Eng Int Syst (2024) 6: 613–623
© 2024 CRL Publishing Ltd

Engineering
Intelligent Systems

Trade Network Pattern and Factors Influencing New Energy Vehicles in RCEP Agreement Countries

Weihua Pan[1], Caihua Liu[2] and Ying Liu[3]*

[1] *School of Economics and Management, Hubei University of Automotive Technology, Shiyan 442002, China*
[2] *School of Economics and Management, Hubei University of Automotive Technology, Shiyan 442002, China*
[3] *School of Foreign Language, Hubei University of Automotive Technology, Shiyan 442002, China*

This study uses social network analysis as a tool to investigate the structure of the trade network and the factors that influence the trade of new energy vehicles in the 15 countries party to the 2022 RCEP agreement. The findings reveal that: (1) The density and correlation of the trade network for new energy vehicles among the countries in the agreement are significant, suggesting strong connection and considerable trade opportunities; (2) South Korea, China, and Japan occupy central positions within the trade network, and the "RCEP" trade network can be divided into three distinct trade clusters; (3) A country's level of economic development and logistics performance index have a significant and positive impact on the establishment of new energy vehicle trade relationships; lithium battery trade discrepancies, fuel trade levels, the presence of a shared border between countries has a significant impact on the establishment and strength of trade partnerships with new energy vehicles; and similarities in business convenience indices and geographical distance facilitate the establishment of new energy vehicle trade connections and enhance trade intensity among nations. Consequently, countries party to the agreement should continue to develop the construction of their transportation infrastructure and increase investment in industrial chain and infrastructure development.

Keywords: "RCEP" agreement; new energy vehicle trade; social network analysis; QAP analysis

1. INTRODUCTION

The report of the 20th National Congress of the Communist Party of China clearly articulates that China will persist in following the accurate course of economic globalization, dedicated to advancing the liberalization and streamlining of trade and investment, and aggressively strengthening bilateral, regional, and international collaboration. Trade facilitation is an effective way to reduce international trade costs and eliminate international trade barriers. Since the 1980 s, regional economic integration and sub-regional economic organizations have emerged rapidly, and the trend of new regionalism has gradually become mainstream. The rapid development of regional economic integration has led to a wider division of labor and cooperation within regions, profoundly impacting the global economic organization and extensively promoting the prosperity of international trade. In the context of global economic integration and world multi-polarization, the development of regional integration has become an irreversible trend [1].

The Regional Comprehensive Economic Partnership Agreement (RCEP) was formally created on November 15, 2020, with signatories comprising the 10 ASEAN states, as well as China, Japan, South Korea, Australia, and New Zealand. This agreement represents the establishment of the largest free trade region in the world and is crucial to advancing regional economic unification. The RCEP not only helps to strengthen economic cooperation with trading partners and ensure the respective interests of member countries; it also encompasses a diverse range of members, including

*Corresponding Author's E-mail: 13508689487@163.com

both developed and developing countries. The RCEP serves as an "integrator" for the regional economy, changing the fragmented landscape of free trade agreements in the Asia-Pacific region and providing strong momentum for the growth of China's and even the world's economy. Given the ongoing trade tensions between China and the United States, China urgently needs to expand the RCEP free trade market. With the implementation of the RCEP agreement, countries can fully leverage the various advantages they have in terms of their own resources.

In the macro context of global sustainable development and rapid advancements in science and technology, achieving harmony between environmental protection and social development has become a common and crucial issue in global governance. As the driving force of social progress, the use of electric power is increasing [1]. The vigorous growth and application of clean energy play a significant role in energy conservation, emission reduction, and protection of non-renewable resources. Therefore, as an essential direction for the future automotive industry, accelerating the transition and upgrading of the traditional automotive industry to new energy vehicles has become a critical means of achieving sustainable development. From 2018 to 2022, there was a significant rise in the total global sales of new energy cars, increasing from 2.01 million to 7.8 million. In 2022, new energy vehicles made up 23% of all vehicle deliveries, which is 20% more than in 2021. The "Global Auto Industry Research Report" published by J.P. Morgan in 2019 estimated that the worldwide adoption of new energy cars would reach 7.7% by 2025, resulting in sales of 33.6 million units. The new energy cars sector is expanding as these vehicles contribute to, energy saving, and environmental preservation, in addition to having low running costs and intelligent connection. The increase in their market share has strategic significance for global energy conservation, emission reduction, and energy security in various countries. Therefore, trade facilitation, multilateral trade systems, and regional economic integration and creating comprehensive and high-standard free trade zones have become common goals of parties to the RCEP agreement. In-depth research on the evolution of trade relationships among RCEP member countries, clarifying the interdependent relationships among members and their positions in the RCEP trade network, and analyzing the influencing factors driving the spatiotemporal evolution of trade network structures are of great significance for promoting China's integration and leadership in the construction of the RCEP free trade zone, optimizing China's foreign trade pattern, and forming a new development pattern of domestic and international dual circulation.

2. LITERATURE REVIEW

The global production and sales of new energy vehicles have a "multipolar" distribution, in which China, Europe, the United States, and Japan hold prominent positions as the leading players. The promotion of supply-side structural changes has been greatly advanced by China's car sector under the auspices of the Regional Comprehensive Economic Partnership Agreement (RCEP). Among them, China's transition from a significant auto nation to a prominent auto power can be measured primarily by the development of new energy vehicles; However, with the domestic market gradually becoming saturated and new energy subsidies being withdrawn, Chinese new energy vehicle companies urgently need to expand and develop overseas markets. China had a 17.5% rise in exports to RCEP trade partners in 2022, surpassing the total export growth rate by 7%. Notably, electric car exports saw a significant spike of 131.8%. Therefore, the strengthening of new energy vehicle trade cooperation among RCEP agreement members will help Chinese companies to expand their overseas markets, accelerate the organization of overseas industries, build a global trade network for Chinese new energy vehicles, and establish a unique environment for the international trade of new energy vehicles [2].

Regarding research on the RCEP agreement, most scholars focus on the significance, challenges, and trade elements. For example, scholars such as Du et al. (2021) point out that the RCEP agreement can promote the internationalization of the Chinese yuan in the financial sector. In regard to the scale and growth rate of foreign trade, RCEP has a significant impact on China's foreign trade. It has the potential to greatly decrease tariffs on trade products within the area and broaden the range of duty-free commodities, thereby fostering additional development in the size of export trade, and also allows member nations to better fulfil their production and consumption requirements by increasing their imports [3]; Zhang and Li (2021) point out that the RCEP is beneficial for China to break through the trade blockade and economic containment that the United States has been vigorously implementing in recent years [4]. Furthermore, Chen (2022) believes that China will face more intense competition in the industrial sector, service trade has not yet provided strong support for participating in the regional industrial and value chain reconstruction, and the level of investment facilitation also needs to be further improved [5]; Qiao et al. (2021) believe that competition in the agricultural sector will become more intense, causing a shock to the domestic industrial landscape, with higher demands on the quality of agricultural products and pressure on agricultural technological innovation. Under the RCEP framework, the pressure on agricultural technological innovation will significantly increase [6]. In terms of trade, most scholars focus on agricultural products. For instance, Zhang et al. (2023) investigated the opportunities and challenges of the apple industry in Shandong Province under the RCEP framework. They believe that after the implementation of RCEP, benefiting from tariff reductions among member countries, China's fresh apple exports to RCEP member countries will further increase [7]; Li et al. (2022) investigated the tea trade between China and RCEP member countries and believe that China has long-term advantages in tea exports, with green tea exports being significantly advantageous, while the benefits of bulk black tea exports lag behind countries like Indonesia and Vietnam [8].

Several scholars have conducted research on trade networks; Cheng et al. (2021) investigated complicated networks and, using product trade data from 1995 to 2015, constructed international product trade networks and total international trade networks to explore the evolution of product trade [9]. They found that although total global trade is the sum of all products, there are significant differences in trade relationships between product countries [9]. Wang (2022), from the perspective of economic geography, discusses the nature and structure of trade networks between countries, as well as the ways in which they participate in trade networks [10]. After studying the structure and characteristics of the national food trade network from 2001 to 2011, Torreggiani et al. (2018) found that countries with connections are more inclined to trade with countries that have close relationships with themselves [11]. Moreover, to investigate the attributes of the development of trade networks, many scholars have conducted research on the flow direction of trade network edges and assigned weights to trade advantages, systematizing and facilitating the study of the evolution of trade network structure. For example, Zhang et al. (2018) used the theory of social network analysis methods to study the international food supply and demand and flow pattern, and provided a detailed explanation of the evolution trend and characteristics of the international food supply and demand pattern, which provides a basis for China's formulation of food trade policies [12]. Kandogan (2018) revised and supplemented the social network analysis method to enable a more precise study of the topological structure of international trade. They used this methodology to study the evolving nature of international trade networks and changes in trends over the past 12 years [13]. Murcia et al. (2018) analysed global trade networks for different types of goods and compared recent data with data from the mid-1990s. They found that international trade has undergone significant changes as a result of lobalization, with increasingly close interactions between countries. The density, clustering and reciprocity of the world trade network has increased [14].

Regarding the factors influencing the development of new energy vehicles, Li (2016) and colleagues analyzed the national policy level and found that the existing policy system has achieved full coverage of all links in the new energy vehicle industry chain. Additionally, the increase in policy support is positively correlated with the overall development of the industry [15]. Qi and Li (2023) believe that factors such as economy, geography, institutions, culture, and industrial chains may influence the structure of the new energy vehicle trade network [16]. Asadi et al. (2020) studied the factors influencing consumers' purchase and use of new energy vehicles such as electric cars. They found that consumers' value perception, perceived effectiveness, subjective norms for choosing new energy vehicles, and recognition of the importance of new energy vehicles all positively impact the new energy vehicles market [17].

In summary, international research on social network analysis theory is becoming increasingly mature, and the study of international trade networks is also gradually increasing. Relevant research on new energy vehicles is relatively abundant; however, the study on new energy vehicles predominantly focuses on examining the elements that impact their prospective market growth. The research on trade networks mainly concentrates on bulk commodities, service trade, and other fields, with most of it limited to the analysis of trade network characteristics of new energy vehicles as a macro concept. There is relatively little research that takes the new energy vehicle trade network as the object and uses network methods to explore the underlying causes. Therefore, in regard to new energy cars, in order to strengthen the trade collaboration among RCEP nations and expedite the global expansion of Chinese new energy vehicle companies, and form a "new channel", "new momentum" and "new situation" for China's new energy vehicle international trade, There is an immediate need to conduct research on the trade ties, trade network patterns, and variables that influence trade of new energy vehicles among RCEP nations.

3. RESEARCH OBJECTIVES, METHODS AND DATA

3.1 Delimitation of Research Scope for New Energy Vehicles

New energy cars are autos that use non-traditional vehicle fuels as their power source. Their features include sophisticated technological concepts, innovative technology, and novel architectures. Specifically, automobile types that use solar energy, electricity, hydrogen, and biofuels as either partial or total power sources can be categorized as new energy vehicles.

The current mainstream definition criteria in China for the 'New Energy Vehicle Production and Product Access Management Rules' released by the Chinese Ministry of Industry and Information Technology in 2009 are: New energy vehicles are autos that use non-traditional vehicle fuels as their power source, or alternatively, employ conventional vehicle fuels and adopt new types of vehicle powertrains), incorporating advanced technologies in vehicle power control and drive systems, resulting in automobiles with advanced technical principles, novel technologies, and new structures. New energy vehicles include pure electric vehicles (BEV, including solar vehicles), hybrid electric vehicles (HEV), fuel cell electric vehicles (FCEV), hydrogen internal combustion engine vehicles (HICEV), and other new energy vehicles (such as high-efficiency energy storage devices, dimethyl ether). This article establishes the study boundaries for new energy vehicle models by focusing on customs HS chapters 870220-870240 and 870340-870380 after analyzing the customs HS codes. The definitions of various types of automobiles and their related customs codes are presented in Table 1.

3.2 Research Methodology

3.2.1 Construction of the New Energy Vehicle Trade Network

Sociological networks can be abstracted as a graph $G = (N, M)$, where N is a set of nodes $\{1, 2, \ldots, n\}$ and M is an $n \times n$ adjacency matrix. Several indicators can be used to characterize the structural features of sociological networks,

Table 1 Classification and definition of new energy vehicle customs HS codes.

Customs Code	Product Definition
870220	Airport buses are powered by compression ignition piston engines, such as diesel or semi-diesel engines, and are propelled by electric motors.
870230	Passenger buses equipped with spark-ignition piston internal combustion engines and driven by electric motors.
870240	Passenger buses are equipped solely with driving electric motors.
870340	Additional cars that are fitted with spark-ignition piston internal combustion engines and driven by electric motors, which cannot be recharged by connecting to an external power source.
870350	Other vehicles are equipped with compression ignition piston internal combustion engines and driven by electric motors, which cannot be recharged by connecting to an external power source.
870360	Other vehicles are equipped with spark-ignition reciprocating piston internal combustion engines and driven by electric motors, which can be recharged by connecting to an external power source.
870370	Some vehicles are fitted with compression ignition piston internal combustion engines, specifically diesel or semi-diesel engines, and are propelled by electric motors. These motors may be replenished by connecting to an external power supply.
870380	Other vehicles are equipped solely with driving electric motors.

including clustering coefficient, degree distribution, coreness, and structural entropy, in addition to other measurement indices. The indicators commonly used for the analysis of overall networks include: degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality. These indicators represent different sociological meanings within the network.

In this study, we employ the social network analysis method, treating economies involved in new energy vehicle trade as network 'nodes' and economic trade relationships as 'edges'. By means of this approach, the new energy vehicle trade network system among RCEP agreement countries, is constructed, represented as $G = (N, E, A, W, T)$. Here, N denotes the participants in new energy vehicle trade, E represents inter-country trade relationships, A indicates the number of trade connections for any country within the trade network; W represents the total import-export trade volume between any two countries; and T indicates the collection of trade networks over a number of years.

(1) Network density and connectivity

Network density is a measure of the tightness and connectivity of the relationships between countries in the overall network, reflecting the degree of economic and trade interactions between countries. The higher the density, the closer the connections in the comprehensive network, and the greater the impact on the overall network, which facilitates resource sharing between nodes. The new energy vehicle trade network density of RCEP agreement countries can be determined with Equation (1):

$$D = \frac{2m}{n(n-1)}, D \in [0, 1] \tag{1}$$

Where the variable D indicates the density of the network, m is the number of real connections between nodes in the network, and n represents the total number of nodes in the network.

(2) Network centrality

Network centrality primarily examines the placement of each nation within the trade network of new energy vehicles, which may be classified into three indicators: degree centrality, betweenness centrality, and closeness centrality.

1) Degree centrality

The degree centrality of an economy is a measure of the number of other economies that are directly related to it. The greater the number of connected economies, the higher the degree of centrality, indicating the stronger functional status and influence of that economy. When comparing the number of relationships between different economies, standardized degree centrality is usually employed to eliminate the impact of the total number of connections. In the overall network of new energy vehicle trade among RCEP agreement countries, degree centrality indicates the ability of a node in the network to send or receive connections from other nodes. The calculation formula can be expressed as Equation (2):

$$C_D(n_i) = \frac{d(n_i)}{N-1} = \frac{\sum_i X_{ij}}{N-1} = \frac{\sum_j X_{ij}}{N-1} \tag{2}$$

Where $C_D(n_i)$ denotes centrality; $X_{ij} \in [0, 1]$, X_{ij} represents the trade connections between economy i and economy j; N represents the total number of economies in the network.

2) Betweenness centrality

Betweenness centrality quantifies the frequency with which a node serves as a connector along the shortest routes connecting two other nodes. The more times a node serves as a bridge, the higher its betweenness centrality, which measures the extent to which that node in the network is located between other nodes. The calculation as shown in Equation (3):

$$C_{Bi} = \frac{\sum_J^N \sum_i^{N-1} D_{ji}{}^{(i)}}{D_{ji}} \tag{3}$$

Where C_{B_i} represents betweenness centrality, $D_{ji}(i)$ is the set of all shortest paths connecting node j and node i through node I, D_{ji} is the set of all shortest paths connecting node j and node i.

3) Closeness centrality

Closeness centrality can further classified as out-closeness centrality and in-closeness centrality. Out-closeness centrality measures how independent a node is from other nodes when sending a relationship, while in-closeness centrality reflects the degree of independence while receiving links. The calculation as shown in Equations (4) and (5):

Table 2 Classification criteria for block model.

Proportion of internal trade relations in blocks	Ratio of import to export trade volume between this block and other blocks	
	$I_{k,e}/I_{k,i} \geq 1$	$I_{k,e}/I_{k,i} < 1$
$I_k/I_{k,t} \geq (n_k-1)/(n-1)$	Bidirectional trade block	Inward trade block
$I_k/I_{k,t} < (n_k-1)/(n-1)$	Outward trade block	Brokerage block

$$OCC_i^{-1} = \sum_{j=1 \cdot j \neq i}^{N} d_{ij} \tag{4}$$

$$lCC_i^{-1} = \sum_{j=1, j \neq i}^{N} d_{ji} \tag{5}$$

Where OCC_i^{-1} represents out-closeness centrality, lCC_i^{-1} represents in-closeness centrality, d_{ij} denotes the shortest path from node i to node j, d_{ji} denotes the shortest path from node j to node i.

(3) Core-periphery structure

Core-periphery structure analysis involves the division of core, semi-periphery, and periphery regions. The overall network structure consists of a dense core and a sparse and dispersed periphery. The status and importance of each node in the new energy vehicle trade network of RCEP agreement countries are not balanced. The aim of core-periphery structure analysis of the new energy vehicle trade network is to clarify the status and importance of each node in the new energy vehicle trade network [18]. This study is based on new energy vehicle trade data from RCEP agreement countries. The Core & Periphery algorithm in Ucinet partitions the core-periphery structure of the new energy vehicle trade network. Nations with a core degree below 0.15 are referred to as peripheral nations, while countries with a core degree ranging from 0.15 to 0.20 are classed as semi-peripheral countries. Countries with a core degree over 0.2 are considered to be core countries.

3.2.2 Block Model Analysis

The block model is a clustering analysis method that divides the overall network into several ‘blocks’ to analyze the structural characteristics of each ‘block’. Based on previous research results, this study divides the block model into four sections (see Table 2). Specifically, the steps of the block model analysis are as follows: first, construct a square matrix of new energy vehicle trade networks within RCEP agreement countries, so that all trading parties can be included in each block; second, build a similarity matrix based on the CONCOR density matrix, where the corresponding elements in the similarity matrix take the value of 1 when the elements in the density matrix are more significant than the average network density, otherwise they take the value of 0; finally, analyze the overall network structure and the relationships between each block based on the CONCOR similarity matrix.

n_k represents the number of countries within each block; I_k denotes the total trade volume among nodes within block k; $I_{k,t}$ indicates the total trade volume of block in the overall trade network; $I_{k,e}$ represents the export trade volume of block k to other blocks; $I_{k,i}$ indicates the total import trade volume of block k from other blocks; $(n_k-1)/(n-1)$ represents the expected proportion of internal trade relationships in block k to the overall trade network.

3.2.3 QAP Regression Analysis

The QAP (Quadratic Assignment Procedure) analysis is a non-parametric estimating approach that use re-sampling to successfully handle the problems of multicollinearity and spurious correlation that occur while processing relational data using standard econometric methods. The analysis encompasses QAP correlation and QAP regression. QAP correlation analysis is primarily employed to assess the level of correlation between two “relation matrices”, so revealing the influence of establishing one relationship on the achievement of another relationship. QAP regression analysis primarily investigates the associations between many relational matrices and a single relational matrix. This study uses QAP regression analysis to simulate and examine the development of the trade network structure for new energy vehicles among the countries included in the RCEP agreement. The aim of this study is to identify the elements that will impact the establishment of the clean energy vehicle trade network, in order to furnish empirical data for facilitating the advancement of excellent commerce between China and the nations included in the RCEP agreement.

3.3 Data Source

The data used in this study on the new energy vehicle import and export trade was obtained from the United Nations Commodity Trade Statistics Database (UNCOM-TRADE). We constructed a weighted undirected trade network for new energy vehicles in 2022 among 15 RCEP agreement countries, as shown in Figure 1. In the figure, nodes represent economies, that is, trading participating countries, and edges indicate the total import and export trade volume of renewable energy vehicles between two countries. The thickness of the edges represents the size of the trade volume. As can be seen from Figure 1, countries such as China, Japan, South Korea, Australia, Thailand, and Singapore have a more significant trade flow of new energy vehicles among the RCEP agreement countries, occupying a relatively central position, and belong to network nodes with stronger influence and control in the trade network.

4. ANALYSIS OF THE NEW ENERGY VEHICLE TRADE NETWORK PATTERN AMONG RCEP AGREEMENT COUNTRIES

4.1 Measurement of Network Density and Correlation Degree

In the overall new energy vehicle trade network among RCEP agreement countries in 2022, there are 15 nodes and 210 trade network connections. The measured network

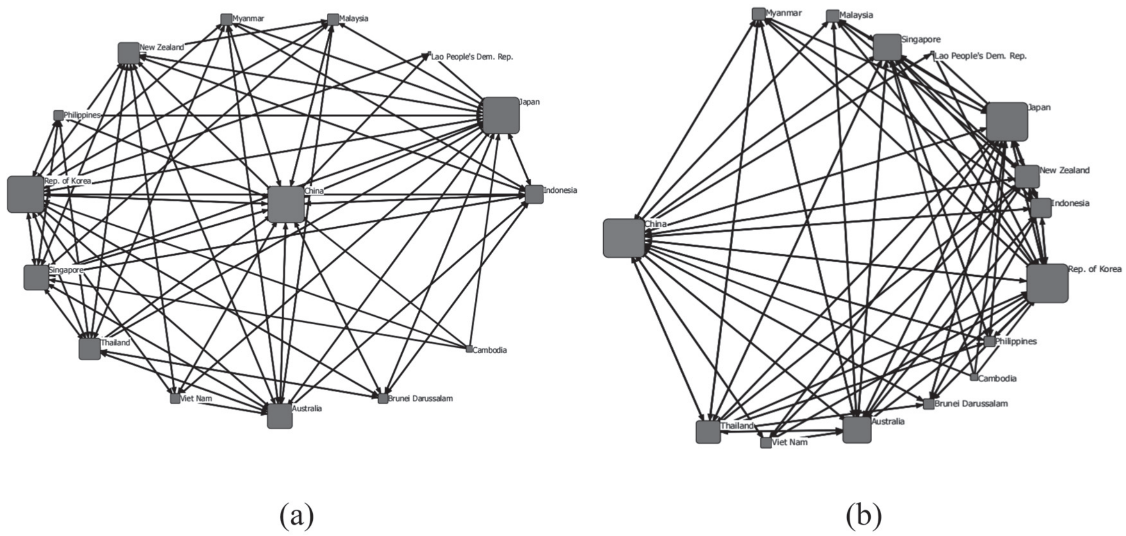

Figure 1 Topological structure of the new energy vehicle trade network of RCEP agreement countries in 2022.

density is 0.5810; the correlation degree is 1; China has formed new energy vehicle trade connections with all RCEP agreement countries. In this paper, the network density of 0.5810 indicates a relatively tightly connected state, and the correlation degree between network nodes reaches the level of 1, indicating that the connection degree between the existing nodes is substantial and has high stability. However, since the global new energy vehicle industry patents and primary production and sales channels are still concentrated in traditional automobile industrialized countries such as Japan, the United States, Germany, and other developed countries, most of the RCEP agreement countries are still developing countries with relatively backward industrial structures, outdated international logistics channels, and imperfect supporting infrastructure for the new energy industry, which limits the effective development of new energy vehicle trade. Furthermore, the burgeoning energy vehicle industry chain and consumer market in the countries that are part of the RCEP agreement are still in the early stages of development and lack significant international competitiveness in terms of production and sales. The rapid growth of the clean energy vehicle sector is constrained by both supply and demand factors. Nevertheless, the policy orientation of the countries party to the RCEP agreement encompasses the new energy vehicle sector, along with the ongoing development of infrastructure in these countries, presents ample opportunities for strengthening the trade network for new energy vehicles among the agreement nations.

4.2 Centrality Analysis

Using the technique indicated earlier, we calculated the degree centrality, intermediary centrality, and closeness centrality of the trade in new energy vehicles among the countries in the 'RCEP' agreement in 2022. The findings are presented in Table 3. The results indicate that in 2022, China, South Korea, and Japan occupied the top positions in degree centrality, closeness centrality, and intermediacy centrality with absolute leading advantages, indicating that these three countries are at the whole center of the new energy vehicle trade network among agreement countries. They not only played the most important role as 'intermediaries' and 'bridges', but also maintained the highest trade penetration and discourse power, fully demonstrating their promoting role in the new energy vehicle trade among agreement countries. Singapore, Australia, Thailand, and New Zealand all showed high centrality in the trade network, reflecting the strong development and increased integration of the 'RCEP' new energy vehicle trade, with more participation and discourse power in countries with different advantages. Brunei, Vietnam, the Philippines, Cambodia, and Laos, due to their relatively backward level of economic development, weak logistics infrastructure, and low trade accessibility, are temporarily in a more marginal position in the new energy vehicle trade network.

4.3 Core-Periphery Structure Analysis

Utilizing the Core-Periphery Continuous Model of Ucinet6, an ideal vector C and the product of C were employed to generate a matrix that closely resembled the original matrix. The core degree of the new energy vehicle trade network among the "RCEP" agreement countries in 2022 was calculated, and the results are presented in Table 4. According to the statistical analysis, there were 10 core countries, accounting for 66%; 3 semi-peripheral countries, accounting for 20%; and 2 peripheral countries, representing only 13% of the total. These peripheral countries were primarily located in Southeast Asia and were developing nations. There is considerable scope for improving the participation of these countries in the new energy vehicle trade and industry chains.

From the perspective of core degree, the core countries remain relatively stable. In the new energy vehicle trade network among the RCEP agreement countries in 2022, South Korea and Japan share the top rank with a core degree of 0.367, while China slightly lags behind with a core degree of 0.365, ranking second. This demonstrates the core position of South Korea, Japan, and China in the RCEP trade countries.

Table 3 Centrality indicators of the new energy vehicle trade network among RCEP agreement countries in 2022.

Degree centrality		Betweenness centrality		Closeness centrality	
Country	Indicator value	Country	Indicator value	Country	Indicator value
South Korea	100.000	South Korea	20.083	South Korea	100.000
China	100.000	China	20.083	China	100.000
Japan	100.000	Japan	20.083	Japan	100.000
Singapore	71.429	Singapore	4.217	Singapore	77.778
Australia	71.429	Australia	4.183	Australia	77.778
Thailand	64.286	Thailand	4.067	Thailand	73.684
New Zealand	64.286	New Zealand	2.517	New Zealand	73.684
Indonesia	57.143	Indonesia	2.267	Indonesia	70.000
Myanmar	42.857	Brunei	0.250	Myanmar	63.636
Malaysia	42.857	Myanmar	0.250	Malaysia	63.636
Brunei	35.714	Cambodia	0.000	Brunei	60.870
Vietnam	35.714	Laos	0.000	Vietnam	60.870
The Philippines	35.714	Malaysia	0.000	The Philippines	60.870
Cambodia	28.571	Vietnam	0.000	Cambodia	56.000
Laos	21.429	The Philippines	0.000	Laos	6.667

Table 4 Core statistics of new energy vehicle trade among the RCEP agreement countries in 2022.

Country	Core Degree	Country	Core Degree
South Korea	0.367	Malaysia	0.207
Japan	0.367	Myanmar	0.202
China	0.365	Vietnam	0.175
Australia	0.307	the Philippines	0.171
Singapore	0.283	Brunei	0.168
New Zealand	0.283	Cambodia	0.142
Thailand	0.273	Laos	0.112
Indonesia	0.251		

Table 5 New energy vehicle trade network blocks among RCEP agreement countries in 2022.

Block	Countries
First Block	Australia, Brunei, Myanmar, New Zealand, the Philippines, Singapore, Laos
Second block	Vietnam, Thailand, Malaysia, Cambodia, and Indonesia
Third block	China, Japan, South Korea

Table 6 New energy vehicle trade overall network block matrix among RCEP agreement countries in 2022.

Block	First Block	Second block	Third block
First Block	0.238	0.457	1.000
Second block	0.486	0.000	1.000
Third block	1.000	0.800	1.000

4.4 Block Model Analysis

Incorporating the block model analysis method mentioned earlier, the Ucinet analysis software's CONCOR method was employed with a maximum segmentation depth of 2 and a convergence standard of 0.2. Upon conducting the division, the overall network of new energy vehicle trade among the "RCEP" agreement countries was divided into three blocks. The results are presented in the Table 5, along with the density matrix table of the blocks, as shown in Table 6. The first block consists of seven countries, the second block comprises five countries, and the third block contains three countries, with China being part of the third block. The first block includes countries like Australia, Brunei, Myanmar, and New Zealand, which are considered as external blocks; the second block comprises Vietnam, Thailand, Malaysia, Cambodia, and Indonesia, representing the core blocks; and the third block consists of China, Japan, and South Korea, which are categorized as internal blocks. Since the primary goal of the RCEP agreement is to establish a modern, comprehensive, high-quality, and reciprocal economic partnership, there is no single country in any one block.

5. RCEP ANALYSIS OF FACTORS INFLUENCING THE NEW ENERGY VEHICLE TRADE NETWORK IN AGREEMENT COUNTRIES

5.1 The QAP Regression Analysis Method

The QAP (Quadratic Assignment Procedure) regression analysis method was applied to determine the regression relationships between multiple matrices and a single matrix.

This approach enables the effective comparison of the correlation coefficients between any two variables. By repeatedly permuting the data and performing regression, a range of values for the correlation coefficient is obtained, thereby facilitating the determination of significance.

5.2 Influencing Factors and Data Sources

The difference matrix of the total import-export trade volume of new energy vehicles between the 15 countries adopting the RCEP agreement was utilized as the biased variable for weighted regression, i.e., the weighted undirected trade network. The trade relationship adjacency matrix, obtained through the partitioning process, serves as the discriminating variable for unweighted regression, i.e., the unweighted undirected trade network. Considering the complexity faced by new energy vehicles, this study extended the analysis to include several other factors: institutional, economic, related supporting industry, and transportation logistics, that may influence the structure and weights of the trade network through correlation and regression analyses.

(1) Institutional Factors

Cultural proximity and similar institutions facilitate international trade, and a country's laws, institutions, and business environment directly affect trade between countries. Improving trade facilitation can promote international trade. Therefore, this study selected the difference matrix of the Business Facilitation Index ($Busi \cdot l$) as an unbiased variable, which indicates the degree of convenience of the policy environment for business operations and trade. Both sets of data were obtained from the World Bank database.

(2) Economic Factors

GDP can indicate the overall scale of the economy, and its differences may be advantageous for establishing trade relationships. Given that economic development has a particular impact on the occurrence and value of international trade, this study selected the difference matrix of GDP (GDP) as an unbiased variable. The GDP data for each country was obtained from the World Bank database.

(3) Related Supporting Industries

The development level and trade activities can affect the import-export trade of new energy vehicles. This study selected the difference matrix of fuel export trade ($Fuel \cdot T$) and the difference matrix of lithium battery trade for vehicles ($Lith \cdot T$) between countries along the route as unbiased variables to examine the impact of related industries. Both data sources are from the United Nations Trade Database.

(4) Transportation and Logistics Factors

Spatial proximity is a crucial factor influencing the trade level between two regions. This study selected the geographical distance, logistics level, and border adjacency as potentially important factors affecting the occurrence and intensity of international trade. The difference matrix of Logistics Performance Index ($Log \cdot I$), the difference matrix of spherical geographical distance between national capitals ($Dist$), and the 0-1 adjacency matrix of whether countries are contiguous ($Contig$) are chosen as unbiased variables. If two countries share a border, the variable is set to 1; otherwise, it is set to 0. The Logistics Performance Index, jointly calculated by institutions such as the World Bank, indicates a country's comprehensive logistics level in terms of customs clearance, transportation, and infrastructure. Data for the Logistics Performance Index is obtained from the World Bank database, while data for geographical distance and adjacency borders of countries are obtained from the CEPII database.

5.3 Model Construction

The QAP method is based on the permutation and resampling of matrix data and is used to study the relationships between variables. Based on the selection and analysis of the aforementioned variables, the analytical model used in this study as shown in Equation (6):

$$G = f\begin{pmatrix} Busi.I, GDP, Dist, Log.I \\ Lith.T, Fuel.T, Contig \end{pmatrix} \tag{6}$$

Where G represents the undirected matrix of new energy vehicle trade networks among RCEP agreement countries; $Busi.I$represents the difference matrix of business convenience index; GDP represents the difference matrix of GDP between countries along the route; $Fuel.T$ represents the difference matrix of total fuel exports by countries; $Lith.T$ represents the difference matrix of total trade in vehicle lithium batteries by countries; $Log.I$ represents the difference matrix of logistics performance index; $Dist$ represents the spherical geographical distance matrix between the capital cities of countries along the route; $Contig$ is a 0-1 adjacency matrix used to indicate whether countries along the route share a border.

5.4 Empirical Analysis

5.4.1 QAP Correlation Analysis

Ucient6 software was used to perform 2000 random permutations on the relevant data. QAP correlation analysis was conducted of the trade network relationship matrix and each single unbiased variable matrix, and the results of the correlation analysis between each unbiased variable matrix and the unweighted trade network were obtained. The correlation coefficients were standardized values, and the significance level was determined through a significance test. The correlation coefficients were calculated based on the one-to-one correspondence between the trade network matrix and other variable matrices. The minimum and maximum values corresponded to the lowest and highest correlation coefficients derived from the random permutation computations, respectively. The significance test indicated the level of significance of the observed correlation coefficient. Observational analysis found that there were significant correlations between the trade network relationship matrix and GDP difference matrix, tariff level difference matrix, geographical distance difference matrix of national capitals, 0-1 adjacency matrix of whether countries share a border, difference in amount of fuel export matrix, difference in

Table 7 Results of the QAP correlation analysis between the trade network and other influencing factors.

Variable	Correlation Coefficient	Significance Level	Mean Correlation Coefficient	Minimum Value	Maximum Value	$P \geq 0$	$P \geq 0$
$Busi.I$	−0.047	0.200	0.001	−0.281	0.080	0.804	0.200
GDP	0.032	0.523	0.001	−0.235	0.042	0.523	0.477
$Fuel.T$	0.159	0.023	−0.003	−0.534	0.185	0.023	0.977
$Lith.T$	−0.015	0.471	−0.001	−0.283	0.409	0.529	0.471
$Log.I$	−0.048	0.228	0.000	−0.238	0.107	0.772	0.228
$Dist$	−0.083	0.179	0.002	−0.298	0.297	0.821	0.179
$Contig$	−0.160	0.123	−0.001	−0.560	0.160	0.940	0.123

Table 8 Results of QAP regression analysis of the new energy vehicle trade network of RCEP agreement countries.

Variable Name	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GDP	0.033	0.032	0.222	0.222	0.222	0.205***
$Lith.T$	−0.018	−0.003	−0.049	−0.129**	−0.119**	−0.152***
$Fuel.T$		−0.040***	−0.0415***	0.047	0.018	−0.065
$Busi.I$			−1.192	−8.17	−8.167	−8.634
$Log.I$				2.266	2.266	2.272
$Contig$					−0.184*	−0.158*
$Dist$						−1.139***

Note:*,**,*** indicate significance at the 0.1, 0.05, and 0.01 statistical levels, respectively.

amount of lithium battery trade matrix, logistics performance index difference matrix, and business convenience index difference matrix. To eliminate the multicollinearity problem associated with unbiased variables, QAP regression analysis was used to determine the impact of each unbiased variable on the trade network correlation intensity as shown in Table 7.

The correlation analysis reveals that the trade network matrix has a correlation coefficient of −0.047 with Busi.I, indicating a negative influence of the business environment on international trade generation. Additionally, the trade network matrix has a correlation coefficient of 0.032 with GDP, suggesting that higher economic strength in a country increases the probability of trade relationships; the correlation coefficients between the trade network matrix and $Fuel.T$, $Lith.T$are 0.159 and −0.015, respectively, indicating that countries with lower fuel trade levels and higher lithium battery trade levels are more inclined to generate new energy vehicle trade relationships and increase trade intensity; the correlation coefficients between the trade network matrix and logistics performance index, distance, and whether countries share a border are −0.028, −0.083, and −0.160, respectively, suggesting that in the trade relationships among RCEP signatories, the level of a country's logistics development, whether countries share a border, and their proximity do not significantly influence the ease with which trade interactions occur between countries. This reflects the diversity of trade relationships among countries in the RCEP trade network and indicates that economic distance is a significant factor affecting economic and trade cooperation between countries.

5.4.2 QAP Regression Analysis

The institutional factors, economic levels, related industries, and transportation logistics factors of countries were regressed against their trade relationships. The regression items were subjected to 4000 random permutations to produce the QAP regression findings of the influencing variables on the trade network of new energy vehicles among the countries that are part of the RCEP agreement. The results are presented in Table 8.

(1) Economic development level. The GDP difference matrix has a positive impact on the unweighted network, with an effect size of 0.205. This indicates that countries with more significant gaps in economic development levels are more likely to generate new energy vehicle trade connections. As a technology- and capital-intensive emerging industry, the absolute price advantage brought about by economies of scale and low marginal costs is a significant reason for the occurrence of new energy vehicle international trade.

(2) Related supporting industries. The trade difference matrix of vehicle lithium batteries has a negative impact on trade connections and trade intensity, with an effect size of -0.152. The fuel export difference matrix also has a negative impact on trade connections. That is, countries with lower levels of lithium battery trade and higher levels of fuel trade are less inclined to generate new energy vehicle trade relationships and increase the intensity of new energy vehicle trade. Vehicle lithium batteries are the primary raw materials for electric motors, a core component of new energy vehicles, and are an essential part of the new energy vehicle industry chain. The trade levels of related supporting industries between countries show that countries with similar new energy vehicle industrial structures and development levels are more likely to form new energy vehicle trade relationships.

(3) Institutional factors. The business convenience index difference matrix significantly negatively impacts the formation of trade connections and trade intensity. That is, the lower the level of trade reciprocity and business convenience between countries, the more unfavorable it is for generating new energy vehicle trade relationships and increasing the strength of new energy vehicle trade. Trade reciprocity and institutional convenience can effectively reduce trade barriers,

decrease transaction costs, and promote supply-demand docking, creating a “win-win” situation. As a strategic, sustainable emerging industry, it is necessary for countries to strengthen their institutional reciprocity to advance mutually beneficial new energy vehicle trade cooperation relationships.

(4) Transportation logistics factors. The logistics performance index difference matrix positively correlates with trade connections, indicating that the smaller the differences in logistics development levels between countries, the easier it is to generate new energy vehicle trade relationships. Geographical distance and the 0-1 adjacency matrix of national border adjacency have a negative correlation with trade connections, indicating that space and whether countries share borders do not have a significant impact on whether RCEP member countries engage in trade.

6. CONCLUSION AND RECOMMENDATIONS

This study combines new energy vehicle trade data from 15 countries based on the 2022 RCEP agreement, constructs an overall network of new energy vehicle trade among RCEP agreement countries, and uses general network analysis methods such as network density, centrality, block model, and QAP method to analyze the overall network structure of new energy vehicle trade among RCEP agreement countries and its influencing factors. The research findings are presented below.

First, the overall network density value of new energy trade among the ‘RCEP’ agreement countries in 2022 is relatively high, reaching 0.5810, indicating that the trade connections between member countries are tight and the degree of interconnectivity is high, which also validates the necessity of having the RCEP agreement.

Second, centrality analysis revealed that China, South Korea, and Japan are at the center of the overall network of new energy vehicle trade among RCEP member countries, indicating that they play a leading role in new energy trade among parties to the RCEP agreement.

Third, according to the results of visual network structure analysis and block model analysis, the overall network of new energy vehicle trade among RCEP agreement countries presents a ‘core-periphery’ structure, in which core countries account for 66%; semi-peripheral countries account for 20%; and peripheral countries account for only 13%, mainly located in Southeast Asia’s developing countries. The overall core-periphery structure of the RCEP agreement countries’ new energy vehicle trade network is relatively stable, with a slight growth trend in core countries. The trade network is divided into three sections, each characterized by inward trade, outward trade, and bidirectional trade, reflecting the excellent interchanges within the trade network.

Fourth, regarding the influencing factors, variations in economic development levels among countries in the RCEP agreement positively impact the formation of new energy vehicle trade relationships. Conversely, disparities in lithium battery trade, fuel export levels, and geographical proximity between countries have notable adverse effects on the establishment of trade relationships and trade intensity. The presence of comparable levels of business convenience, logistical performance, and geographical proximity between national capitals creates favorable conditions for developing strong commercial ties and strengthening the trade between nations.

In recent years, countries around the world have developed electric vehicles as an important strategy for national energy security and transformation to a low carbon economy [19]. Based on the aforementioned research findings, this study makes the following recommendations.

First, healthy and orderly trade relationships are essential for complying with the RCEP agreement. They are at the core of its role as a new regional economic development model [20]. Therefore, it is necessary to strengthen economic and trade cooperation among RCEP agreement countries, give full play to the core role and coordinating role of core countries in the RCEP new energy vehicle trade network, further deepen trade cooperation between governments, optimize the layout of export destinations, prevent excessive competition, and form a ‘benign competition, complementary advantages’ favorable cooperation situation. It is essential to maintain the cohesive role of each country in the network and coordinate the relationship between various entities, driving the peripheral countries in the network to achieve shared prosperity.

Second, countries party to the agreement can continue to develop the construction of transportation infrastructure among RCEP signatories, reduce the impact of spatial distance factors on trade activities, further broaden the scope of trade agreements with other countries, deepen trade collaboration fields, and better serve the development of bilateral trade. A multi-level feedback mechanism can also be established to minimize the impact of institutional differences.

Third, signatories should actively negotiate and promote the establishment of a new energy vehicle strategic cooperation mechanism among RCEP agreement countries, accelerate the process of trade facilitation, reduce transaction costs, facilitate the diversified development of the new energy vehicle market, and achieve smooth trade and mutual benefits among countries along the route. Countries party to the agreement should increase R&D investment, promote the upgrading of supply chains and industrial chains to high-end manufacturing, and assist in forming a new high-end development environment for new energy vehicles.

ACKNOWLEDGEMENTS

This work was supported by Key Project of Philosophy and Social Sciences Research of Hubei Provincial Department of Education "Efficiency Identification and Classification Governance of Resale Price Maintenance (RPM) in Platform Economy" (23D105).

REFERENCES

1. Li, Y., Luo, C., Xu, Y., Yu, H. (2022). Intelligent mode design for the electricity market based on compound bidding matchmaking. International Journal of Engineering Intelligent Systems, 30(5), 407–412.

2. Cong, H., Zou, D., Gao, B., Shao, J. (2021). Network patterns and influence factors of new energy vehicle trade along the countries of the belt and road. Economic Geography, 41(07), 109–118.
3. Du, J. F., Zhang, H. D., Wang, Y. Z. (2021). The active meaning to China in terms of RCEP. China Finance, (03), 46–48.
4. Zhang, S. X., Li, W. W. (2021). Deconstruction of RCEP's significance for the development of China and the Asia-Pacific region. Theoretical Investigation, 219(2): 80–86.
5. Chen, H. (2022). Opportunities, challenges and countermeasures of China's participation in the reconstruction of regional industrial chains and value chains after RCEP takes effect. Economic Review Journal, (08), 76–82.
6. Qiao, C. X., Wang, X. C., Ning, J. B. (2021). Agricultural rules under the Framework of RCEP: Opportunities and challenges. Study & Exploration, (09), 98–106.
7. Zhang, Y., Ren, C., Ding, L., Cao, H. J. (2023). Opportunities and challenges of Shandong province apple industry under the framework of RCEP. China Fruits, (02), 132–135+140.
8. Li, Z., Liu, D., Huo, Z., Chen, F. (2022). Analysis on the competitiveness and complementarity of tea trade between China and RCEP members. Journal of Tea Science (05), 740–752.
9. Cheng, J. J., Fan, Y. (2021). International trade product categorization based on network similarity measures. Journal of University of Electronic Science and Technology of China, (02), 303–310.
10. Wang, W. Y., He, C. F. (2022). Relational economic geography and trade network research. Progress in Geography, (03), 461–476.
11. Torreggiani, S., Mangioni, G., Puma, J. M., et al. (2018). Identifying the community structure of the food-trade international multi-network. Environmental Research Letters, (5), 054026–054026.
12. Zhang, J., Wang, N., Lu, Y. K., Lin, W. N. (2018). The evolution characteristics of world grain supply-demand and flow pattern. Resources Science, (10), 1915–1930.
13. Kandogan, Y. (2018). Topological properties of the international trade network using modified measures. The International Trade Journal, 32(3): 268–292.
14. Murcia, A. Vargas, H., León, C. (2018). International trade networks and the integration of Colombia into global trade. BIS Papers Chapters, 100, 105–123.
15. Li, S. X., Liu, Y. Q., Wang, J. Y., Zhang, L. (2016). China's new energy vehicle industry development policy: Based on the market performanc. China Population, Resources and Environment, (09), 158–166.
16. Qi, W., Li, Q. H. Study on the dynamic evolution characteristics and influencing factors of global new energy vehicle trade network. World Regional Studies, 1–16.
17. Asadi, S. Nilashi, M. Samad, S. et al. (2020). Factors impacting consumers' intention toward adoption of electric vehicles in Malaysia. Journal of Cleaner Production, 282, 124474.
18. Wang, X. Z. Social network analysis of textile trade in "The Belt and Road" countries. World Regional Studies, 1-14.
19. Li, K., Wang, Y., Pan, H. (2022). Location selection of charging stations based on improved evolutionary algorithms. International Journal of Engineering Intelligent Systems, 30(4), 285–292.
20. Chong, Z. H., Qin, C. L. (2017). The trade network structure of "One Belt One Road" and its influence factors: A study based on analytic network process. International Economics and Trade Research, 33, 16–28.