicators which are specific to complex networks such as connectivity, clustering, assortativity/disassortativity, centrality, etc. In this analysis, international trade of crude oil and coal which are types of fossil fuel has been analyzed from 2005 to 2014 via network analysis. First, it has been analyzed in terms of some topological parameters such as density, transitivity, clustering etc. Afterwards, fitness to Pareto distribution has been analyzed via Kolmogorov-Smirnov test. Finally, weighted HITS algorithm has been applied to the data as a centrality measure to determine the real prominence of countries in these trade networks. Weighted HITS algorithm is a strong tool to analyze the network by ranking countries with regards to prominence of their trade partners. We have calculated both an export centrality and an import centrality by applying w-HITS algorithm to the data. As a result, impacts of the trading countries have been presented in terms of high-degree indicators.

***Keywords*—**Complex network approach, fossil fuel, international trade, network theory.

I. Introduction

TRADITIONAL approaches to international trade analyze international trade in terms of first-degree indicators. These indicators are country-specific indicators such as total import/export, number of trade partners, export/GDP ratio which is also known as trade openness index, share of a good in total import/export etc. since they only take a main country into consideration. However, complex network analysis enables us to analyze international trade in terms of high-degree indicators. Thus, it becomes possible to analyze indirect relationships and impact of them among countries [1]. It is also possible to analyze international trade in terms of some complex network measures such as centrality, connectedness, assortativity or disassortativity, etc.

There are a great number of complex network analyses on international energy trade in the literature. Recently, international energy trade has become a popular subject to analyze as a complex network. In one of these studies, [2] analyzed international crude oil trade as a network. They analyzed the period from 1993 to 2012 for 181 countries as export and import flows. They analyzed the evolution of the basic features of international crude oil trade and they also studied some properties of these networks such as stability, hierarchy, and partition. As a result of the analysis, they found that the network evolved into a stable system in terms of their members and those members in import flow network was more stable than members in export flow network. They also found that this network evolved into an ordered hierarchy. Additionally, they found that the exporter countries were more integrated than the importer countries. They also observed that crisis in a part of the world caused the fluctuations of demand and this affected both exporting countries and importing countries [2].

Reference [3] analyzed also international oil trade network as unweighted and weighted network structure consisting of import and export flows among 176 countries for the period from 2002 to 2011. They detected the communities and the evolution of these communities in the network. They found different features between weighted and unweighted networks in terms of community number and community scale, stability of communities, distribution of countries etc. [3]. In another study, [4] analyzed international crude oil trade network and some properties of China in this network such as trade relation, control and anti-control abilities, and selection of trade partners by using weighted and directed network. They used export and import flows among 181 countries from the year 1993 to year 2012. As a result, they found a high increase in import volume of China and a severe decline in export. They also found that control and anti-control abilities of China increased during this period [4].

Reference [5] analyzed the evolution of spatial pattern of crude oil trade from 2001 to 2012. According to the results, there was little variation of importing and exporting nodes in spatial pattern from 2001 to 2012. They also revealed that the spatial pattern of world crude oil trade was heterogeneous.

Semanur Soyyiğit Kaya was with the Istanbul University, Istanbul, 34452 Turkey. She is now with the Department of Economics, University of Essex, Colchester, CO4 3SQ, UK as a post-doctoral research student (phone: +90 216 508 1406-20; fax: +90 216 508 1407; e-mail: ssoyyi@essex.ac.uk, semanurs83@gmail.com).

Ercan Eren is with the Department of Economics at Yildiz Technical University, Istanbul, 34220 Turkey (e-mail: eren@yildiz.edu.tr).

Either the structure entropy or weight entropy indicated that the spatial structure was not random network [5].

Reference [6] analyzed international fossil energy trade, which include crude oil, coal, and natural gas from 1996 to 2012 by using directed and weighted (out-weighted) network. According to the results, interdependency of countries increased while they carried out trade. Small countries had tendency to trade with regional hubs in local area while global trading countries had a lot of partners around the world [6].

In this study, it is aimed to analyze international energy trade as coal and crude oil networks in terms of their complex network structures. After analyzing and comparing these topological properties, w-HITS algorithm as a centrality measure is also applied to the data for each network. w-HITS algorithm, as a high-degree indicator, takes into consideration the prominence of a node's neighbors and assigns each node a hub score and an authority score.

II. Methodology and Data

The first step to examine complex systems is to decompose all system into its parts. In this context, networks are proper tools to represent complex systems [7]. A network is defined as a set which consists of nodes and links that connect these nodes. Networks correspond to graphs in mathematical literature.

A network is represented as G=(V,E) in mathematical terms. In this statement, V represents nodes (vertices) and E represents links (edges) [7]. Networks are classified as binary-weighted or directed-undirected with regards to properties of links. Links in binary networks have equal importance while links in weighted networks represent distinct values. Besides, links do not have a casual or a directional meaning in undirected networks while links represent the direction of the relations between nodes in directed networks [8].

As pointed out in [9], dynamics of state variables and evolution of network are two important features to distinguish in economic networks. A state variable x_i associated with a network can represent agent i's wealth, firm i's output etc. The dynamics on this state variable occur as a result of interaction among connected nodes. However, in case of evolution of a network, nodes and edges are added to or removed from the network by a specific mechanism. On this basis, they say that there are four types of dynamics to examine in economic networks. Table I summarizes these types of dynamics. There is also a difference between the dynamics of state variables and network evolution in terms of time scales. Dynamics of the state variables are fast while evolution of the network is slow [9].

TABLE I
Possible Combinations of Types of Dynamics in Economic Networks

	Static (State variables)	Dynamic (State variables)
Static (Network)	$\frac{dx_i}{dt}=0, \frac{da_{ij}}{dt}=0$	$\frac{dx_i}{dt}\neq 0, \frac{da_{ij}}{dt}=0$
Dynamic (Network)	$\frac{dx_i}{dt}=0, \frac{da_{ij}}{dt}\neq 0$	$\frac{dx_i}{dt}\neq 0, \frac{da_{ij}}{dt}\neq 0$

We can basically say that trade networks have dynamic structure in terms of either state variables or network evolution.

Degree / strength distribution is an important feature of a network since it indicates the complexity of network. It has been observed that there is power-law distribution in most real world networks. This structure can also be seen in wide range of places such as sizes of city population, earthquakes, the frequency of the use of words in language, sales of books and so on [10]. Mathematical function form of power-law distribution is as:

$$P(k) = Ck^{-\alpha} \quad (1)$$

α is known as the exponent of the power-law distribution and is usually in the range of $2 \leq \alpha \leq 3$ [10].

A network is analyzed in terms of four extents to examine its topological properties. These extents are connectivity, assortativity (or disassortativity), clustering, and centrality. Connectivity is measured by node degree for binary networks and by node strength for weighted networks. High node degree or node strength measure for any node i means that node i has big impact over the network [11]. Connectivity is measured by density throughout the network. Density is a coefficient between 0 and 1 and shows in what ratio the maximum possible number of links exist in network.

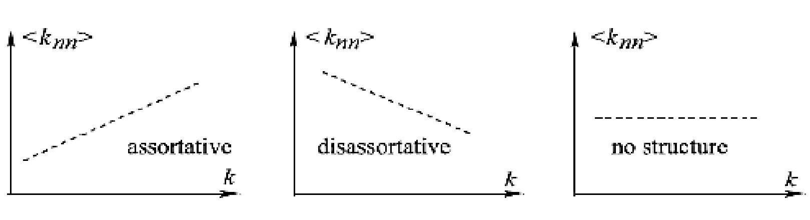


Fig. 1 Assortative / Disassortative Relationship

In the case of the assortativity, nodes which have high degree/strength tend to have link with nodes which have high degree/strength and vice versa. In disassortative case, nodes with high degree/strength tend to have link with nodes which have low degree/strength and vice versa. One method to determine the assortative or disassortative structure is to plot degree and ANND/ANNS (average nearest node degree/ strength) [7].

In Fig. 1, positive relation between ANND and degree indicates the existence of assortative structure while negative relation indicates the existence of disassortative relation [12]. Disassortative relation is also related to core-periphery structure in networks [13]. Another way to determine assortative/disassortative structure in networks is to calculate assortativity correlation coefficient. If this coefficient is negative then there is disassortative structure in the network and vice versa [7].

Clustering, as another property studied in networks, refers to the relation between two different nodes which are related to a node in common. It can also be stated as transitivity. Clustering coefficient is a number between 0 and 1. If it is 1 then there is perfect transitivity among nodes [14]. Clustering coefficient of node i is formulized for weighted networks as [15]:

$$C_i(W) = \frac{\frac{1}{2}\sum_{j\neq i}\sum_{h\neq(i,j)} w_{ij}^{\frac{1}{3}} w_{ih}^{\frac{1}{3}} w_{jh}^{\frac{1}{3}}}{\frac{1}{2}k_i(k_i-2)} \quad (2)$$

There are a large number of measures to determine centrality which is also a major feature of a network. Centrality refers to importance of a node in the network. Degree centrality, closeness centrality, betweenness centrality, eigenvector centrality, Katz centrality and PageRank centrality represent different measures which use distinct approaches to centrality. Hub and authority centralities are also one of the centrality measures which have become prevalent recently.

HITS algorithm which has been developed to analyze the centralities of web pages that are the results of a specific query in the internet assigns a hub score and an authority score to each web page. As is known, nodes with much out-degree are called hubs and nodes with much in-degree are called authorities in graph theory. Kleinberg has stated that there exist a ‘mutually reinforcing relationship’ between hubs and authorities. It means that a hub which has a large number of good authorities is a good hub. In a similar way, an authority which has a large number of good hubs is a good authority. Kleinberg has developed an algorithm which assigns a hub score and an authority score to each node on the basis of this relationship [16].

Hub and authority equations can be written in matrix notation as:

$$x = \alpha A y, \qquad y = \beta A^T x \quad (3)$$

By combining these equations in (3), we get (4):

$$AA^T x = \lambda x, \qquad A^T A y = \lambda y, \quad (4)$$

in which $\lambda = (\alpha\beta)^{-1}$. It can be seen that eigenvectors of AA^T and $A^T A$ are respectively equal to authority and hub centralities with the same eigenvalue in (4). If we multiply the both side of $AA^T x = \lambda x$ by A^T, then we get;

$$A^T A(A^T x) = \lambda(A^T x) \quad (5)$$

in which it can be seen that $A^T x$ is an aigenvector of $A^T A$ with the same eigenvalue, λ. Thus, this can be written comparing with (4);

$$y = A^T x \quad (6)$$

Equation (6) shows that it is easy to calculate hub centrality vector once we have authority centrality vector [10].

HITS algorithm which was developed for search query on the internet has also been applied to trade network data. Afterwards, HITS algorithm has been developed for weighted networks and has been turned into weighted HITS (w-HITS) algorithm in one of the applications of this method to trade data. This method enabled us to reveal international trade network structure and to rank countries according to their import/export impacts taking reciprocal dependency among them into consideration [17].

w-HITS algorithm which works with an iterative process represents the spreading impact among countries in international trade. In this process, each country u is linked with an export property y^u which represents the export impact of country u on international trade network and is linked with an import property x^u which represents the import impact of country u on international trade network. Afterwards, two operations (α and β) is defined to determine the import impact and export impact of country u as a result of trade with other countries. Operation α updates the import impact x^u and operation β updates the export impact y^u continually.

$$x^u \leftarrow \sum_{v:(v,u)\epsilon E} w_{vu} y^v$$
$$y^u \leftarrow \sum_{v:(u,v)\epsilon E} w_{uv} x^v \quad (7)$$

In (7), w_{vu} represents the export from country v to country u. It can be said that import property of country u depends on the import value of country u from country v and depends on export property of country v. In a similar way, export property of country u depends on the export value of country u to country v and depends on the import property of country v. these x^u and y^u values converge to their equilibrium values at the end of this iterative process [17].

In [18], the change of hubs and authorities of World trade from 1992 to 2012 was analyzed by applying w-HITS algorithm. The authors revealed that, although USA has saved its position as the biggest economic authority in this period, it has started to decrease since 2001. Authority score of China has been in uptrend whereas it has been the biggest hub country. Hub and authority scores of Europe have been in downtrend since European countries trade in the context of intra-EU. Authority score of Japan has increased slowly whereas its hub score has decreased. In [19], authors also used w-HITS algorithm to analyze international trade of food and beverages, industrial supplies and capital goods among the EU-28 countries and Turkey which is a candidate country for EU. They revealed that founder members of EU, excluding Luxembourg, have core positions for all groups of goods while countries which became participant in 2000’s represent periphery countries. Besides, they concluded that Turkey has specialized in export of goods that do not require much knowledge and capital stock.

In this study, international trade network of coal and crude oil has been analyzed from 2005 to 2014. The data have been obtained from United Nations COMTRADE database. R statistic software has been used for the application. First of all, these networks has been analyzed in terms of some topological properties such as clustering coefficient, density, transitivity, etc.. Then, some topological properties has been tested such as strength distribution, assortativity/disassortativity. Finally, hub and authority centralities of countries and evolution of them within 10-year period has been analyzed.

III. Results

A. International Coal Trade Network

Coal is a very major energy resource around the world although usage of it is aimed to be confined since excess use of it is one of the reasons of global warming and other environmental reasons. In 2012, 80% of world total final coal consumption is used in industry sector [20]. This ratio shows the importance of coal supply for the real economy. Thus, supplier countries in international coal network have strategic prominence while demander countries are in a risky position in terms of their own economies due to their dependency on this resource. There are some descriptive network statistics in Table II for international trade network of coal.

TABLE II
Network Statistics for International Trade of Coal

Years	Nodes	Links	Clustering	Density	Transitivity	Reciprocity
2005	172	1787	0.6063	0.0608	0.4183	0.3268
2006	176	1859	0.5955	0.0604	0.4066	0.3432
2007	173	1936	0.5877	0.0651	0.4121	0.3585
2008	175	1933	0.6230	0.0635	0.4151	0.3404
2009	170	1893	0.6397	0.0659	0.4248	0.3423
2010	170	2002	0.6137	0.0697	0.4219	0.3666
2011	181	2026	0.6097	0.0622	0.4082	0.3712
2012	180	2033	0.6185	0.0631	0.4120	0.3483
2013	179	2097	0.6394	0.0658	0.4239	0.3615
2014	179	1904	0.6070	0.0598	0.3940	0.3225

TABLE III
Assortativity Correlation Coefficient

Year	Assortativity Correlation Coefficient	Year	Assortativity Correlation Coefficient
2005	-0.01087	2010	-0.01216
2006	-0.02742	2011	-0.01466
2007	-0.02434	2012	0.00022
2008	-0.01666	2013	-0.01968
2009	-0.00608	2014	-0.00869

TABLE IV
KS Goodness of Fit Test for Power-Law Distribution

Years	alpha	KS statistics	p-value
2005	3.23531	0.09156	0.99999
2006	3.25899	0.11267	0.99985
2007	1.44574	0.11969	0.76615
2008	1.40221	0.14437	0.55928
2009	2.54969	0.10091	0.99999
2010	1.41574	0.13649	0.63128
2011	1.24971	0.11764	0.33854
2012	1.26473	0.13130	0.29918
2013	1.34230	0.12560	0.47667
2014	1.50465	0.12415	0.74427

When we look at the count of nodes and links, it can be said that international coal market has a stable structure. There are small fluctuations of the trade links. Thus, density of the network also fluctuates around the same rate which is almost always 6%. It can be seen that clustering coefficient as an indicator of transitivity of a network also changes with transitivity coefficient synchronically. Reciprocity coefficient which is defined as the probability of that the opposite counterpart of a directed edge is also included in the graph, also looks very stable and it indicates that there are some dominant supplier of coal and this situation does not change much within this period.

Assortativity correlation coefficients in Table III indicate that there is a disassortative structure of international coal trade network for each year except 2012. It also means that there is a core-periphery structure in the international coal trade network due to this disassortative structure.

As mentioned in methodology, one of the most important topological properties of complex networks is degree distribution since it shows how complex a network is. There are Kolmogorov-Smirnov (KS) test results for goodness of fit to power-law distribution in Table IV. Out-strength values have been used for testing since we are interested in export. Alpha in Table IV represents the exponent of power-law function in (1). If the p-value is greater than 0.05 then we cannot reject the H_0 hypothesis which claims fitness to power-law distribution. The results in Table IV show that the data fit to power-law distribution for each year. This also means that there is heterogeneity among countries in terms of connectivity and capability of exporting coal.

As explained in methodology, hub and authority centralities are high-degree indicators that take the prominence of the countries with which the main country is connected, into account. Thus, they are more informative than the first- degree indicators. Table V involves first degree indicators such as shares of the countries in the world coal export and also involves hub centralities to compare with these first degree indicators regarding to rank order of countries for 2005 and 2013.

Though we included 2014 in the analysis, we prefer to use the statistics of 2013 for comparison since it is a more stable year than 2014. Firstly, comparing the share of the countries in the world coal export with hub centrality for 2005 it can be seen that the top three countries are the same countries. However, though Russia, USA, South Africa, Poland, and the Netherlands have higher rank order in terms of share of export, their real performances is lower in terms of hub centrality. On the contrary, Canada, Vietnam, New Zealand, Belgium, Japan, and Germany have higher performance in terms of hub centralities.

In 2013, it can be said that Canada, China, Mongolia, Vietnam, Mozambique, Philippines, Ukraine and Japan have more central role in terms of hub centralities in comparison to export share. However, USA, Colombia, Poland, the Netherlands, and Ukraine are less central in terms of hub centralities.

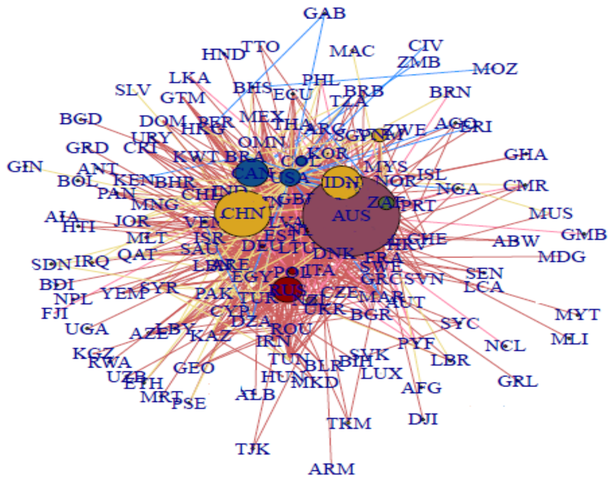
When we compare the hub centralities of 2005 and 2013, it can be said that Australia is the most central country, however, there is a decline in the hub centrality value. Indonesia, Russia, Canada, and South Africa has become more central while China has become apparently less central in terms of hub centrality. There are also import shares of countries as a first-degree indicator and authority centralities of countries as a high-degree indicator in Table VI. This table will also help us to see the difference between first and high degree indicators in terms of rank order and the prominence of countries. Looking at the authority centralities for 2005, it can be said that the Netherlands, Brazil, China, Mexico and Belgium are more central in terms of rank order in comparison to their import shares. Spain, Italy, Germany, Turkey and USA are lower in rank order in terms of authority centralities when compared to import shares.

TABLE V
COMPARISON OF HUB CENTRALITIES WITH FIRST-DEGREE INDICATORS

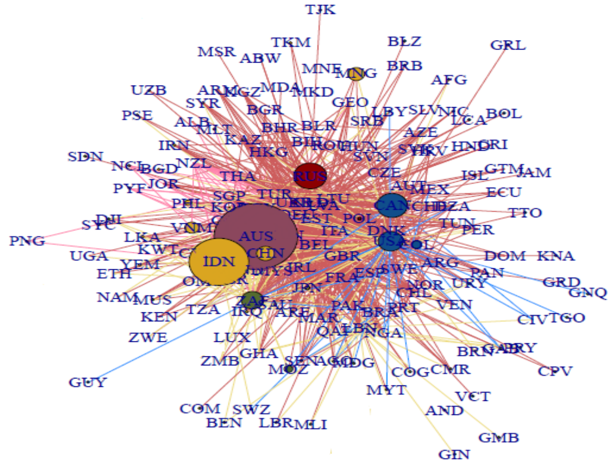
2005				2013			
ISO Codes	Hub centrality	ISO Codes	Share in the world coal export	ISO Codes	Hub centrality	ISO Codes	Share in the world coal export
AUS	0.9274	AUS	0.3152	AUS	0.8717	AUS	0.3202
CHN	0.3069	CHN	0.1253	IDN	0.4445	IDN	0.2033
IDN	0.1568	IDN	0.0822	RUS	0.1335	RUS	0.1030
CAN	0.1034	RUS	0.0803	CAN	0.1117	USA	0.0951
RUS	0.0864	USA	0.0663	USA	0.0740	COL	0.0555
USA	0.0408	ZAF	0.0618	ZAF	0.0591	ZAF	0.0484
ZAF	0.0230	CAN	0.0563	CHN	0.0387	CAN	0.0469
VNM	0.0229	POL	0.0496	MNG	0.0328	POL	0.0248
COL	0.0099	COL	0.0490	VNM	0.0239	CHN	0.0182
NZL	0.0097	CZE	0.0162	COL	0.0108	NLD	0.0110
POL	0.0064	VNM	0.0126	MOZ	0.0091	UKR	0.0095
BEL	0.0029	NLD	0.0120	PHL	0.0054	MNG	0.0093
NLD	0.0024	BEL	0.0100	UKR	0.0039	VNM	0.0076
JPN	0.0023	UKR	0.0090	JPN	0.0030	CZE	0.0073
DEU	0.0017	KAZ	0.0086	POL	0.0018	BEL	0.0064

TABLE VI
COMPARISON OF AUTHORITY CENTRALITIES WITH FIRST-DEGREE INDICATORS

2005				2013			
ISO Codes	Authority centrality	ISO Codes	Share in the world coal import	ISO Codes	Authority centrality	ISO Codes	Share in the world coal import
JPN	0.9139	JPN	0.2287	JPN	0.6808	CHN	0.2179
KOR	0.2914	KOR	0.0866	CHN	0.5759	JPN	0.1808
IND	0.2232	IND	0.0639	IND	0.3419	IND	0.1182
NLD	0.0823	DEU	0.0638	KOR	0.2800	KOR	0.0979
GBR	0.0689	GBR	0.0582	NLD	0.0533	DEU	0.0475
BRA	0.0552	USA	0.0433	MYS	0.0411	GBR	0.0354
CHN	0.0503	ITA	0.0390	GBR	0.0328	BRA	0.0219
FRA	0.0485	FRA	0.0337	THA	0.0287	NLD	0.0209
MEX	0.0477	ESP	0.0290	PHL	0.0244	FRA	0.0199
BEL	0.0424	NLD	0.0282	FRA	0.0235	ITA	0.0191
ESP	0.0391	TUR	0.0268	BRA	0.0231	UKR	0.0163
ITA	0.0385	BRA	0.0262	HKG	0.0204	MYS	0.0144
DEU	0.0290	CHN	0.0221	ITA	0.0152	ESP	0.0111
TUR	0.0209	BEL	0.0204	ESP	0.0138	BEL	0.0111
USA	0.0203	CAN	0.0186	TUR	0.0127	AFG	0.0109



(a) 2005

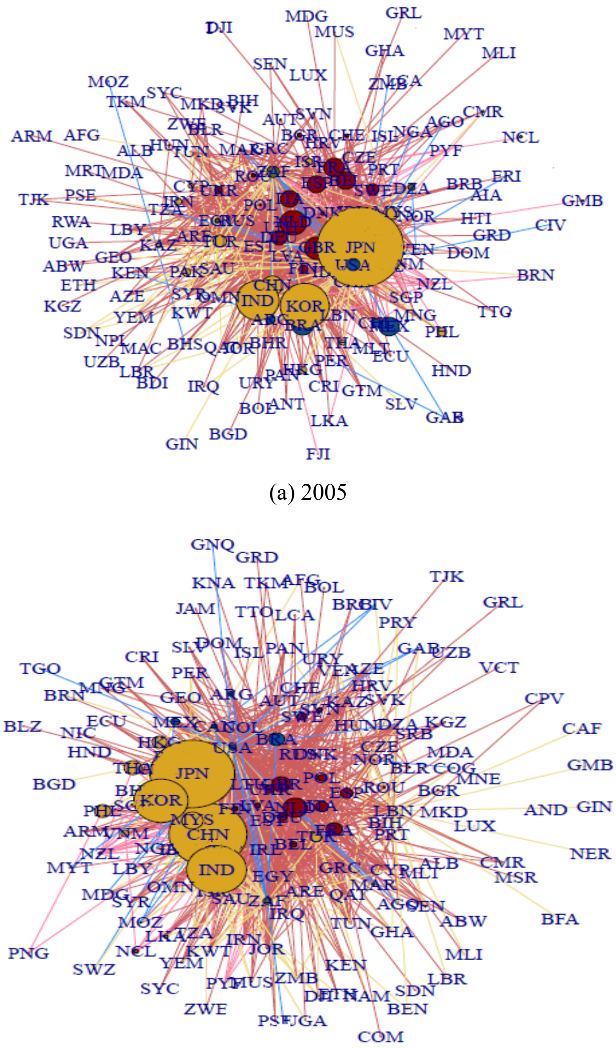


(b) 2013

Fig. 2 Visualization of international coal trade network regarding to hub centralities

In 2013, though the share of China in world coal import is higher than the share of Japan, Japan has more central role than China in terms of authority centrality. The Netherlands, Malaysia, Thailand, Philippines, Hong Kong and Turkey are more central in rank order in terms of authority centralities in comparison to import share. Comparing the authority centralities for both years it can be seen that there is a major decline in the authority centrality of Japan from 2005 to 2013 while there is a massive increase in the authority centrality of China. It can also be observed that there is an increase in authority centralities of India and Malaysia. On the contrary, there is a decline in the authority centralities of European countries such as the Netherlands, the United Kingdom, France, Italy, and Spain.

The visualizations (a) and (b) in Fig. 2 summarize the explanations related to Table V. In these visualizations, countries have been grouped continentally and each color represents a distinct continent. The size of the nodes is proportional to their hub centrality measures. It can be seen that Australia has the most important role in the supply chain of coal. The decline of the hub centrality of China and the increase of the hub centrality of Indonesia from 2005 to 2013 can also be seen in Fig. 2.



(a) 2005

(b) 2013

Fig. 3 Visualization of international coal trade network regarding to authority centralities

It is also possible to see the rise of authority centrality of China from 2005 to 2013 in the visualization (a) and (b) in Fig. 3. Besides, we observed a rise in authority centralities of Asian economies in general. However, the import centralities of European countries decreased within the period.

B. International Crude Oil Trade Network

Crude oil maintains being the most major energy resource of economies as in the past. It has the biggest share with 34% in the world primary energy consumption in 2010 [21].

Some network statistics of international crude oil network from 2005 to 2014 can be seen in Table VII. Accordingly, it can be seen that count of nodes and links moves around 140 and 700, respectively. This stability shows that there is not a dynamic structure of international crude oil trade network. Density coefficients for each year are also around 3% and this is also an indicator of that stable structure.

TABLE VII
NETWORK STATISTICS FOR INTERNATIONAL TRADE OF CRUDE OIL

Year	Nodes	Links	Clustering	Density	Transitivity	Reciprocity
2005	149	694	0.5428	0.0315	0.3013	0.1556
2006	143	747	0.5819	0.0368	0.3035	0.1687
2007	147	755	0.5602	0.0352	0.2959	0.1775
2008	149	757	0.5727	0.0343	0.2904	0.1427
2009	145	724	0.5976	0.0347	0.3024	0.1519
2010	142	727	0.6264	0.0363	0.3130	0.1651
2011	145	741	0.5379	0.0355	0.3109	0.1727
2012	145	744	0.5319	0.0356	0.3122	0.1774
2013	143	708	0.5900	0.0349	0.3183	0.1497
2014	136	629	0.5242	0.0343	0.3139	0.1717

Clustering coefficient, as an indicator of transitivity, almost fluctuates simultaneously with transitivity measure. Reciprocity coefficient also looks very stable. It can be thought that the counterparties of the trade relationship are stable which means that there are almost certain importers and exporters.

TABLE VIII
ASSORTATIVITY CORRELATION COEFFICIENT

Year	Assortativity Correlation Coefficient	Year	Assortativity Correlation Coefficient
2005	-0.01943	2010	-0.00716
2006	-0.01728	2011	-0.01631
2007	-0.02581	2012	-0.00726
2008	0.03131	2013	-0.01113
2009	-0.00720	2014	0.01024

Assortativity correlation coefficients in Table VIII indicate that there is disassortative structure for each year except 2008 and 2014. These statistics are proofs of that there is a core-periphery structure in crude oil network. Thus, there are some countries in the core which are powerful exporters and some countries in the periphery which are importers.

Goodness of fit test results for power-law distribution are shown in the Table IX. Apart from 2009, out-strength distribution fits to power-law for each year. Power-law distribution means that there are a lot of countries with low out-strength (export) and there are a few countries with high out-strength (export). This distribution indicates heterogeneity of connectivity in the network.

TABLE IX
KS TEST RESULTS FOR FITNESS TO POWER-LAW DISTRIBUTION

Year	alpha	KS statistics	p-value
2005	2.7650	0.1417	0.9799
2006	2.9426	0.1151	0.9994
2007	2.8377	0.1550	0.9352
2008	3.2106	0.1731	0.7959
2009	1.1722	0.2308	0.0033
2010	2.3844	0.1575	0.8781
2011	3.4359	0.1186	0.9999
2012	3.0646	0.1205	0.9999
2013	1.6114	0.1531	0.5755
2014	3.3017	0.1203	0.9995

TABLE X
COMPARISON OF HUB CENTRALITIES WITH FIRST-DEGREE INDICATORS

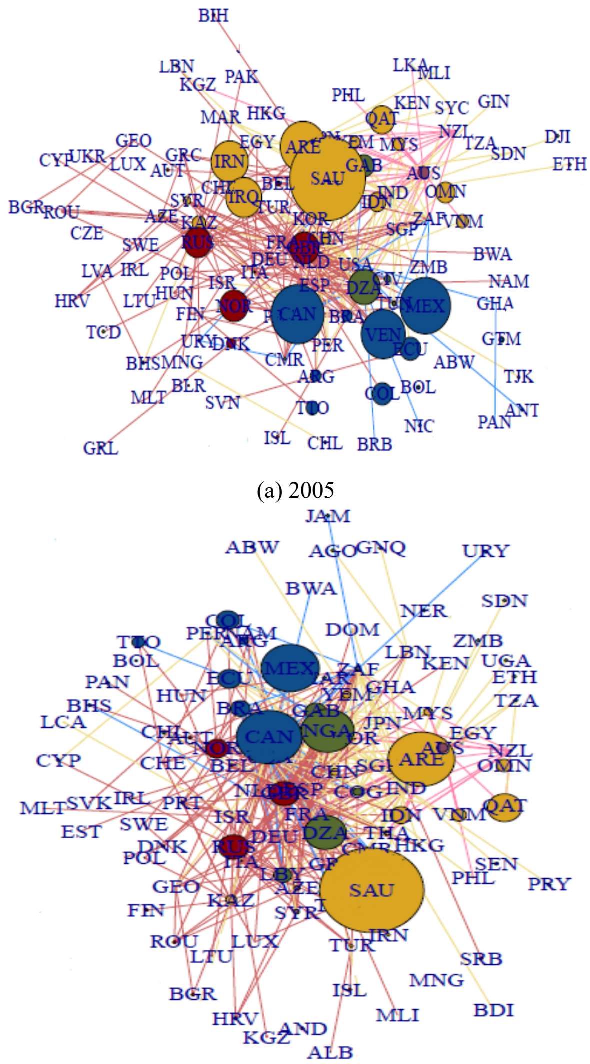
2005				2007			
ISO Codes	Hub centrality	ISO Codes	Share in the world coal export	ISO Codes	Hub centrality	ISO Codes	Share in the world coal export
SAU	0.7239	SAU	0.2198	SAU	0.8029	SAU	0.2080
CAN	0.3538	RUS	0.1275	ARE	0.3298	RUS	0.1320
MEX	0.3225	IRN	0.0774	CAN	0.3188	ARE	0.0682
ARE	0.2603	NOR	0.0756	MEX	0.2497	NOR	0.0628
VEN	0.2444	ARE	0.0650	NGA	0.2074	NGA	0.0579
IRN	0.1745	VEN	0.0530	DZA	0.1286	IRQ	0.0457
IRQ	0.1623	MEX	0.0454	QAT	0.0832	CAN	0.0451
DZA	0.1266	CAN	0.0397	RUS	0.0629	KWT	0.0446
GBR	0.1008	DZA	0.0393	GBR	0.0621	MEX	0.0438
NOR	0.0971	GBR	0.0321	ECU	0.0375	DZA	0.0390
RUS	0.0905	IRQ	0.0305	NOR	0.0373	KAZ	0.0325
QAT	0.0769	KAZ	0.0279	COL	0.0370	GBR	0.0297
ECU	0.0519	OMN	0.0211	IDN	0.0307	LBY	0.0294
GAB	0.0481	QAT	0.0206	GAB	0.0306	QAT	0.0222
COL	0.0480	IDN	0.0131	BRA	0.0266	OMN	0.0167

TABLE XI
COMPARISON OF AUTHORITY CENTRALITIES WITH FIRST-DEGREE INDICATORS

2005				2013			
ISO Codes	Authority centrality	ISO Codes	Share in the world coal import	ISO Codes	Authority centrality	ISO Codes	Share in the world coal import
USA	0.7860	USA	0.2436	USA	0.9964	USA	0.1726
JPN	0.5092	JPN	0.1021	NLD	0.0414	CHN	0.1385
KOR	0.1759	CHN	0.0611	ESP	0.0410	IND	0.0933
IND	0.1216	DEU	0.0558	IND	0.0314	JPN	0.0919
CHN	0.1201	KOR	0.0545	CHN	0.0279	KOR	0.0626
ITA	0.1150	IND	0.0445	GBR	0.0247	DEU	0.0468
NLD	0.1149	ITA	0.0430	ITA	0.0228	NLD	0.0329
FRA	0.0871	FRA	0.0427	DEU	0.0157	ITA	0.0293
SGP	0.0867	NLD	0.0302	FRA	0.0106	FRA	0.0288
ESP	0.0571	ESP	0.0285	POL	0.0100	ESP	0.0286
BHR	0.0558	GBR	0.0276	BRA	0.0089	GBR	0.0253
DEU	0.0502	SGP	0.0237	CAN	0.0073	THA	0.0245
GBR	0.0474	CAN	0.0231	JPN	0.0070	SGP	0.0224
THA	0.0403	THA	0.0216	KOR	0.0064	BEL	0.0180
ZAF	0.0364	BEL	0.0160	BLR	0.0048	CAN	0.0165

In Table X, there are hub centrality measures of top 15 countries as a high-degree indicator and export shares of top 15 countries to compare and evaluate rank order over time. However, our adjacency matrices do not reflect export impact of some Arab countries in the network since they have reported export volumes on a regional basis, not on a country basis, since 2008. Thus, we included 2005 and 2007 to compare in terms of hub centralities. Accordingly, Saudi Arabia is the biggest exporter of crude oil for each year. Canada, Mexico, Venezuela, United Arab Emirates, Iraq, Qatar and the United Kingdom are at a higher level in the rank order in terms of hub centralities when compared to rank order in terms of export shares. It means that these countries are more central when we take the countries with which they are in relation into account. However, Norway, Iran, Russia and Indonesia are less central in the rank order in terms of hub centralities when compared to export shares. In 2007, Nigeria can be seen as a central exporter in the rank order in terms of both hub centrality and export share.

When we look at Table XI, it can be seen that the USA is the biggest importer for each year and for each measure. In 2005, some countries such as Korea, India, the Netherlands, and Singapore are at higher level of rank order in terms of authority centralities when compared to import shares while China, Germany, Belgium, and the United Kingdom are at lower level of rank order in terms of authority centralities when compared to import shares. In 2013, the Netherlands, Spain, the United Kingdom, Italy, Poland, Brazil, and Canada are at higher level of rank order in terms of authority centralities when compared to import shares while China, Japan, Korea, Germany, Thailand, and Singapore are at lower level of rank order in terms of authority centralities when compared to import shares.



(a) 2005

(b) 2007

Fig. 4 Visualization of international coal trade network regarding to hub centralities

Comparing the authority centralities of 2005 and 2013 it can be said that there is a severe decline in the import centralities of Asian economies such as China, Japan, Korea, India, Singapore, and Thailand. There is also a decline in import centralities of European countries; however, it is not as severe as of Asian countries.

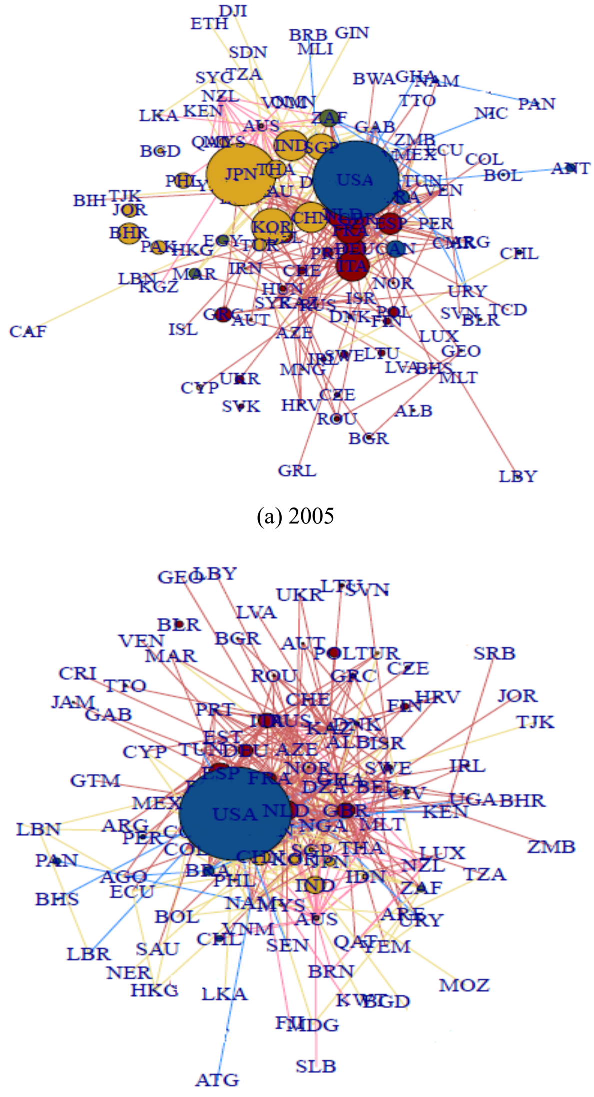
In Fig. 4, there are visualizations of hub centralities for 2005 and 2007. In these visualizations, domination of Arab countries in crude oil export market can be seen. Some American and African countries are also central exporters though they are not as strong as Arab countries. European countries are the weakest exporter of crude oil.

The visualizations (a) and (b) in Fig. 5 represent authority centralities for 2005 and 2013. Severe decline of import centralities of Asian economies can apparently be seen in these figures. The USA has become the biggest importer around the world. European countries also have a severe decline in import centralities in crude oil market. Economic recession of European countries after Eurozone crisis may have a role in this decline.

IV. Conclusion

In conclusion, it can be said generally that both of the export networks have power-law distribution and core-periphery structure. This result means that international trade network of coal and crude oil has a complex structure. In complex structures, system is more or less than sum of its parts. This analysis also enables us to show this relations since the centralities of countries are more than a simple share. When we take the prominence of counterparties into consideration, the centralities of exporter and importer countries become more different. The differences between rank orders of countries regarding to centrality measures and import/export shares are proofs of that.

Generally, we can conclude that Asian countries have become more central importer of coal while their import centralities for crude oil have declined within the period. Thus, it may be thought as a result of substitution of crude oil with coal in Asian countries. It can be said that coal becomes more important energy resource strategically when we take the potential growth and dynamics of developing Asian economies into consideration.



(a) 2005

(b) 2013

Fig. 5 Visualization of international coal trade network regarding to authority centralities

References

[1] G. Fagiolo, T. Squartini and D. Garlaschelli, "Null models of economic networks: the case of the world trade web", *Journal of Economic Interaction and Coordination*, vol.8, pp.75-107, 2013.

[2] H. An, W. Zhong, Y. Chen, H. Li and X. Gao, "Features and evolution of international crude oil trade relationship: a trading-based network analysis", *Energy*, vol. 74, pp.254-259, 2014.

[3] W. Zhong, H. An, X. Gao and X. Sun, "The evolution of communities in the international oil trade network", *Physica A*, vol. 413, pp.45-52, 2014.

[4] W. Zhong and H. An, "The role of China in the international crude oil trade network", *Energy Procedia*, vol. 61, pp.2493-2496, 2014.

[5] S. Cheng, L. Song and X. Li, "Evolution of spatial pattern of crude oil trade", *Studies in Sociology of Science*, vol. 5, no. 1, pp. 1-7, 2014.

[6] H. Xiaoqing, A. Haizhong and Q. Hai, "Evolution of fossil energy international trade pattern based on complex network", *Energy Procedia*, vol. 61, pp.476-479, 2014.

[7] J. Reichardt, "Introduction to complex networks", in *Structure in Complex Networks Lecture Notes in Physics*, vol 766, Springer-Verlag Berlin Heidelberg, 2009: pp.1-11.

[8] W. Chow, "An anatomy of the world trade network", http://www.hkeconomy.gov.hk/en/pdf/An%20Anatomy%20of%20the%

20World%20Trade%20Network%20%28July%202013%29.pdf, (31.10.2013), pp. 1-20
[9] M. D. König and S. Battiston, "From graph theory to models of economic networks: a tutorial" in *Networks, Topology and Dynamics*, A.K.Naimzada et.al., Ed. Springer-Verlag Berlin Heidelberg, 2009, pp. 23-63.
[10] M. E. J. Newman, *Networks An Introduction*, Oxford University Press, 2010.
[11] A. Howell, "Network statistics and modeling the global trade economy: exponential random graph models and latent space models: is geography dead?", University of California, 2012, unpublished thesis.
[12] G. Caldarelli, "Lectures in complex networks", http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf
[13] P. Csermely, A. London, L. Wu, B. Uzzi, "Structure and dynamics of core/periphery networks", *Journal of Complex Networks*, vol. 1, pp.93-123, 2013.
[14] X. F. Wang, G. Chen, "Complex networks: small-world, scale-free and beyond", *IEEE Circuits and Systems Magazine*, pp. 6-20, 2003.
[15] G. Fagiolo, J. Reyes and S. Schiavo. "The evolution of the world trade web: a weighted-network analysis" *Journal of Evolutionary Economics*, vol .20, no. 4, pp. 479-514, 2010.
[16] Jon M. Kleinberg, "Authoritative sources in a hyperlinked environment", *Journal of the ACM*, vol. 46, no. 5, pp.604-632, 1999.
[17] W. Wei and G. Liu, "Bringing order to the world trade network," in *Int. Conf. on Economics Marketing and Management*, IPEDR, vol.28, 2012, pp. 88-92.
[18] T. Deguchi, K. Takahashi, H. Takayasu and M. Takayasu, "Hubs and authorities in the world trade network using a weighted HITS algorithm", *PLOSONE*, vol.9, no. 7, pp. 1-16, 2014.
[19] E. Eren and S. Soyyiğit Kaya, "Network analysis of Turkey's trade with EU-28 with regards to BEC classification," in 1st Annual Int. Conf. on Social Sciences, Istanbul, 2015, pp. 39-64.
[20] International Energy Agency, *Key World Energy Statistics 2014*.
[21] M. Aktaş, "Türkiye'de kömür madenciliği ve enerjideki rolü", http://www.tki.gov.tr/Dosyalar/Dosya/YAZILI%20B%C4%B0LD%C4%B0R%C4%B0%20METN%C4%B0.pdf, p.1-16.

Semanur Soyyiğit Kaya worked as a research assistant at Istanbul University in Turkey. She is now post-doctoral research student at University of Essex in the UK. Her research interests focus on Macroeconomics, Social and Economic Networks and Complexity Economics.

Ercan Eren works as a Professor in the Department of Economics at Yildiz Technical University in Turkey. His research interests focus on Macroeconomics, History of Economic Thoughts, Methodology of Economics, Heterodox Economics, and Austrian School of Economics, Post-Keynesian Economics and Complexity Economics.