Journal of Digital Intelligence and Economic Growth
Website: https://www.jdieg.com
Vol. 1 No.3， December 2024， 1-19
ISSN (Print): 3058-3535
ISSN (Online): 3058-6518
DOI: https://doi.org/10.63768/jdieg.v1i3.001

Analysis of Fossil Fuel Trade Networks in the RCEP Region: Characteristics, Evolution, and Resilience Insights

Rui Liang[1], Ping Liang[2], Jinyan Tian[3*]

[1] Ph.D., Professor, Beijing Union University, Beijing , China
[2] M.A., Associate Professor, Shanghai Minyuan Vocational College, Shanghai, China
[3] Ph.D., Hunan University of Arts and Science, Hunan, China

Abstract: Fossil fuel trade is a crucial pillar of global energy markets, playing an essential role in ensuring socio-economic stability and sustainable development due to its inherent stability and resilience. This study analyzes the characteristics and evolution of RCEP's fossil fuel trade, identifying the roles of nations and core players, and discusses the network's resilience based on these insights. The study reveals that: (1) The characteristics and evolution of RCEP's fossil fuel trade networks show significant heterogeneity across different energy types and countries during the observation period; (2) In terms of overall network traits, the oil trade network demonstrates strong connectivity and stability, along with high efficiency. However, the trade networks for natural gas and coal exhibit high concentrations of out-degree and in-degree, indicating a reliance on certain key countries. This reliance reduces trade diversity and increases the network's vulnerability and instability. Furthermore, the RCEP fossil fuel trade network demonstrates distinct subgroup characteristics with varying levels of diversity and cohesion; (3) The key country identification analysis within the network reveals an imbalanced development of the RCEP fossil fuel trade network, with a few dominant countries exerting substantial control and influence. This study, through an analysis of the structural and resilience characteristics of the fossil fuel trade network in the RCEP region, reveals heterogeneous patterns across energy types and identifies risks stemming from reliance on key nodes. It provides empirical evidence for improving regional energy security governance and enhancing the resilience of the trade network, while offering insights into advancing sustainability-oriented regional cooperation.

Keywords： RCEP; Fossil Fuel; Trade Network; Resilience; Social Network Analysis

*Fund: This research was supported by the Major Project of The National Social Sciences Fund of China (2022&ZD178).
Author Correspondence: （First author） Rui Liang （rui.liang @buu.edu.cn）, （Second author） Ping Liang (lpgrug@163.com) ,
（Corresponding author） Jinyan Tian （tianjinyan0903@gmail.com）
Received 30 Nov. 2024, Revised 10 Dec. 2024, Accepted 25 Dec. 2024

1 Introduction

Energy is of crucial importance to the economic, social, and political security of countries and regions. Despite global efforts to transition to cleaner energy sources, fossil fuels continue to dominate global energy consumption. According to the data presented in the Statistical Review of World Energy 2024, fossil fuels accounted for 81.5% of the global energy consumption in 2023 (Energy Institute, 2024). Given the uneven distribution of global energy reserves, production, supply, and demand among nations and territories, energy trade plays a significant role in meeting their energy requirements. In 2023, the total international trade in fossil fuels was 53% higher than it was in 2000 (Energy Institute, 2024). Secure supply of energy, along with sustainability and affordability, forms a key pillar of the energy trilemma (Energy Institute, 2024). The current international energy landscape is characterized by complexity and diversity, influenced by geopolitical disruption and climate change. This situation increases the uncertainty and vulnerability of existing traditional energy supply chains, while also highlighting the growing impact of energy transition on energy system restructuring and energy security in response to climate change (OECD, 2024). Moreover, the focus on regional supply chains has been heightened by the influence of counter-globalization and considerations of supply chain security (Gurtu et al., 2015; Gurtu and Johny, 2021). In this complex and evolving international energy landscape, building a stable, resilient, and sustainable energy trade supply chain is crucial. It ensures the long-term stability and development of countries and regions.

The Regional Comprehensive Economic Partnership(RCEP) encompasses 15 member countries, including the 10 ASEAN countries, China, Japan, South Korea, Australia, and New Zealand. It officially took effect on January 1, 2022, and is the world's largest free trade area. Drawing from the Energy Institute's data, China is the world's largest consumer of coal and the second-largest consumer of oil (Energy Institute, 2024). Furthermore, in accordance with the data calculations derived from the CHRTD Resource Trade Database,* the RCEP region holds significant importance in the global fossil fuel trade market. From 2011 to 2020, Australia was the world's largest coal exporter. China became the top coal importer in 2012, surpassing Japan. By 2018, it also surpassed Japan and the US to become the world's largest importer of coal, natural gas, and oil. During the same period, Indonesia and China ranked among the top ten global coal exporters, Malaysia's natural gas exports and Singapore's oil exports also held top positions. Moreover, Japan, South Korea, Malaysia, Singapore, and Vietnam ranked among the top ten global coal importers, and Japan and South Korea, as well as Singapore, were among the top ten global natural gas and oil importers, respectively. Throughout 2011-2020, RCEP members experienced a growing trend in the share of total global trade in fossil fuel. In 2020, coal exports and imports accounted for 51.2% and 47% of the global share, respectively, while natural gas exports and imports accounted for 18.5% and 36%, and oil exports and imports accounted for 9.2% and 31.8%. Furthermore, the intra-regional market played a critical role in RCEP members' trade in fossil fuel. In 2020, the intra-regional market accounted for 67.8% and 47% of RCEP members' coal exports and imports, respectively, 86.8% and 16% of natural gas exports and imports, and 71.4% and 6.6% of oil exports and imports.

Based on the differences in member countries' economic development and resource endowment, the RCEP region benefits from resource and technological complementarities in the energy sector. This synergy allows members to fully utilize their resource endowments and advantages in participation in energy trade. The implementation of RCEP will also provide a more liberal and convenient trading environment and a sound cooperation mechanism for traditional energy trade, energy transition, and new energy development among member countries. However, the complex and ever-changing international environment and global energy development pattern also present certain challenges to the stability and sustainable development of RCEP's energy trade.

In an environment filled with high uncertainty and risks, it is crucial to prioritize the resilience building of supply chains (Cohen and Kouvelis, 2020; Hoggett, 2014). Modern supply chains have evolved from simple linear structures to intricate and interconnected networks, where any changes in a single node (country) or any segment (trade flow) can trigger cascading

* https://resourcetrade.earth/.

effects (Zeng and Tang, 2023). Energy trade networks involve broader complexities (Roy, 2021), encompassing diverse stakeholders, infrastructures, technologies, and fuels, influenced by national policies and trade regulations (Gurtu et al., 2015). The resilience of energy trade networks directly impacts the stability and reliability of energy supply chains. A robust energy trade network is better able to withstand external shocks, reducing the risk of supply chain disruptions and thereby enhancing the overall resilience of the energy supply chain. In this context, understanding the spatial-temporal dynamics, evolution, and resilience of fossil fuel trade within the RCEP market is crucial. Recognizing the significance of fossil fuels and the substantial impact of the RCEP market, this comprehensive insight is vital for all members to effectively leverage the platform and cooperation mechanisms offered by RCEP. Such efforts are essential for maintaining regional energy market stability, ensuring energy security, and facilitating a swift transition to low-carbon energy sources.

This study employs social network analysis to investigate the RCEP regional fossil fuel trade network, focusing on its characteristics, evolution, and resilience. It offers a comprehensive, data-driven understanding of the network's structural dynamics. By integrating network and resilience analysis, this study examines the trade network's resilience from both structural and evolutionary perspectives. The findings provide valuable insights for strengthening regional energy security, diversifying trade, and advancing RCEP's sustainable energy transition, offering crucial guidance for policy development. The rest of this article is organized as follows: In the second section, a comprehensive review is conducted on social network analysis, supply chain resilience, and RCEP energy cooperation. The third section presents the research methodology, including model construction and data description. The fourth section conducts a comprehensive data analysis to deconstruct the characteristics, evolution, and preliminary assessment of resilience of the fossil fuel trade networks in the RCEP region from 2011 to 2020. Finally, the fifth section presents the conclusions and implications.

2 Literature Review

2.1 Social Network Analysis

Social Network Analysis (SNA) is a method for studying relationships and interactions, used to analyze social network structures and characteristics. It has been widely applied in various fields such as organizational management, economic trade, and health sciences. SNA, scientifically equivalent to link analysis, serves as both theory and methodology, enabling fine-grained research on complex social structures (Emirbayer and Goodwin, 1994; Van der Hulst, 2009). Its applications extend beyond graphical visualization, as it involves mathematical computations to analyze the relationships between nodes and ties within a network. By quantifying key features and behavioral patterns of the network using metrics, SNA identifies core nodes, major structures, and critical pathways (Koschade, 2006), a functionality not present in traditional analytical approaches (Hollenbeck and Jamieson, 2015).

Around the 1990s, scholars initially explored supply chain networks from a network perspective (Choi et al., 2001; De Toni and Nassimbeni, 1995; Lazzarini et al., 2001; Wilding, 1998). Subsequently, researchers deepened the application of SNA in supply chain management, supply chain networks, and supply chain risk research from different perspectives (Borgatti and Li, 2009; Carter et al., 2011; Gao and Zhen, 2009; Ketchen and Hult, 2007; Wen et al., 2021; Wichmann and Kaufmann, 2016). They found that SNA plays a significant role in identifying structural characteristics and inherent relationships within supply chain networks.

With the expanding application of SNA, scholars have focused on different research scopes and subjects to study the structural characteristics and evolution of trade networks. The main research scopes include the global scale, the Asia-Pacific Economic Cooperation (APEC), the Group of Twenty (G20), the Belt and Road Initiative (Aller et al., 2015; Chen, 2011; De Benedictis and Tajoli, 2011; Garlaschelli and Loffredo, 2005; Gong and Li, 2021; Liang et al., 2024). The main research subjects encompass agricultural products, high-tech products, and digital trade (Ding and Feng, 2022; Ni and Cao, 2022; Zhao et al., 2023). These studies demonstrate the significant role of SNA in understanding the structure and dynamics of trade networks.

The use of SNA in studying the structural characteristics and evolution of energy trade networks involves various research scopes and energy types. Existing research has mainly focused on global scales (Kan et al., 2020; Kan et al., 2019; Liu et al., 2017; Sun et al.,2012), APEC (Liang et al., 2024), the Silk Road Economic Belt (Ma and Lei, 2019; Wang and Qiang, 2020), and countries along the Belt and Road Initiative (Han and Li, 2020; Jing et al., 2020). The studied energy types mainly include natural gas, coal, international crude oil, iron ore, copper ore, bauxite, and rare earths (Hao et al., 2013; Li and Wei, 2024; Liu, 2016; Liu et al., 2017; Shi et al., 2018; Xiao et al., 2013; Xu, 2015; Zhuang et al., 2022)

2.2 Supply Chain Resilience

The initial research on Supply Chain Resilience (SCR) originated in the UK in response to the 2000 fuel protests and the 2001 outbreak of foot-and-mouth disease, which caused transportation disruptions (Pettit et al., 2013). Since then, numerous scholars have studied supply chain resilience, but there lacks a unified definition of supply chain resilience (Kamalahmadi and Parast, 2016; Kochan and Nowicki, 2018; Mensah and Merkuryev, 2014).

Based on the RRR framework, namely Readiness, Response, and Recovery, supply chain resilience refers to the capability of a supply chain to be prepared for unforeseen circumstances, actively respond to ongoing disruptions, and recover from interruptions (Chandra and Kumar, 2000; Lee, 2002; Ponomarov and Holcomb, 2009). Additionally, a resilient supply chain should possess the ability to predict, address, and adapt to risks as well as meet customer demands after recovering from disturbances (Ahi and Searcy, 2013). The concept of supply chain resilience has expanded over time, initially emphasizing reactive measures and recovery from disruptive events, and later shifting focus to proactive measures, adaptability, and continuous improvement.

Over the past two decades, the frequency and severity of disruptions experienced by supply chains have increased, as evident from the poor response to the Covid-19 crisis (Khan et al.,2022). The advent of Industry 4.0 has completely transformed traditional business processes, enabling automation along the value chain (Mubarik et al., 2022; Fragapane et al., 2022) and elevating the competition among participants to competition among supply chains (Barratt, M and Barratt, 2011). Traditional supply chain management models are no longer sufficient to address new uncertainties and risks, making supply chain security and resilience a focal point in supply chain management.

Ensuring supply chain security crucially involves managing the risks of supply chain disruptions (Zhang and Luo, 2022). The essence of supply chain security is interconnected with supply chain resilience, as supply chain resilience embodies the fundamental requirement for supply chain security (Hong et al., 2023). Moreover, an ideal supply chain network should consider both resilience and sustainability simultaneously (Jabbarzadeh et al., 2018). Resilience, as an integral component of sustainability, constitutes a necessary condition for achieving sustainability (Marches et al., 2018). The management of supply chain networks necessitates upholding their resilience from a sustainability perspective (Ivanov, 2018; Ruiz-Benitez et al., 2019).

2.3 RCEP Energy Cooperation

Existing research on energy from the perspective of RCEP mainly includes studies on international trade's implicit energy flow and implicit carbon emissions (Ma and Luo, 2021), energy efficiency (Zhang and Chen, 2022), mechanisms of international cooperation in energy regions (Xu and Yuan, 2021), energy investment layout, and risks (Xia, 2022) , as well as energy industry development (Yu and Wang, 2022).

Considering the existing research on the RCEP region is limited, especially studies that comprehensively analyze the three major fossil fuels. Few studies examine the resilience and sustainability of fossil fuel trade networks within the region. Furthermore, there is a lack of research that approaches the subject from the perspective of fossil fuel trade networks in th e context of RCEP's energy cooperation framework. Therefore, this study aims to investigate the fossil fuel trade networks in the RCEP region. By employing complex network analysis techniques, this research aims to dissect the characteristics and evolutionary patterns of these networks, as well as to assess their resilience. Building on these insights, the study will cu lminate in the formulation of policy recommendations.

3 RCEP Fossil Fuel Trade Network Model Construction

3.1 Research Subjects and Data Sources

This paper focuses on the trade networks of coal, natural gas, and oil among the 15 member countries within the RCEP region, spanning the period from 2011 to 2020. The analysis aims to uncover the characteristics, evolution, and resilience of the fossil fuel trade network. This study uses data from the CHRTD Resource Trade Database. It offers detailed bilateral trade information on over 1,350 natural resources and products across more than 200 countries and regions, including their trade volumes and monetary values.

The trade data for the fossil fuel trade among the 15 RCEP countries from 2011 to 2020 were extracted from the CHRTD Resource Trade Database. Utilizing UCINET software, trade networks for the three fossil fuel were constructed annually, and various network metrics were calculated. This process facilitated an examination of the structural characteristics and evolutionary trajectories of the fossil fuel trade networks, enabling an assessment of their resilience.

3.2 RCEP Fossil Fuel Trade Network Model

The network model consists of a set of nodes and ties (or edges). Nodes represent individual entities in the network, while ties signify relationships between nodes. In a trade network, the direction of ties indicates the flow of trade, and the thickness of ties represents the magnitude of trade volume. Network models are distinguished as either undirected or directed, depending on the significance of the directional aspect of ties. Similarly, they are classified as unweighted or weighted, contingent upon the importance attributed to the quantitative metrics of the ties. In this study, a directed weighted network is constructed for RCEP's fossil fuel trade using network analysis. The 15 RCEP member countries serve as network nodes, and their fossil fuel trade relations represent the ties. The direction of ties denotes the import and export directions, and the trade value serves as the weight of the ties, enabling a comprehensive analysis of the characteristics of RCEP's fossil fuel trade network.

The RCEP energy trade networks for coal, natural gas, and oil are represented as N= （C,R）, where N denotes the fossil fuel trade network constituted by member countries, encompassing three weighted trade networks. C signifies the 15 member countries, denoted as C={$c_1, c_2, ... c_{15}$}, and R denotes the set of weighted edges within the energy trade network, representing the volume of energy trade from country i to country j .This representation captures both the presence and the strength of trade relationships.

4 Integrated Analysis of RCEP Fossil Fuel Trade Networks: Evolution, Structure with Resilience Considerations

4.1 Evolution of RCEP Fossil Fuel Trade Network

The descriptive statistics in Table 1, along with the visual representations of the trade networks in Figures 1(a)-(f), offer a detailed view of the evolution of the RCEP region's coal, natural gas, and oil trade networks from 2011 to 2020. Here, the size of the nodes corresponds to their degree, indicating the number of countries with which a node has trade relations; the thickness and color of the ties represent the magnitude of trade values.

The number of ties refer to the sum of all connections within the network. The average degree indicates the mean number of ties per node. The average distance refers to the average length of the shortest path between all pairs of nodes in a network, reflecting the efficiency of information, resources propagating in the network. The smaller the average distance, the closer the connections between nodes, and the stronger the cohesion of the network. The diameter is the maximum of all shortest paths within the network. The network diameter reflects the connectivity risk of the network. The larger the network diameter, the more intermediate nodes in the path, and the greater the risk of information transmission, resulting in poorer network stability.

Both the coal and oil trade networks saw a general increase in their ties and average degree, while the natural gas trade network exhibited a declining trend. Moreover, the oil trade network's ties and average degree significantly surpassed those of the coal and natural gas networks. This indicates that new trade relationships emerged within the coal and oil networks, strengthening their connections, whereas the natural gas network experienced the opposite. This finding aligns with the results displayed in Figure 1.

In the coal network, the average distance between nodes fluctuated irregularly, remaining largely unchanged in 2020 compared to 2011, with the network diameter consistently maintaining a value of 2 in nearly every year. In the natural gas network, the average distance initially increased before decreasing; while the network diameter reduced from 3 to 2. In the oil network, the average distance gradually decreased, with the network diameter remaining constant at 2.

The findings are supported by the visual representations in Figures 1(a)-(f). In the coal and oil trade networks, the growing size of nodes and widening edges over time indicate an increase in trading partners and trade volumes, respectively. In contrast, the natural gas network shows a reduction in node size and edge thickness, indicating a contraction in trade activity. From 2011 to 2020, the structure of the three fossil fuel trade networks in the RCEP region underwent a distinct evolution. It is important to note that a clear heterogeneity exists between the three fossil fuel networks.

In conclusion, the oil trade network in the RCEP region exhibits the most robust connectivity and stability, followed by the coal network, with the natural gas network lagging behind. These insights highlight the dynamic nature of energy trade within the RCEP region and underscore the importance of understanding the evolving structure and resilience of these critical energy trade networks.

Table 1. Descriptive Statistical Results

	Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Coal	Ties	124	127	129	128	132	130	134	134	145	142
	Avg Degree	8.267	8.467	8.600	8.533	8.800	8.667	8.933	8.933	9.667	9.467
	Avg Distance	1.319	1.400	1.291	1.395	1.275	1.381	1.367	1.362	1.310	1.324
	Diameter	2	3	2	3	2	2	3	2	2	2
Gas	Ties	103	104	106	101	102	97	94	95	93	94
	Avg Degree	6.867	6.933	7.067	6.733	6.800	6.467	6.267	6.333	6.200	6.267
	Avg Distance	1.344	1.456	1.451	1.531	1.526	1.478	1.441	1.533	1.446	1.390
	Diameter	3	3	3	3	3	3	2	3	2	2
Oil	Ties	156	163	163	167	175	176	169	171	174	173
	Avg Degree	10.400	10.867	10.867	11.133	11.667	11.733	11.267	11.400	11.600	11.533
	Avg Distance	1.257	1.224	1.224	1.205	1.167	1.162	1.195	1.186	1.171	1.176
	Diameter	2	2	2	2	2	2	2	2	2	2

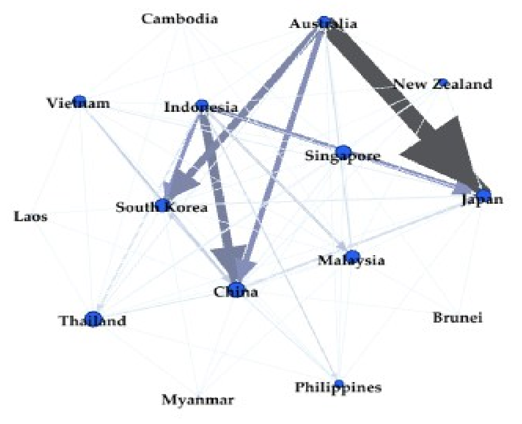

Figure1.(a) Coal Trade Network in 2011

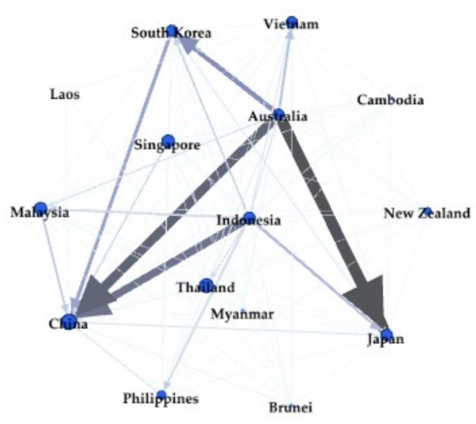

Figure1.(b) Coal Trade Network in 2020

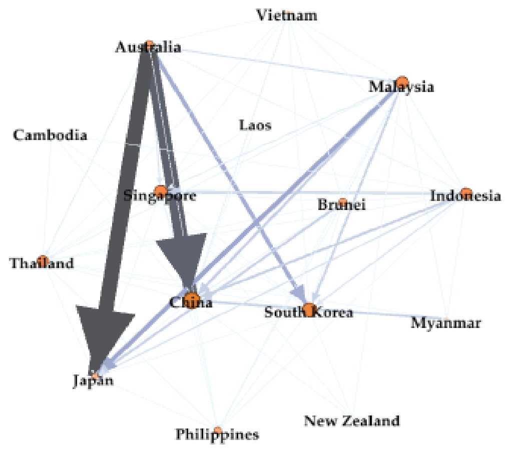

Figure1.(c) Gas Trade Network in 2011

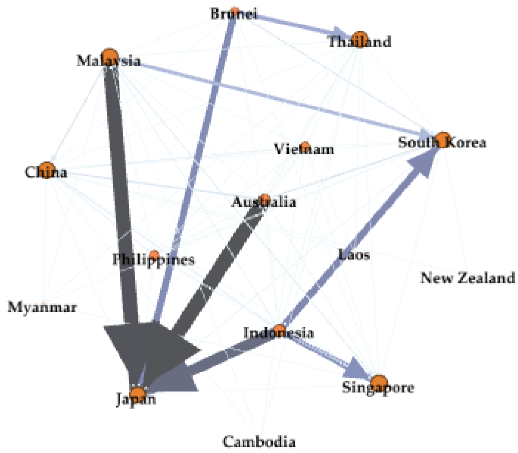

Figure1.(d) Gas Trade Network in 2020

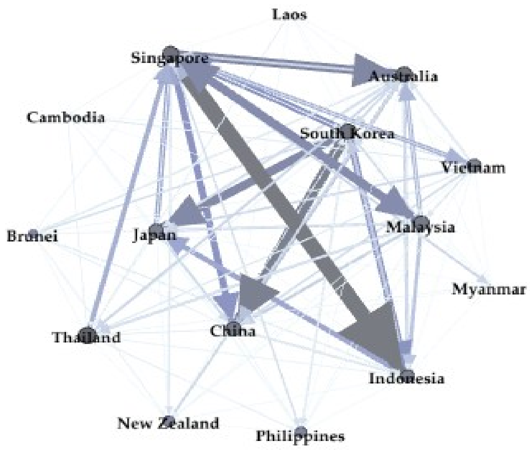

Figure1.(e) Oil Trade Network in 2011

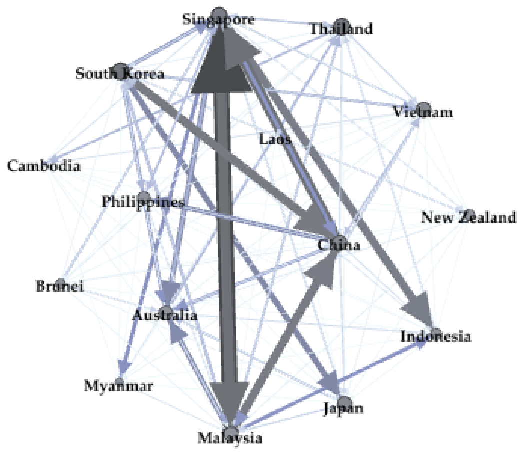

Figure1.(f) Oil Trade Network in 2020

4.2 Overall Network Analysis

4.2.1 Network Density

Network density refers to the ratio of the actual number of ties between nodes in a network to the maximum possible number of ties. It reflects the degree of interconnectedness among the nodes in the network. Network density typically ranges from 0 to 1, with a value closer to 1 indicating denser network connections and a value closer to 0 indicating sparser connections. High density implies more connections, allowing information and resources to be propagated through multiple paths, thereby preventing trade flows from being interrupted and enhancing network resilience.

The formula for network density in a directed network is as follows, where m represents the actual number of ties and n represents the number of nodes, while $n(n-1)$ represents the maximum possible number of ties.

$$D = \frac{m}{n(n-1)} \text{ (Formula 1)}$$

Figure 2 delineates the network density trends for RCEP's coal, oil, and natural gas trade networks from 2011 to 2020. The networks exhibit a moderately high density, indicating robust trade connections. However, there are distinct patterns among energy types: oil trade network density increases from 0.743 to 0.824, indicating the strongest resilience; coal trade network density rises from 0.590 to 0.676; in contrast, natural gas trade network density declines from 0.490 to 0.448, suggesting the weakest resilience among the three. The upward trend for oil and coal contrasts with the downward trend for natural gas.

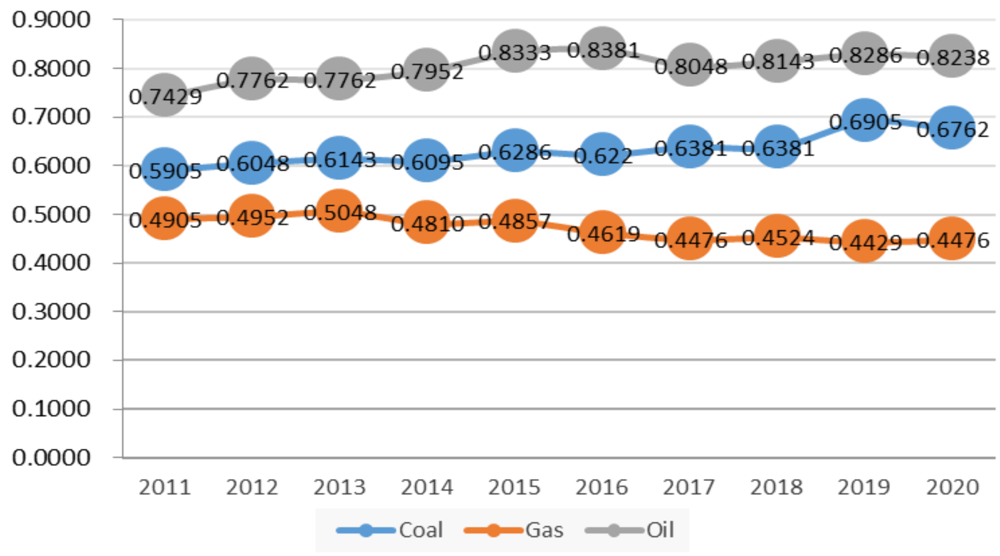

Figure 2. Evolution of Network Density for Energy Trade Networks in the RCEP Region

4.2.2 Network Centralization

Centralization is an overall characteristic of a network that reflects the dispersion of individual centrality degrees within the network, indicating the overall centripetal level of the network. A high degree of centralization suggests that there is a significant disparity in the centrality degrees of individuals, and the network is controlled by a few important nodes. If these nodes are removed or damaged, it can lead to the fragmentation of the entire network. Therefore, a network with high centralization has lower resilience, while a network with low centralization tends to have higher resilience. In directed networks, it is divided into out-degree centralization (Out-C) and in-degree centralization (In-C).

The formula for network centralization is expressed as follows, where c_{max} represents the possible maximum degree centrality value, c_i is the degree centrality of node i, and n is the number of nodes.

$$C = \frac{\sum_{i=1}^{n}(c_{max}-c_i)}{max[\sum(c_{max}-c_i)]} \quad \text{(Formula 2)}$$

The centralization and change trend of the RCEP fossil fuel trade networks from 2011 to 2020 are shown in Table 2 and Figure 3. The out-degree centralization is generally higher than the in-degree centralization. The out-degree centralization remains relatively stable in most years with small fluctuations. In contrast, the in-degree centralization has larger fluctuations, especially in coal and natural gas networks. Data shows that the in-degree centralization values of coal, natural gas, and oil are relatively close but have different fluctuation characteristics. Coal's in-degree centralization fluctuates significantly between 0.235 and 0.408. natural gas' in-degree centralization varies between 0.225 and 0.367, indicating large fluctuations in its import network. Oil's in-degree centralization is relatively low and stable, ranging from 0.163 to 0.276. Regarding the out-degree centralization, the differences among the three fossil fuels are more significant. Coal's out-degree centralization has certain fluctuations but with a relatively small amplitude, ranging from 0.332 to 0.418. Oil's out-degree centralization is the lowest throughout the period and changes most stably. natural gas' out-degree centralization is significantly higher than that of coal and oil and fluctuates more, ranging from 0.510 to 0.597.

In general, coal's in-degree and out-degree centralization fluctuates, with higher export concentration indicating reliance on key nodes and lower export network resilience. Natural gas shows the highest and rising out-degree centralization in the decade, reflecting dominance by a few nodes and low resilience, while its import network also trends toward increased centralization, further reducing resilience. In contrast, oil exhibits low, stable centralization, signifying a decentralized trade network with greater resilience and stability. Overall, natural gas trade networks are the most concentrated and least resilient, followed by coal, while oil networks are the most decentralized and resilient.

Table 2. Network Centralization

Year		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
In-centralization	Coal	0.286	0.270	0.260	0.265	0.245	0.408	0.235	0.311	0.255	0.347
	Gas	0.240	0.235	0.225	0.327	0.245	0.347	0.362	0.357	0.367	0.286
	Oil	0.276	0.163	0.240	0.219	0.179	0.174	0.209	0.199	0.184	0.189
Out-centralization	Coal	0.362	0.347	0.413	0.418	0.398	0.408	0.388	0.388	0.332	0.347
	Gas	0.546	0.541	0.531	0.556	0.551	0.577	0.592	0.510	0.597	0.592
	Oil	0.276	0.240	0.240	0.219	0.179	0.174	0.209	0.199	0.184	0.189

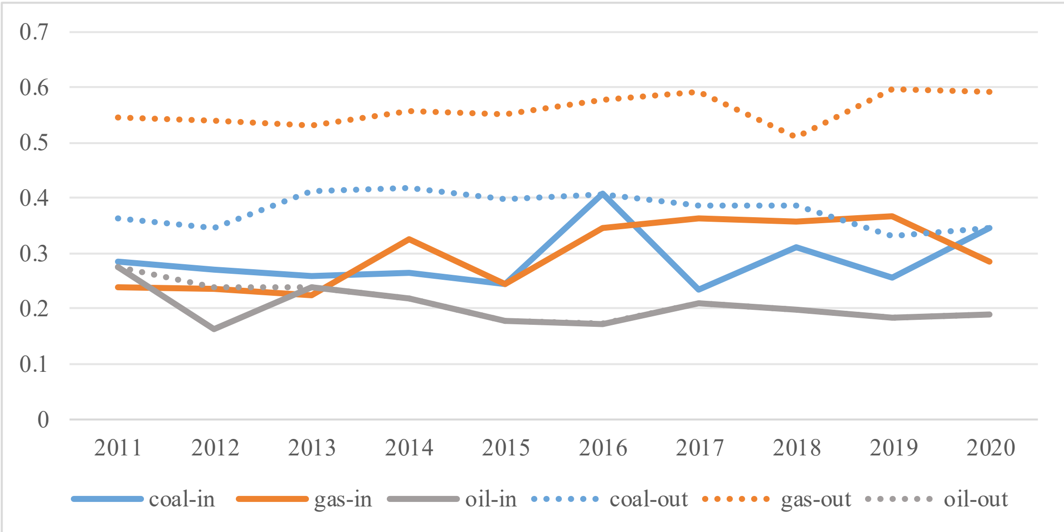

Figure 3. Trend of Network Centralization in the RCEP Region

4.2.3 Cohesive Subgroups

Cohesive Subgroups refer to clusters of nodes within a network that exhibit high internal cohesion and tight connections. This study employs clique analysis to identify cohesive subgroups within the network. Cliques are defined as subgroups within a social network where all nodes are interconnected, forming a fully connected subset. Clique analysis can reveal hidden structures and relational patterns within the RCEP region, as well as key groups within the network. Members within these groups exhibit reciprocity and similarity.

The distribution of cliques for coal, natural gas, and oil in 2011 and 2020 is illustrated in Figures 4(a)-4(f). Blue square nodes represent cliques within the network, with larger nodes indicating a greater number of countries within the clique; circular nodes represent the 15 countries within the region. Red circles indicate countries that are part of at least two cliques, while yellow circles represent countries within a single clique. The color and size of the circular nodes demonstrate the number of cliques each country is involved in.

Figures 4(a)-4(b) illustrate a decrease in the number of cliques within the coal network from six in 2011 to five in 2020, accompanied by an increase in the size of the cliques and enhanced integration between them. This trend indicates an increase in cohesion and cooperation within the RCEP region, which helps to mitigate external shocks and enhances the resilience of the trade network.

As illustrated in Figures 4(c)–(d), the number of cliques within the natural gas network increased from seven to eight, with no significant changes in their respective scales, suggesting a more intricate internal structure. The addition of clique serves as supplementary "backup units", enabling other cliques to assume a compensatory role when one clique faces external shocks or internal disruptions, thereby preserving the network's stability and resilience.

Figures 4(e)-4(f) demonstrate that the number of cliques in the oil network decreased from five in 2011 to four in 2020, with a concurrent enlargement of clique size. This suggests that members within cliques have stronger, more direct, and tighter connections, indicating a strong cohesive force within the oil network and a high degree of resilience.

In summary, the structure of the RCEP fossil fuel trade networks exhibits diversity and variation, which is crucial for understanding the complexity and dynamics of regional energy trade. The natural gas network is characterized by a larger number of smaller subgroups, while the oil network is dominated by a smaller number of larger subgroups, with the coal network occupying an intermediate position. This reflects the diverse nature of natural gas trade relations and the close-knit nature of oil trade relations within the RCEP region, highlighting the structural characteristics and the intricate network structure of different fossil fuel networks.

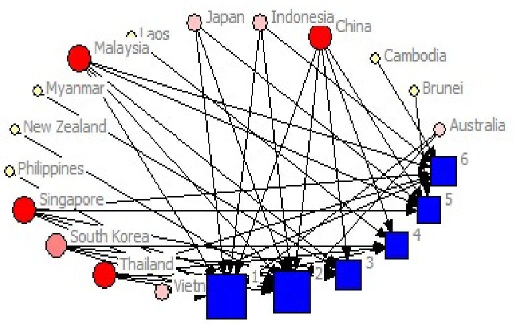

Figure 4(a): Cliques in the Coal Network, 2011

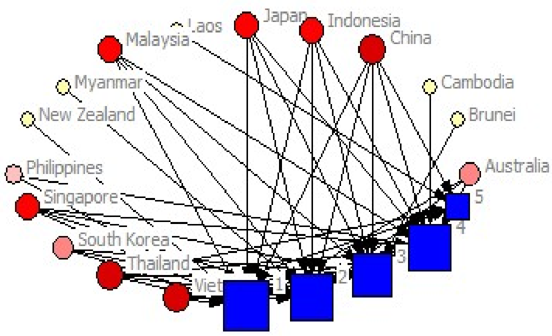

Figure 4(b): Cliques in the Coal Network, 2020

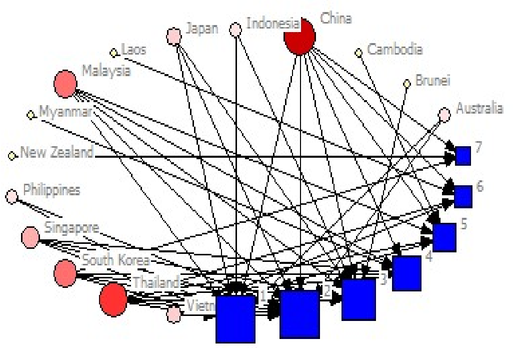

Figure 4(c): Cliques in the gas Network, 2011

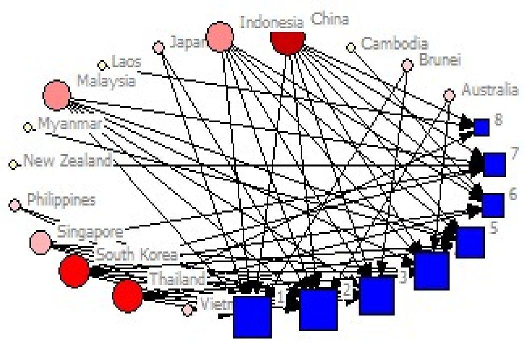

Figure 4(d): Cliques in the gas Network, 2020

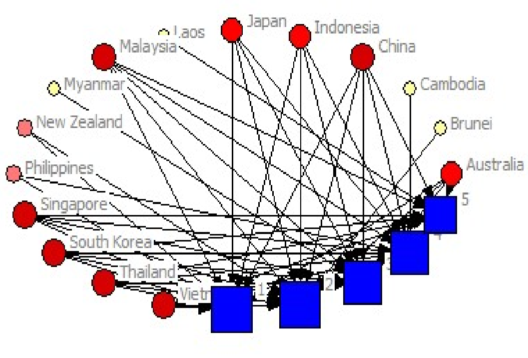

Figure 4(e): Cliques in the Oil Network, 2011

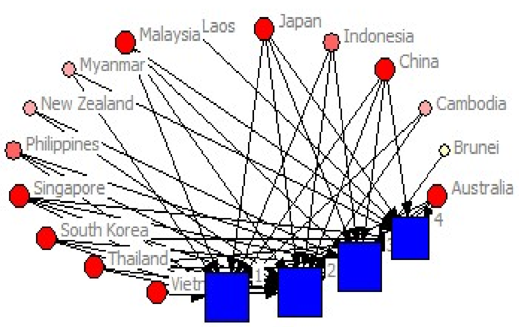

Figure 4(f): Cliques in the Oil Network, 2020

4.3 Analysis of Network Core Nodes

4.3.1 Intermediary Analysis

Intermediarity refers to the potential of a node to occupy a position between other node pairs within a network, serving a significant intermediary function. This node facilitates the transmission of information or resources, thereby exerting control or influence over other nodes in the network. Furthermore, acting as bridges, these nodes introduce heterogeneous resources and adaptable mechanisms for adjustment, thereby enhancing the network's diversity and resilience. The Betweenness Centrality and Structural Hole indexes measure a node's intermediation from different dimensions.

Betweenness centrality (BC) is a metric that signifies the extent to which a node lies on the shortest paths between node pairs. A node with a BC of 0 is peripheral and lacks control over other nodes, whereas a node with a BC of 1 is centrally positioned within the network. The calculation formula for betweenness centrality is as follows, where g_{ik} represents the number of shortest paths from node j to node k, and g_{jk}^{i} represents the number of shortest paths from node j to node k that pass through node i.

$$BC_i = \sum_{j,k} \frac{g_{jk}^{i}}{g_{jk}} \quad \text{(Formula 3)}$$

Structural holes refer to the unconnected spaces between nodes or subgroups within a network. Nodes that bridge these gaps can exert control over interactions between disconnected nodes or subgroups, thereby increasing their influence. This analysis employs three metrics to assess structural holes: Effective size, Efficiency, and Constraint. Effective size (Eff-Size) denotes the number of non-redundant connections a node possesses; a higher value indicates a more pronounced intermediary role. Efficiency is calculated as the ratio of a node's effective size to its actual size, reflecting the node's influence on other nodes within the network. A high-efficiency network facilitates rapid transmission of information or resources. Structural hole constraint refers to a node's capacity to leverage or bridge structural holes within a network ,serving as a measure of the node's independence and freedom within that network. A lower constraint coefficient implies greater independence for the node, enabling it to control or exploit a larger number of structural holes. Conversely, a higher constraint coefficient indicates a greater influence of other nodes within the network, suggesting stronger network closure and a reduction in the availability of structural holes.

In the analysis of intermediary status within the RCEP fossil fuel trade networks, the coal trade network shows China as a central node with the highest betweenness centrality, reflecting its pivotal role in mediating coal trade. China's betweenness centrality values increased from 16.708 in 2011 to 27.639 in 2020. Thailand also plays a significant intermediary role, with betweenness centrality values rising from 16.008 in 2011 to 21.401 in 2020. Moreover, Thailand's structural hole indicators performed exceptionally well. Its effective size increased from 8.313 to 9.822, indicating increased diversity of connections within the coal trade network. Efficiency also improved from 0.639 to 0.702, suggesting more efficient allocation of information and resources. Thailand's constraint coefficients decreased from 0.481 to 0.385, indicating enhanced capability to leverage structural holes.

In the natural gas trade network, China's dominant position is evident with the highest betweenness centrality, marked by values of 8.976 in 2011 and a significant rise to 37.767 in 2020. China's effective size decreased from 12.360 to 11.452 but remained the highest, reflecting its strong intermediary role. Both China and South Korea demonstrate high efficiency within the network, maintaining high values in both 2011 and 2020, indicating efficient transfer of information and resources. However, China's constraint increased, while South Korea's decreased from 0.407 to 0.346, indicating further enhanced ability to exploit structural holes.

In the oil trade network, South Korea acts as the primary intermediary country, with the highest betweenness centrality values increasing from 5.892 in 2011 to 9.950 in 2020. However, Thailand shows superior performance in structural hole indicators. Its effective size increased from 11.681 to 11.867, indicating more diversified connections within the oil trade network. Efficiency improved from 0.834 to 0.848, and constraint values decreased from 0.293 to 0.273, indicating enhanced ability to exploit structural holes.

Overall, China holds a significant intermediary position in coal and natural gas trade networks, Thailand's intermediary influence in coal and oil trade networks is noteworthy, and South Korea plays a crucial intermediary role in natural gas and oil trade networks. Especially, the structural hole indicators for Thailand and South Korea indicate these countries have a high capacity to leverage their network positions, with lower constraint coefficients suggesting they can better exploit structural holes for their advantage.

Table 3. Top 10 Countries by Intermediary Status in the RCEP Fossil Fuel Trade Networks

ID	BC	Eff-Size	Efficiency	Constraint	ID	BC	Eff-Size	Efficiency	Constraint
		Coal-2011					Coal-2020		
China	16.708	9.831	0.756	0.348	China	27.639	9.160	0.654	0.474
Thailand	16.008	8.313	0.639	0.481	Thailand	21.401	9.822	0.702	0.385
Singapore	6.175	10.674	0.821	0.306	Malaysia	5.139	6.924	0.533	0.545
South Korea	4.875	8.148	0.679	0.448	Singapore	5.139	9.677	0.744	0.468
Vietnam	4.800	8.136	0.740	0.367	Vietnam	2.347	7.246	0.518	0.643
Malaysia	4.425	8.196	0.630	0.460	Indonesia	1.806	11.284	0.868	0.226
Japan	3.292	6.816	0.620	0.637	Japan	1.694	7.100	0.546	0.683
Indonesia	0.925	9.992	0.908	0.190	South Korea	1.528	6.896	0.575	0.582
Australia	0.792	8.660	0.866	0.311	Australia	0.960	10.199	0.850	0.275
Brunei	0.000	3.724	0.931	0.458	Philippines	0.222	4.537	0.412	0.824
		Gas-2011					Gas-2020		
Thailand	11.210	12.056	0.927	0.397	China	37.767	11.452	0.818	0.373
China	8.976	12.360	0.883	0.277	South Korea	7.767	10.321	0.794	0.346
Malaysia	8.043	9.296	0.775	0.434	Singapore	5.167	7.912	0.719	0.611
South Korea	7.860	10.023	0.835	0.407	Thailand	4.600	11.401	0.877	0.286
Singapore	7.443	8.614	0.783	0.447	Malaysia	2.600	9.904	0.825	0.311
Japan	5.926	7.356	0.736	0.576	Indonesia	2.100	8.721	0.727	0.474
Vietnam	2.667	8.347	0.835	0.575	Japan	0.000	4.806	0.534	0.742
Indonesia	0.733	7.123	0.791	0.381	Brunei	0.000	7.905	0.878	0.313
Australia	0.143	6.901	0.767	0.427	Myanmar	0.000	3.942	0.788	0.619
Brunei	0.000	6.128	0.875	0.342	Cambodia	0.000	3.869	0.967	0.796
		Oil-2011					Oil-2020		
Thailand	31.892	11.681	0.834	0.293	South Korea	9.950	11.229	0.802	0.317
South Korea	5.892	11.385	0.813	0.336	Thailand	9.950	11.867	0.848	0.273
Singapore	5.892	12.015	0.858	0.217	Singapore	5.283	11.330	0.809	0.275
China	2.225	9.520	0.680	0.428	Myanmar	2.417	6.711	0.559	0.728
Malaysia	2.225	9.099	0.650	0.422	China	2.200	10.116	0.723	0.373
Australia	1.846	8.782	0.676	0.388	Japan	2.200	9.108	0.651	0.562
Japan	1.487	8.998	0.692	0.435	Vietnam	2.200	9.575	0.684	0.384
Vietnam	1.130	10.141	0.724	0.355	Malaysia	1.033	9.977	0.713	0.361
Indonesia	0.808	7.766	0.597	0.450	Australia	1.033	9.760	0.697	0.386
Philippines	0.504	6.401	0.582	0.456	Philippines	0.533	7.908	0.608	0.535

4.3.2 Core-Periphery Structure

Core-periphery structure reveals the hierarchical relationship between central and peripheral nodes within a network, enabling swift identification of nodes positioned at the core and those on the periphery, thereby uncovering the pivotal points of control and influence within the energy trade network. Table 4 presents the coreness rankings for fossil furl trade networks across the specified years.

Table 4. Top 10 Countries in terms of Coreness in the RCEP Fossil Fuel Trade Networks

Coal-2011		Coal-2020		Gas-2011		Gas-2020		Oil-2011		Oil-2020	
Australia	0.715	Australia	0.721	Japan	0.800	Australia	0.860	Singapore	0.677	Malaysia	0.647
Japan	0.618	China	0.440	Indonesia	0.336	Japan	0.395	Indonesia	0.459	Singapore	0.615
South Korea	0.189	Japan	0.435	Australia	0.329	China	0.281	Malaysia	0.320	China	0.360
China	0.183	South Korea	0.213	Malaysia	0.317	South Korea	0.105	South Korea	0.305	South Korea	0.197
Indonesia	0.182	Indonesia	0.188	Brunei	0.104	Malaysia	0.086	China	0.220	Australia	0.150
New Zealand	0.037	Singapore	0.067	China	0.084	Indonesia	0.074	Australia	0.209	Indonesia	0.096
Malaysia	0.027	Laos	0.061	Myanmar	0.071	Singapore	0.033	Japan	0.174	Japan	0.036
Laos	0.025	Myanmar	0.054	South Korea	0.053	Thailand	0.015	Brunei	0.058	Thailand	0.031
Thailand	0.022	Philippines	0.051	Thailand	0.052	Brunei	0.013	Thailand	0.053	Philippines	0.018
Cambodia	0.021	Thailand	0.034	Philippines	0.049	Laos	0.009	Cambodia	0.049	Myanmar	0.016

In the coal trade network, Australia and Japan held prominent core positions in both 2011 and 2020, with significantly higher coreness than other countries. However, it is noteworthy that Japan's coreness index has been declining over the years, from 0.618 in 2011 to 0.435 in 2020. South Korea, China, and Indonesia closely follow, with pronounced core positions. China's coreness index has risen from 0.183 in 2011 to 0.44 in 2020. In 2020, China surpassed Japan, becoming the second-largest core country.

In the natural gas trade network, Japan is the dominant core country in 2011, with coreness index significantly higher than other countries. However, in 2020, Australia surpassed Japan, becoming the top core country in the natural gas network. China's performance in the natural gas trade network is notable, with its coreness index increasing from 0.084 in 2011 to 0.281 in 2020, transitioning from the periphery to the semi-periphery.

In the oil trade network, Singapore and Malaysia respectively had the highest coreness indices in 2011 and 2020 . Malaysia's core position is gradually strengthening, and it surpassed Singapore to become the top-ranked country in 2020. China, South Korea, and Australia have always occupied a semi-peripheral position. China's core ranking has risen from 5th to 3rd. However, the core index values of South Korea and Australia have decreased.

Through the analysis of the Core-Periphery Structures of the fossil fuel trade networks within the RCEP region, the following characteristics have been observed: From the perspective of the core dimension, the core positions in the networks are controlled by a few countries, and these countries have a significant influence on the operation of the entire trade network and the flow of resources. For example, Australia, Japan, and Singapore occupied core positions in the years under examination. In addition, the coreness of countries such as China, South Korea, Malaysia, and Indonesia in the RCEP fossil energy trade network is increasing. Their participation has gradually enhanced the diversity and resilience of the energy trade network. The index value of China's coreness has increased significantly, which indicates the importance and influence of China in the energy trade within the RCEP region.

5. Conclusion and Policy Implications

5.1 Conclusions

Fossil fuels are the cornerstone of economic development, and the resilience fossil fuel trade networks is essential for ensuring energy security and sustainable development. Through social network analysis, this study has gained an in-depth understanding of the characteristics and evolution of RCEP's fossil fuel trade networks. It helps assess whether the regional energy trade system is resilient enough to handle various challenges. Below are the key findings regarding the characteristics, evolution, and resilience of the RCEP fossil fuel trade networks as revealed by the analysis.

1. Through the analysis of network evolution, this paper finds that the fossil fuel trade networks in the RCEP region have undergone significant structural changes over the observation period, exhibiting distinct patterns and heterogeneity among different energy types and countries. The oil trade network within the RCEP region exhibits the strongest connectivity and highest resilience, followed by the coal network, while the natural gas network shows comparatively weaker performance in these aspects.

2. The overall network analysis reveals distinct characteristics and resilience levels across the RCEP fossil fuel trade networks. The oil trade network demonstrates the highest resilience, with increasing density and stable, decentralized centralization, indicating robust and evenly distributed trade connections. The coal trade network shows moderate resilience, with rising density but fluctuating centralization, reflecting reliance on key export nodes. In contrast, the gas trade network exhibits the weakest resilience, marked by declining density and the highest centralization, suggesting dominance by a few nodes and vulnerability to disruptions. These findings highlight the varying structural dynamics and stability among the three energy trade networks.

3. The core node analysis reveals that the development of the RCEP fossil fuel trade networks is unbalanced, with a few dominant countries exerting substantial control and influence. China, Thailand, South Korea, Singapore, Japan, Australia, Indonesia, and Malaysia occupy pivotal positions in the networks, significantly shaping resource flows and network operations. These nations' stability and cooperation are crucial for regional energy security and sustainable development.

In summary, the RCEP fossil fuel trade networks have undergone significant structural changes, with oil exhibiting the highest resilience, followed by coal, while the natural gas network shows greater vulnerabilities.The core node analysis highlights an imbalanced development of the network, with a few dominant countries holding substantial influence over regional energy flows.

Above findings contribute to the understanding of the structural dynamics and resilience of fossil fuel trade networks within RCEP, offering insights into the varying stability across energy types and the role of dominant players in shaping energy security. The findings provide critical guidance for improving trade diversification, strengthening regional cooperation, and ensuring the sustainability of the energy transition in RCEP countries.

5.2 Policy Implications

1. Fostering integrated regional approaches for sustainable energy transition. While the oil network's high resilience suggests robust and stable trade patterns, the coal and natural gas networks exhibit vulnerability to fluctuations in centralization and trade dependencies. Therefore, RCEP countries should adopt a region-wide strategy that balances the continued reliance on fossil fuels with the integration of renewable energy sources. A gradual energy transition plan should be developed to improve the diversification of energy types within the trade network. This would not only reduce long-term dependence on fossil fuels but also ensure that the transition to cleaner energy is secure, efficient, and supports the resilience of the entire energy system. Additionally, enhancing cooperation on cleaner fossil fuel technologies, such as carbon capture and storage (CCS), could strengthen the existing networks while preparing them for future sustainability challenges.

2. Enhancing connectivity to improve network resilience, particularly for natural gas. In light of the weaker resilience seen in the natural gas network, RCEP members should prioritize the development of cross-border infrastructure (such as pipelines and LNG terminals) and diversify export and import routes. Facilitating better connectivity and reducing the reliance on a small number of key trade nodes would alleviate centralization risks and enhance the overall stability of the gas trade network. Policies that promote collaborative investments in infrastructure, especially between natural gas-exporting and -importing countries, will help achieve a more resilient and flexible regional gas trade network.

3. Strengthening diversification of trade nodes(countries) to address network imbalances. Given the concentrated control of key countries like China, Japan, South Korea, and Australia, it is essential for RCEP nations to promote diversification within the trade network. This can be achieved by encouraging smaller and emerging economies to play a more active role in

fossil fuel trade through targeted infrastructure development, market access policies, and fostering inter-country partnerships. Reducing dependency on dominant nodes and strengthening the role of intermediate and smaller countries would improve overall network resilience, thereby mitigating the risks associated with disruptions in trade caused by changes in the stability of a few key players.

References

Ahi, P., & Searcy, C. (2013). A comparative literature analysis of definitions for green and sustainable supply chain management. Journal of Cleaner Production, 52, 329-341. https://doi.org/10.1016/j.jclepro.2013.02.018

Aller, C., Ductor, L., & Herrerias, M. J. (2015). The world trade network and the environment. Energy Economics, 52, 55-68. https://doi.org/10.1016/j.eneco.2015.09.008

Barratt, M., & Barratt, R. (2011). Exploring internal and external supply chain linkages: Evidence from the field. Journal of Operations Management, 29, 514-528. https://doi.org/10.1016/j.jom.2010.11.006

Borgatti, S. P., & Li, X. (2009). On social network analysis in a supply chain context. Journal of Supply Chain Management, 45(2), 5-22. https://doi.org/10.1111/j.1745-493X.2009.03166.x

Carter, C. R., Ellram, L. M., & Tate, W. (2011). The use of social network analysis in logistics research. Journal of Business Logistics, 28(1), 137-168. https://doi.org/10.1002/j.2158-1592.2007.tb00235.x

Chandra, C., & Kumar, S. (2000). Supply chain management in theory and practice: A passing fad or a fundamental change? Industrial Management & Data Systems, 100(3), 100-114. https://doi.org/10.1108/02635570010286168

Chen, Y. F. (2011). Analysis on social network of world trade situation in 2000-2009. Journal of International Trade, 31-42. https://doi.org/10.13510/j.cnki.jit.2011.11.005

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: Control versus emergence. Journal of Operations Management, 19(3), 351-366. https://doi.org/10.1016/S0272-6963(00)00068-1

Cohen, M. A., & Kouvelis, P. (2020). Revisit of AAA excellence of global value chains: Robustness, resilience, and realignment. Production and Operations Management, 30(3), 633-643. https://doi.org/10.1111/poms.13305

De Benedictis, L., & Tajoli, L. (2011). The world trade network. The World Economy, 34(8), 1417-1454. https://doi.org/10.1111/j.1467-9701.2011.01360.x

De Toni, A., & Nassimbeni, G. (1995). Supply networks: Genesis, stability and logistics implications. A comparative analysis of two districts. Omega, 23(4), 403-418. https://doi.org/10.1016/0305-0483(95)00024-I

Ding, Y. B., & Feng, Z. X. (2022). Analysis on the evolution trend and influencing factors of agricultural trade between China and RCEP countries. Journal of Northeast Normal University (Philosophy and Social Sciences), 319, 112-126. https://doi.org/10.16164/j.cnki.22-1062/c.2022.05.015

Emirbayer, M., & Goodwin, J. (1994). Network analysis, culture, and the problem of agency. American Journal of Sociology, 99(6), 1411-1454. https://doi.org/10.1086/230450

Energy Institute. (2024). Statistical review of world energy 2024. https://www.energyinst.org/statistical-review

Fragapane, G., Ivanov, D., Peron, M., Sgarbossa, F., & Strandhagen, J. O. (2022). Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics. Annals of Operations Research, 308, 125-143. https://doi.org/10.1007/s10479-020-03526-7

Gao, J., & Zhen, H. (2009). Evaluation of supply chain integration based on social network analysis. Systems Engineering, 27, 19-24.

Garlaschelli, D., & Loffredo, M. I. (2005). Structure and evolution of the world trade network. Physica A: Statistical Mechanics and its Applications, 355(1), 138-144. https://doi.org/10.1016/j.physa.2005.02.075

Gong, J., & Li, Y. Z. (2021). Analysis of China's trade network with countries along the Belt and Road Initiative. Economic and Management Review, 37, 27-37. https://doi.org/10.13510/j.cnki.jit.2011.11.005

Gurtu, A., & Johny, J. (2021). Supply chain risk management: Literature review. Risks, 9(1), 16. https://doi.org/10.3390/risks9010016

Gurtu, A., Jaber, M. Y., & Searcy, C. (2015). Impact of fuel price and emissions on inventory policies. Applied Mathematical Modelling, 39(3-4), 1202-1216. https://doi.org/10.1016/j.apm.2014.08.001

Han, M. W., & Li, S. L. (2020). Network characteristics and community structure of marine energy products trade among the countries along the Belt and Road. Economic Geography, 40, 108-117. https://doi.org/10.15957/j.cnki.jjdl.2020.10.013

Hao, X. Q., An, H. Z., Chen, Y. R., & Gao, X. Y. (2013). Research on the evolution laws of international iron ore trade based on complex network analysis. Economic Geography, 33, 92-97. https://doi.org/10.15957/j.cnki.jjdl.2013.01.027

Hoggett, R. (2014). Technology scale and supply chains in a secure, affordable and low carbon energy transition. Applied Energy, 123, 296-306. https://doi.org/10.1016/j.apenergy.2013.12.006

Hollenbeck, J. R., & Jamieson, B. B. (2015). Human capital, social capital, and social network analysis: Implications for strategic human resource management. Academy of Management Perspectives, 29, 370-385. https://doi.org/10.5465/amp.2014.0140

Hong, L., Zhao, X. B., Wang, S. Y., Huo, H., Zhang, W., Song, J., Xiao, Y. B., & Li, J. (2023). Key scientific issues on supply chain resilience and security. Bulletin of National Natural Science Foundation of China, 37, 418-428. https://doi.org/10.16262/j.cnki.1000-8217.2023.03.012

Ivanov, D. (2018). Revealing interfaces of supply chain resilience and sustainability: A simulation study. International Journal of Production Research, 56(10), 3507-3523. https://doi.org/10.1080/00207543.2017.1343507

Jabbarzadeh, A., Fahimnia, B., & Sabouhi, F. (2018). Resilient and sustainable supply chain design: Sustainability analysis under disruption risks. International Journal of Production Research, 56(17), 5945-5968. https://doi.org/10.1080/00207543.2018.1461950

Jing, S., Zhihui, L., Jinhua, C., & Zhiyao, S. (2020). China's renewable energy trade potential in the "Belt-and-Road" countries: A gravity model analysis. Renewable Energy, 161, 1025-1035. https://doi.org/10.1016/j.renene.2020.06.134

Kamalahmadi, M., & Parast, M. M. (2016). A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research. International Journal of Production Economics, 171, 116-133. https://doi.org/10.1016/j.ijpe.2015.10.023

Kan, S. Y., Chen, B., Wu, X. F., Chen, Z. M., & Chen, G. Q. (2019). Natural gas overview for world economy: From primary supply to final demand via global supply chains. Energy Policy, 124, 215-225. https://doi.org/10.1016/j.enpol.2018.10.002

Kan, S., Chen, B., Meng, J., & Chen, G. (2020). An extended overview of natural gas use embodied in the world economy and supply chains: Policy implications from a time series analysis. Energy Policy, 137, 111068. https://doi.org/10.1016/j.enpol.2019.111068

Ketchen Jr., D. J., & Hult, G. T. M. (2007). Bridging organization theory and supply chain management: The case of best value supply chains. Journal of Operations Management, 25(2), 573-580. https://doi.org/10.1016/j.jom.2006.05.010

Khan, S. A., Mubarik, M. S., Kusi-Sarpong, S., Gupta, H., Zaman, S. I., & Mubarik, M. (2022). Blockchain technologies as enablers of supply chain mapping for sustainable supply chains. Business Strategy and the Environment, 31(8), 3742-3756. https://doi.org/10.1002/bse.3029

Kochan, C. G., & Nowicki, D. R. (2018). Supply chain resilience: A systematic literature review and typological framework. International Journal of Physical Distribution & Logistics Management, 48(8), 842-865. https://doi.org/10.1108/IJPDLM-02-2017-0099

Koschade, S. (2006). A social network analysis of Jemaah Islamiyah: The applications to counterterrorism and intelligence. Studies in Conflict & Terrorism, 29(6), 559-575. https://doi.org/10.1080/10576100600798418

Lazzarini, S. G., Chaddad, F. R., & Cook, M. L. (2001). Integrating supply chain and network analyses: The study of netchains. Journal on Chain and Network Science, 1(1), 1-14. https://doi.org/10.3920/JCNS2001.x002

Lee, H. L. (2002). Aligning supply chain strategies with product uncertainties. California Management Review, 44(3), 105-119. https://doi.org/10.2307/41166135

Li, H. F., & Wei, S. B. (2024). Research on the spatio-temporal evolution of the global rare earth trade network and the change of China's position. World Geographical Research, 6, 1-13.

Liang, M. L., Hong, J. H., Luo, H. S., Peng, B. W., & Xiong, C. R. (2024). Research on the spatio-temporal evolution and influencing factors of APEC trade network structure. World Geographical Research, 1, 18-32.

Liu, J. S. (2016). Evolution of the global natural gas trade pattern based on social network analysis. Economic Geography, 36, 89-95. https://doi.org/10.15957/j.cnki.jjdl.2016.12.013

Liu, L. T., Shen, L., Liu, X. J., Cheng, S. K., Zhong, S., Cao, Z., Zhang, C., Kong, H. X., & Sun, Y. Z. (2017). Spatial-temporal features of China’s oil trade network and supply security simulation. Resources Science, 39, 1431-1443.

Liu, Y., Huang, J. B., & Chen, J. Y. (2017). Analysis of network connections and influencing factors of global copper ore resource flow. Statistics & Decision, 475, 146-149. https://doi.org/10.13546/j.cnki.tjyjc.2017.07.038

Ma, Y., & Lei, H. F. (2019). Simulation of energy trade network evolution and connectivity effects of countries along the Silk Road Economic Belt. Statistics & Information Forum, 34, 92-102.

Ma, Y., & Luo, P. (2021). Implicit energy flow and carbon emissions in China's international trade: A case study of RCEP. Prices Monthly, 532, 69-78. https://doi.org/10.14076/j.issn.1006-2025.2021.09.10

Marchese, D., Reynolds, E., Bates, M. E., Morgan, H., Clark, S. S., & Linkov, I. (2018). Resilience and sustainability: Similarities and differences in environmental management applications. Science of the Total Environment, 613, 1275-1283. https://doi.org/10.1016/j.scitotenv.2017.09.086

Mensah, P., & Merkuryev, Y. (2014). Developing a resilient supply chain. Procedia - Social and Behavioral Sciences, 110, 309-319. https://doi.org/10.1016/j.sbspro.2013.12.875

Mubarik, M. S., Bontis, N., Mubarik, M., & Mahmood, T. (2022). Intellectual capital and supply chain resilience. Journal of Intellectual Capital, 23(3), 713-738. https://doi.org/10.1108/JIC-06-2020-0206

Mubarik, M. S., Naghavi, N., Mubarik, M., Kusi-Sarpong, S., Khan, S. A., Zaman, S. I., & Kazmi, S. H. A. (2021). Resilience and cleaner production in industry 4.0: Role of supply chain mapping and visibility. Journal of Cleaner Production, 292, 126058. https://doi.org/10.1016/j.jclepro.2021.126058

Ni, N., & Cao, Y. C. (2022). Research on the impact of high-tech products trade network on the upgrading of global value chain. Journal of Dongbei University of Finance and Economics, 143, 86-97. https://doi.org/10.19653/j.cnki.dbcjdxxb.2022.05.008

OECD. (2024). Climate resilience for energy security. https://www.oecd.org/en/publications/climate-resilience-for-energy-security_2a931f53-en.html

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring supply chain resilience: Development and implementation of an assessment tool. Journal of Business Logistics, 34(1), 46-76. https://doi.org/10.1111/jbl.12009

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. The International Journal of Logistics Management, 20(1), 124-143. https://doi.org/10.1108/09574090910954873

Roy, V. (2021). Contrasting supply chain traceability and supply chain visibility: Are they interchangeable? The International Journal of Logistics Management, 32(3), 942-972. https://doi.org/10.1108/IJLM-05-2020-0214

Ruiz-Benitez, R., López, C., & Real, J. C. (2019). Achieving sustainability through the lean and resilient management of the supply chain. International Journal of Physical Distribution & Logistics Management, 49(2), 122-155. https://doi.org/10.1108/IJPDLM-10-2017-0320

Shi, C. Y., Gao, X. Y., Sun, X. Q., & Hao, X. Q. (2018). Research on the evolution characteristics of international bauxite trade from a complex network perspective. China Mining Magazine, 27, 57-62.

Sun, X. L., Yang, Y. Y., & Wu, D. S. (2012). Identification of topological structure and evolution properties of global crude oil trade network. World Economy Studies, 11-17+87. https://doi.org/10.13516/j.cnki.wes.2012.09.002

Van der Hulst, R. C. (2009). Introduction to social network analysis (SNA) as an investigative tool. Trends in Organized Crime, 12, 101-121. https://doi.org/10.1007/s12117-008-9057-6

Wang, W., & Qiang, P. (2020). Spatial network characteristics and influencing factors of energy trade in the Silk Road Economic Belt. Guizhou Social Sciences, 363, 123-131. https://doi.org/10.13713/j.cnki.cssci.2020.03.017

Wen, S. B., Chen, J. B., & Hao, X. Q. (2021). Research on the supply chain risk of global copper resources from the perspective of complex network. Mining Research and Development, 41, 171-178. https://doi.org/10.13827/j.cnki.kyyk.2021.09.032

Wichmann, B. K., & Kaufmann, L. (2016). Social network analysis in supply chain management research. International Journal of Physical Distribution & Logistics Management, 46(8), 740-762. https://doi.org/10.1108/IJPDLM-05-2015-0122

Wilding, R. (1998). The supply chain complexity triangle: Uncertainty generation in the supply chain. International Journal of Physical Distribution & Logistics Management, 28(8), 599-616. https://doi.org/10.1108/09600039810247524

Xia, Q. F. (2022). China's spatial-temporal characteristics of energy investment layout and risks in RCEP countries. World Regional Studies, 31, 814-826.

Xiao, J. Z., Peng, Y., & Wang, X. L. (2013). Evolution of the international natural gas trade network and regional characteristics: A social network analysis approach. Journal of China University of Petroleum (Edition of Social Sciences), 29, 1-8.

Xu, B. (2015). Social network analysis of the international iron ore trade pattern. Economic Geography, 35, 123-129. https://doi.org/10.15957/j.cnki.jjdl.2015.10.018

Xu, Q. H., & Yuan, M. (2021). The effectiveness of the Regional Comprehensive Economic Partnership (RCEP) and energy cooperation within the Asia-Pacific Economic Cooperation (APEC) mechanism. Area Studies and Global Development, 5, 5-19+154.

Yu, G. M., & Wang, Y. J. (2022). Current status and prospects of oil and gas resources and refining industry in the member countries of the Regional Comprehensive Economic Partnership (RCEP). International Petroleum Economics, 30, 60-71.

Zeng, C., & Tang, S. (2023). The role of state-owned enterprises as economic stabilizer during COVID-19 pandemic: Evidence from supply chain support. Economic Research, 58, 78-96.

Zhang, C. Q., & Chen, P. Y. (2022). Applying the three-stage SBM-DEA model to evaluate energy efficiency and impact factors in RCEP countries. Energy, 241, 122917. https://doi.org/10.1016/j.energy.2021.122917

Zhang, L., & Luo, Y. (2022). Progress, prospect and the effect of the security cooperation of the supply chain between the U. S, Japan, India and Australia. Indian Ocean Economic and Political Review, 67-83+153. https://doi.org/10.16717/j.cnki.53-1227/f.2022.03.004

Zhao, W. X., Xi, Y. L., & Yang, J. G. (2023). Research on the structure characteristics and cooperation tendency of trade network on digital products. Forum on Science and Technology in China, 146-158. https://doi.org/10.14089/j.cnki.cn11-3664/f.2022.10.002

Zhuang, D. L., Li, J. H., Chen, Z. R., & Liu, Y. C. (2022). Dynamic evolution and influencing mechanism of global rare earth trade network: Based on the perspective of industrial chain. Scientia Geographica Sinica, 42, 1900-1911. https://doi.org/10.13249/j.cnki.sgs.2022.11.005

Author Introduction

First author, Rui Liang, Female, born in 1980, Ph.D., Professor, College of Business, Beijing Union University, Obtained a PhD in International Trade from Graduate School of Chinese Academy of Social Sciences in 2009 , research interest in regional trade agreements, email: rui.liang @buu.edu.cn.

Second Author, Ping Liang, Female, born in 1977, M.A., Associate Professor, School of Economics and Management, Shanghai Minyuan Vocational College, Obtained a M.A. from Yangzhou University in 2010, research interest in Trade and Finance, email: lpgrug@163.com.

Corresponding author, Jinyan Tian, Female, born in 1991, Ph.D., College of Economics and Management, Hunan University of Arts and Science, Obtained a PhD in Global Business from Kyonggi University in 2024, research interest in global business and regional economics, email: tianjinyan0903@gmail.com.