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Dynamic Evolution of Electric Vehicle Trade Network between China-Europe

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Abstract

China and Europe have promoted the development of electric vehicles to reduce carbon emissions and cope with climate change. In recent years, the sales share of Chinese electric vehicle brands in the Europe market has increased rapidly, and Europe has become China's largest export market for electric vehicles. However, the European Union implemented various temporary tariffs on Chinese electric vehicle brands in 2024, which posed a major challenge to the development of the China-Europe electric vehicle trade. Based on the social network analysis, the paper focuses on examining the dynamic evolution of the electric vehicle trade network between China and Europe from 2018-2022. The empirical results indicate a general upward trend in tighter trade groups and increased connectivity efficiency within the network, while the network density and reciprocity display some fluctuations during this period. From a structural perspective, countries that hold central positions in both centrality measures and core-periphery indicators show statistically significant convergence patterns in the electric vehicle trade network between China and Europe. This study has theoretical and practical implications, in highlighting the dynamics changes in the electric vehicle trade network between China-Europe, and providing critical insights for

Chinese policymakers and Chinese electric vehicle enterprises to refine their trade strategy and enhance strategic partnerships in European countries.

Keywords: Dynamic evolution, electric vehicle, trade network, China-Europe

Introduction

It is widely acknowledged that climate change is one of the serious challenges to realizing global sustainable development, and countries have increasingly felt economic losses and other serious consequences caused by climate change (Jiang et al.,2021). At the 2015 United Nations Climate Change Conference (COP 21), more than 190 participating countries signed the Paris Agreement on climate change mitigation, agreeing to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees (Voituriez et al., 2019; Yu et al., 2022). The transportation industry has created huge carbon emissions and become a key area of carbon reduction concern for major countries around the world. In 2023, the transport sector generated 8.24 billion tons of carbon emissions, which accounted for 23.5% of global carbon emissions (Energy Institute, 2024). Transport carbon emissions are mainly from vehicles, ships, and aircraft transport, of which vehicle emissions account for 75% of transport carbon emissions(Hannah, 2020). The global trend of de-carbonization and sustainability has prompted governments and automotive manufacturers worldwide to reduce their carbon footprint. Consequentially, electric vehicle (EV) emerges as a viable and attractive solution to reduce carbon emissions and cope with climate change (Hu and Pan, 2023). More and more countries have issued policy initiatives to encourage the adoption of EVs.

China has actively promoted the development and application of EV to cope with the challenges of energy security and environmental protection. As early as 2001, the Chinese Ministry of Science and Technology established the “three verticals and three horizontals” research and development framework for new energy vehicles. The 11th Five-Year Plan (2006-2010) was a critical phase in transitioning China’s EV sector to early-stage industrialization, and the 12th five-year plan (2011-2015) identified the new energy vehicles as one of the seven strategic industries. China’s 14th Five-Year Plan issued in 2021 explicitly identified the development of EV sector as one of the key priority strategies in the industry. The Chinese government has implemented various policies and regulations to support the production and purchase of EVs, including R&D subsidies, dual-credit policy, purchase subsidies, and charging facility construction (Yao et al., 2023). Due to a national strategy that prioritizes the development of the EV sector, China has been the world's largest and fastest-growing producer of EVs since 2015 and formed industrial chain integration advantages in battery technology and EV manufacturing. In 2023, the number of Chinese EV registrations reached 8.1 million, accounting for 60% of the global EV market (IEA, 2024). To achieve climate neutrality goals by 2050 and a green transition, Europe is committed to becoming a global leader in clean, competitive, and connected transport. the European Commission and European Parliament have issued a series of strategies and regulations, including"A European Strategy for low-emission mobility" in 2016, "Europe on the Move" in 2017, "Europe on the Move: Commission Completes its agenda for Safe, clean and connected mobility" in 2018, "Sustainable and Intelligent Transport Strategy" in 2020, and "The 2035 ban on the sale of internal-combustion vehicles" in 2023, to promote R&D, market and infrastructure development, and international cooperation of the EV sector. In Europe, the number of EV registrations reached nearly 3.2 million in 2023, increasing by almost 20% relative to 2022. Europe became the second EV market in the world, accounting for 25% of global EV sales in 2023 (IEA, 2024).

In recent years, the sales share of Chinese brands in the global EV market has increased rapidly, from just 4% of global EV exports in 2020 to 21 % in 2022 (Boullenois et al., 2023). As for the EV trade between China and Europe, European exports of EVs to China have fallen slightly since 2018, while European imports of EVs from China have accelerated. Chinese EV brands' share in the European EV market grew from less than 0.5 % in 2018 to 8% in 2023, and Europe became China's largest export market for EVs (Van Wieringen, 2024). China exported over 500 thousand EVs to Europe in 2023, accounting for nearly 40% of its total EV exports. According to the European Commission's forecast, this value will further leap to 15% by 2025. The European Commission announced the initiation of EU anti-subsidy investigations into Chinese EV supply chains in October 2023. The Commission concluded in June 2024 that Chinese-made EVs had benefited from unfair subsidies and implemented various provisional tariffs in response, ranging from 17.4 % to 38.1 % (European Commission, 2024). In October 2024, the Commission received the necessary support from Member States to impose definitive duties on Chinese EVs. Through the strategic deployment of import duties and anti-subsidy inquiries, European markets present significant challenges to Chinese EV producers, particularly disrupting their export strategies and market penetration efforts. EV industry embodies dual strategic value in energy security and climate governance, serving not merely as a systematic solution for dismantling the constraints of traditional fossil fuels, but as the key driving force for reconstructing the global low-carbon economy. As nations promote the development of the EV sector, greater emphasis must be placed on collaboration and equitable competition to prevent protectionist policies from undermining the industry's progress. As key players in the global EV industry, the collaboration between China and Europe is crucial for the sustainable development of the EV market. Based on the social network analysis (SNA), this paper analyzes the evolution characteristics of the EV trade network between China and Europe, and the empirical results will provide references for China to adjust its EV trade strategy and optimize its EV cooperation with Europe.

Literature Review

Factors affecting the China-Europe EVs trade

Researchers mainly examine the factors affecting the China-Europe EV trade from the perspectives of trade status, subsidy policy, supply chain, and trade policy. The EV trade between China and Europe has grown rapidly in recent years, driven by Europe's green transition and China's manufacturing prowess (IEA, 2024). Boullenois et al. (2023) and van Wieringen (2024) provided an analytical overview of EV trade development between China and Europe during the period of 2019- 2023. Favorable subsidy policies have been the main driving forces of the EV trade between China and Europe. Europe countries have issued different levels of tax benefits and purchase incentives for EVs since 2020 (ACEA, 2023). The European EV market increased rapidly due to the expanding incentive policies of EU member states and provided a good opportunity for Chinese EV brands to enter the European market. However, the phase-out of the subsidy policy poses a challenge for EV trade between China and Europe. For example, Germany canceled EV purchase subsidies at the end of 2023, resulting in a 27.4% decline in German EV sales in 2024 (IEA, 2024). This had a certain negative impact on Chinese EV brands to enter the German market.

The wave of EVs is propelling a rapid restructuring of the automotive industry's value chain. China has leveraged the geographic clustering advantages of critical mineral supply chains and EV infrastructure to achieve economies of scale in manufacturing (Dadush, 2024). Complemented by labor cost advantages and breakthroughs in battery technology and smart manufacturing, China's manufacturing sector continues to strengthen its cost management capabilities within the global EV industrial chain. China has developed a strategic multidimensional deployment in building the comprehensive EV industrial chain from mining raw materials to battery production and final assembly. This deeply embedded industrial interdependence has essentially positioned China as the foundational infrastructure supporting Europe's green transition (Van Wieringen， 2024). European trade policy has a significant impact on EV trade development between China and Europe. Through tariffs and anti-subsidy investigations, Europe forms a serious obstacle for Chinese EV manufacturers, particularly in terms of their export activities in the short term (Martyn, 2024). In the long term, Europe seeks a strategic balance between curbing over-reliance and maintaining the development of its own EVs through mechanisms such as mutual recognition of standards under the framework of technological sovereignty and alliances for supply chain resilience. Faced with the tariff barriers imposed by the EU, Chinese EV companies need to reassess and adjust their market strategies and reconsider the configuration of their global supply chains (ARC, 2024; IISS, 2024).

SNA *approach to analyze EV trade network*

SNA examines social behaviors, information dissemination, and group dynamics by analyzing the connections and structural characteristics between individuals or organizations (Scott, 2011). In the 1980s, SNA began to be widely used in sociology and statistics. SNA provides a relational perspective for analyzing trade policy interactions, revealing how inter-state network structures (such as centrality and clustering) shape policy diffusion pathways and negotiation game strategies.

Snyder and Kick (1979) introduced SNA into the study of international trade issues, discussing the dependency of differences in economic growth among countries. Smith and White (1992) divided the participants in the global trade network into different structures such as core, semi-periphery, and periphery. Since then, SNA has been extensively employed in global and regional trade systems, including energy sectors, automotive industry, and trade relationships, etc. For example, Kim and Shin (2002) analyzed the international trade network based on international commodity trade data by using SNA. The empirical results revealed the dynamic game between globalization and regionalization, and formed a pattern of regionalization under the framework of globalization. An et al. (2014) examined the structural characteristics and dynamic evolution patterns of global crude oil trade relationships based on SNA. The study shows that the crude oil trade network exhibits a core-periphery structure and a strong dependence on geopolitical factors. Pavlínek (2021) depicted the core structure, semi-peripheral structure, and peripheral structure of the European automotive industry by using SNA.

In recent years, SNA has been used to analyze in the field of the trade development of EV sector, including value chain, technology cooperation network, and trade structure evolution. For example, Shao et al. (2021) analyzed the evolution of the global lithium competition network pattern based on the trade data from 2009 to 2018 and found that the trade network structure of lithium has certain path dependencies with a core-periphery structure. Sun et al. (2018) measured EV-related patent cooperation networks in China by using SNA. The results showed that the EV-patents cooperation network has evolved smoothly with a growing network density, stable structure, and more cohesive subgroups. Yao et al. (2024) constructed an industrial network from the perspective of the value chain and employed the SNA to study the characteristics, evolution, and formation mechanisms of different value chain networks in the Belt and Road regions. Even though SNA has been widely used, few studies have applied it to the EV trade network between China and Europe.

In summary, current research has examined the various factors influencing the trade of EV trade between China and Europe. However, these studies are largely confined to analyzing the relationships at the trade or micro-market level. There exists a gap in the literature regarding the dynamic analysis of EV trade between China and Europe from a regional and national perspective. Therefore, this paper provides a more comprehensive reflection on the evolving characteristics of the EV trade network based on the trade links between China and Europe.

Methods

SNA demonstrates strong methodological advantages in studying the EV trade network between China and Europe. SNA maps out these relationships in the form of networks where nodes stand for countries and edges symbolize connections between them. Its core focus on relational structures and dynamic interdependencies aligns precisely with the multi-level interactions between China and European countries. The paper conducts a systematic examination of trade network overall structural characteristics, node centrality metrics, and core-periphery architecture by using SNA. Unicet 6.0 is used to conduct the calculations and analysis of the EV trade network between China and Europe in the paper.

Network Structure Analysis

The complex trade relationships between China and Europe in the EV sector form the trade network, and the overall structure of this network, in turn, influences the development of EV trade. The measurement of EV trade network structure is drawn on the metrics selected in the study of Yao et al. (2024) and covers four indicators, including network density, reciprocity, average path length, and clustering coefficient. Table 1 shows the four indicators ’ formulas and descriptions.

Table 1: The formula and description of four indicators

Indicator	Formula	Indicator description
Network density (ND)	$ND = \frac{m}{n \times (n-1)}$	m is the actual associated edge between two actual points, n is the number of nodes.
Reciprocity (RY)	$RY = p/m$	p is bidirectional relationships; m is the total number of relationships m in a directed network.
Average Path Length (AL)	$AL = \frac{1}{1/2n(n+1)} \sum_{i \geq j} d_{ij}$	n is the number of nodes, d_{ij} is the shortest path from node i to node j.
Clustering coefficient (CC)	$CC = \frac{2T_i}{k_i(k_i-1)}$	T_i is the actual number of edges between nodes connected to node i, k_i is the degree of node i.

Network density is used to measure the overall closeness of nodes in the EV trade network. The higher the density value, the closer the overall trade connections are. Reciprocity is the indicator of mutuality and reciprocal exchange, the average path length refers to the average of the shortest path lengths between any two nodes in the EV trade network. The clustering coefficient is a measure of the degree to which nodes in the EV trade network cluster together.

Network node centrality

Centrality is used to measure the importance of nodes in a network in terms of connectivity, identifying nodes that have a critical impact or relevance on the network (Shen et al., 2024). Centrality metrics primarily include degree centrality, closeness centrality, and betweenness centrality. These three centrality metrics possess distinct characteristics and can be employed to shed light on the differential roles and functions of nodes within a network.

Degree centrality measures the number of direct node connections in the network, and nodes with high degree centrality are hubs or highly connected entities. Degree centrality can be divided into out-degree centrality and in-degree centrality. Closeness centrality quantifies how close a node is to all other nodes in the network via the shortest paths, and is typically measured by out-closeness centrality and in-closeness centrality. Betweenness centrality measures how often a node lies on the shortest path between pairs of other nodes. Table 2 shows the formula and description of the three centrality metrics.

Table 2: The formula and description of three centrality metrics

Indicator	Formula	Indicator description
Out-degree centrality(OD)	$OD = \frac{\sum_{j=1,j\neq i}^{n} x_{ij}}{n-1}$	The ratio of the actual trade connection x_{ij} from node i to node j to the theoretical maximum value of $(n-1)$.
In-degree centrality (ID)	$ID = \frac{\sum_{j=1;j\neq i}^{n} x_{ji}}{n-1}$	The ratio of the actual trade connection x_{ji} from node j to node i to the theoretical maximum value of $(n-1)$.
Out-closeness centrality(OC)	$OC = \frac{1}{(n-1)\sum_{j=1;j\neq i}^{n} d_{ij}}$	The ratio of the shortest path length d_{ij} from node i to node j to the theoretical minimum value of $(n-1)$.
In-closeness centrality(IC)	$IC = \frac{1}{(n-1)\sum_{j=1;j\neq i}^{n} d_{ji}}$	The ratio of the shortest path length d_{ji} from node j to node i to the theoretical minimum value of $(n-1)$.
Betweenness centrality(BC)	$BC = \frac{2\sum_{j=1;k=1;j\neq k\neq i,j<k}^{n} \frac{g_{jk}(i)}{g_{jk}}}{(n-1)(n-2)}$	The ratio of the probability that node i lies on the shortest path between nodes j and k to the theoretical maximum value.

Empirical analysis of EV trade network between China-Europe

Data sources

This study examines the trade dynamics in the EV sector, focusing on China, the United Kingdom (UK), and European Union (EU) member states with a time span of 2018-2022. The research scope encompasses two core product categories: pure electric buses (HS2017 code 870240) and other electric road vehicles (HS2017 code 870380). Trade data is collected from the United Nations Comtrade Database (UN Comtrade), with a focus on bilateral trade flow statistics between the selected economies during the specified period.

Network structure results of EV trade between China-Europe

The network structure of EV trade between China-Europe included in the paper are ND, RY, AL, and CC. Table 3 shows the empirical results of the EV trade network structure between China and Europe. Firstly, the network density of EV trade between China and Europe showed an overall upward trend from 2018 to 2021, reaching its peak at 0.130 in 2021. There was a slight decline in 2022, which suggested potential supply chain disruption in EV trade possibly due to the Russia-Ukraine conflict. The relatively low value of network density indicates that the overall connection is sparse and there is still a large space for development. The reciprocity of EV trade network reached a peak of 0.309 in 2020 with an increase of 58.2%

compared to 2018, highlighting the enhanced complementarity between the Chinese and Europe. Despite a pullback to 0.247 in 2021, the rebound to 0.277 in 2022 indicates a resilient foundation in EV trade dependency.

The average path length decreased from 1.845 in 2018 to the lowest point of 1.637 in 2021, reflecting the reduction of supply chain tiers and the increased direct connectivity between nodes. Despite a slight increase to 1.672 in 2022, this indicator was still 8.1% lower than in 2018. The decreasing trend indicates that trade connections have become more direct over time, with fewer intermediary links. The clustering coefficient showed a steady increase from 2018 to 2022, reaching its highest value of 0.749 in 2022. The increasing clustering coefficient suggests a higher degree of local connectivity and more concentrated trade activities. This trend is indicative of the formation of tighter trade groups, which can enhance the overall network's resilience and efficiency.

Table 3: The network structure results of EV trade between China-Europe

Indicators	Year				
	2018	2019	2020	2021	2022
ND	0.124	0.112	0.127	0.130	0.119
RY	0.176	0.253	0.309	0.247	0.277
A L	1.820	1.769	1.647	1.637	1.672
CC	0.669	0.683	0.700	0.736	0.749

Network centrality of EV trade between China-Europe

The network centrality indicators included in the paper are OD, ID, OC, IC, and BC. Table 4 shows the network centrality results of EV trade between China and Europe from 2018-2022. Firstly, Germany showed high centrality scores across all metrics, indicating its dominant role in the EV trade network. Germany ranked first in the both OD and ID indicators during the period of 2020-2022, indicating its strong export and import activities. The country maintained the highest value of OC from 2018–2022, reflecting core connectivity as an exporter. The country's centrality scores generally increased in IC over time, reaching its highest IC score of 0.839 in 2022. Moreover, the country frequently ranked highest in BC indicator, underscoring its role as a critical intermediary in the network. These centrality indicators suggest Germany's growing importance as both a producer and a consumer hub in the EV trade network.

Table 4: The centrality of EV trade network between China-Europe

Year	Country	OD	Country	ID	Country	OC	Country	IC	Country	BC
2018	NL	0.137	DE	0.114	DE	1	DE	0.667	DE	0.1
	FR	0.114	UK	0.083	NL	1	NL	0.65	NL	0.067
	DE	0.107	NL	0.080	FR	0.929	ITA	0.634	PL	0.061
	AT	0.063	BE	0.043	AT	0.867	ES	0.634	LT	0.048
	BE	0.041	FR	0.042	CHN	0.867	PL	0.634	CHN	0.044
2019	BE	0.061	DE	0.055	BE	1	PL	0.703	DE	0.069
	DE	0.037	NL	0.032	CHN	1	DE	0.684	UK	0.054
	FR	0.022	UK	0.026	DE	1	ES	0.667	BE	0.047
	NL	0.020	BE	0.013	FR	1	BE	0.634	ES	0.048
	UK	0.020	FR	0.012	NL	1	NL	0.634	CHN	0.044
2020	DE	0.119	DE	0.108	DE	1	DE	0.788	DE	0.084
	BE	0.071	UK	0.073	FR	1	NL	0.722	BE	0.044
	SK	0.048	NL	0.065	UK	1	BE	0.703	NL	0.038
	FR	0.041	FR	0.045	NL	1	PL	0.703	FR	0.033
	CHN	0.032	BE	0.026	AT	0.963	FR	0.684	UK	0.032
2021	DE	0.137	DE	0.118	AT	1	DE	0.788	UK	0.058
	CHN	0.099	UK	0.089	BE	1	BE	0.722	DE	0.056
	BE	0.061	BE	0.054	CHN	1	NL	0.722	BE	0.026
	SK	0.038	FR	0.050	DE	1	DK	0.722	NL	0.022
	CZ	0.021	NL	0.034	ES	1	UK	0.703	DK	0.022
2022	DE	0.135	UK	0.081	BE	1	DE	0.839	UK	0.066
	CHN	0.119	DE	0.072	DE	1	NL	0.813	DE	0.053
	BE	0.038	BE	0.059	ES	1	DK	0.813	NL	0.037
	ES	0.034	FR	0.043	FR	1	BE	0.788	DK	0.023
	FR	0.021	NL	0.034	UK	1	HU	0.788	BE	0.023

Note: The country name uses country abbreviation

Secondly, both Belgium and the Netherlands are strategic hubs in the EV trade network. Belgium maintained a relatively high centrality across all metrics throughout the period, with notable scores in OD, OC and IC. Especially, Belgium emerged as a key intermediary and achieved a significant increase in the IC indicator over time, indicating critical export connectivity. However, the score of indicator BC appeared to decline slightly over time. The Netherlands had a high OD ranking in 2018 and 2019, and a high value of ID over time. The country also had a consistently strong IC score, emphasizing its role as a trade gateway. However, the country's centrality scores in OD and BC declined during the period of 2018-2021, suggesting a reduced role in the EV trade network.

Thirdly, both the UK and France are key players in the EV trade network. France has a consistent presence in the network with moderate centrality scores in OD and ID. Its centrality scores of OC fluctuated slightly but remained significant from 2018 to 2022, indicating a stable role as both a producer and consumer of EVs. The UK had significant centrality scores in

BC and ID from 2018 to 2022. UK ranked first in both BC and ID indicators in 2022, suggesting growing import reliance and intermediary role.

Finally, China's OD scores increased from the fifth in 2018 to the second in 2022, signaling growing export activity. The country achieved the highest OC scores from 2019 to 2021, suggesting enhanced export network efficiency. In 2022, China had a BC score of 0.053 and an OC score of 0.813, indicating its growing role in the EV trade network. The rising centrality scores suggest that China is becoming a more important player in the trade network, due to its expanding EV production and exports to Europe. Other countries like Austria, Poland, and the Czech Republic had higher centrality scores and played important roles in the EV trade network from 2018 to 2022, particularly in terms of OC and IC indicators.

Network core-periphery structure of EV trade between China-Europe

The paper uses the Core-Periphery algorithm in Ucinet 6.0 to conduct a quantitative analysis of the core-periphery structure for the EV trade network between China and Europe. The criteria for identifying core countries in the trade network are set as having a coreness value greater than 0.1. A country with a coreness value between 0.05-0.1 is classified as a semi-peripheral country, and all other nodes with a coreness value less than 0.05 are considered to be in the peripheral countries. Table 5 shows the network core countries of EV trade between China and Europe from 2018 to 2022.

Table 5: Network core countries of EV trade between China-Europe

Year	Core country
2018	DE(0.476), NL (0.457), AT (0.420), FR(0.353), ES (0.251), UK(0.237), BE(0.206), SK(0.144),PL(0.139), HU(0.120)
2019	DE(0.425), NL (0.398), BE(0.377), FR(0.367), AT (0.366), ES (0.300), UK(0.291), SE(0.129), ITA (0.124)
2020	DE(0.445), NL (0.376), FR(0.372), UK(0.369),BE(0.346), ES (0.317), ITA (0.236), AT (0.209), CHN (0.162), SE(0.121),
2021	DE(0.494), FR(0.382), BE(0.346), UK(0.324), ES (0.316), ITA (0.307), NL (0.212), AT (0.208), CHN (0.203), SE(0.152)
2022	DE(0.509), FR(0.398), BE(0.356), ES (0.331), UK(0.314), ITA (0.286), CHN (0.245), NL (0.202), SE(0.133)

Note: The country name use country abbreviation

According to table 5, Germany consistently remained the most central country in the EV trade network throughout the period, with its centrality score increasing from 0.476 in 2018 to 0.509 in 2022. This indicates Germany's dominant position and growing importance as a core hub in the China-Europe EV trade network. This advantage stems from the country's strong automotive manufacturing industry, technological leadership in sustainable mobility solutions, and comprehensive international trade facilities.

Secondly, Belgium, France, UK, and the Netherlands were consistently among the core countries, maintaining relatively high centrality scores across the period of 2018-2022. Among the four countries, France maintained a consistently high and stable centrality score, especially ranking second in 2021 and 2022. This underscores France's important role in the EV trade network, driven by its automotive industry and government support for EV adoption and production. Belgium maintained prominent positions throughout the period of 2019-2022, and ranked third in 2021 and 2022 respectively. The UK's centrality score fluctuated but remained significant, particularly in 2020 and 2021. The Netherlands showed a notable decline in centrality from 0.457 in 2018 to 0.212 in 2021, with slightly recovering to 0.212 in 2022. This indicates a potential reduction in its role as a core intermediary in the network.

Thirdly, China's rising centrality scores, especially as it moved to the forefront of the trade network in 2021 and 2022, signal its increasing prominence in the EV trade network. This changing role of China is mainly attributed to its expanding EV exports to Europe and increasing technological capabilities in the EV sector. Austria, Spain, Italy, and Sweden also maintained high centrality scores, indicating their important roles in the EV trade network. These countries contribute to the network through their automotive industries, trade infrastructure, and strategic locations.

Discussion

The paper constructs a China-Europe EV trade network and conducts a systematic examination of overall structural characteristics, node centrality metrics, and core-periphery architecture by using SNA.

The overall structure of the China-Europe trade network in the field of EV sector is undergoing continuous dynamic changes. Although the network density and reciprocity fluctuated, there was an obvious trend of tighter trade groups and improving connectivity efficiency. The dynamic changes of EV trade network are driven by combinations of policy and regulatory environment, market demand, geopolitical and economic factors, and value chain. China is the world's largest and fastest-growing producer, consumer, and battery producer of EVs, and has formed an industrial chain integration advantage in battery technology and electric vehicle manufacturing. European countries have provided support measures such as purchase subsidies, tax incentives, and the construction of charging networks, which have promoted the popularity of EVs. Especially, the European Commission launchedthe Sustainable and Intelligent Transport Strategy in 2020, which aimed to have at least 30 million zero-emission cars on European roads by 2030 (European Commission, 2021). The increasing market demand has provided a broad market space for Chinese brand's EV to enter Europe countries.

In the context of EV trade between China and Europe, countries that exhibit a high degree of centrality and coreness in the network tend to overlap significantly. The EV trade forms a core-periphery network structure, with Germany, Belgium and other major European automobile countries as the center countries. Firstly, Germany hasa dominant position in the EV trade network, which is matched by the country's share of the European market. According to IEA (2023), Germany is the largest EV market in Europe with 830 thousand EVs sold in 2022. The country also serves as the headquarters for globally renowned automotive manufacturers such as Volkswagen and Mercedes-Benz Group. Secondly, France, Belgium, the UK, and the Netherlands are countries with developed automotive industries, and their manufacturing advantages and larger market space have become the basis for the core countries of EV trade network between China and Europe. Moreover, Belgium and the Netherlands maintain significant positions in the EV trade network due to their advantageous geographic positioning and developed transport system. Thirdly, the geographical redistribution of core countries within the EV trade network demonstrates significant structural realignment during the period of 2018-2022. For example, the Netherlands experienced a progressive decline in network centrality, ultimately falling outside the top five influential nodes in 2022. China has experienced a dynamics change from a semi-marginal country to a core country. China's share in the EV trade network has increased rapidly since 2020 and will become the core country in the trade network by the end of 2022.

This research acknowledges several limitations that should be addressed in subsequent studies. Future investigations should prioritize incorporating more updated data to enhance the precision and dependability of the China-Europe EV network analysis. A second limitation lies in the absence of a comprehensive examination of mechanisms behind the EV trade network within China-Europe, especially the impact of the Russia-Ukraine conflict on the supply chain of China-Europe EV trade. This gap necessitates targeted investigation in future research to shed light on the underlying mechanisms shaping cross-regional EV market interactions.

Conclusions

EV as a strategic emerging industry has become an important measure to achieve green and sustainable development. Based on the SNA, the paper analyzes the dynamic evolution characteristics of the EV trade network between China and Europe from 2018 to 2022. Empirical findings demonstrate an overall upward trend in tighter trade groups and increased connectivity efficiency, although network density and reciprocity exhibit certain fluctuations. From a structural analysis perspective of the China-Europe EV trade network, countries occupying central positions in both core-periphery indicators and centrality metrics demonstrate statistically significant convergence patterns.

From a theoretical perspective, this paper provides a multidimensional assessment of trade patterns, actor influence, and hierarchical dynamics by examining the overall structural characteristics, node centrality indicators, and core-periphery structure of the EV trade network between China and Europe. The SNA adopted in the paper not only enriches the understanding of the EV trade network but also provides insights into the roles of key players and the underlying mechanisms that form the structure of the network. In addition, the findings contribute to the broader international trade literature by highlighting the importance of core-periphery structures and centrality indicators in analyzing trade network dynamics between China and Europe.

From a managerial perspective, this paper intends to provide actionable insights for decision-makers and industry stakeholders in the China-Europe EV trade. Firstly, Chinese government agencies should actively engage in strategic dialogue with the EU to address concerns about subsidies, while transparently demonstrating the consistency of China's EV subsidy policies with international trade norms. The government should highlight the key role of Chinese EVs in accelerating the global shift to sustainable transportation, including emission reduction and technological innovation. Meanwhile, government agencies could advocate a cooperative trade framework that prioritizes reciprocity to ensure fair competition and shared growth opportunities in the EV industry. Secondly, Chinese EV manufacturers could explore strategic partnerships with firms in key European markets, such as Germany, France, and Belgium through joint ventures, technology-sharing arrangements, and collaborative R&D programs. These alliances would facilitate smoother market penetration and technology acquisition while mitigating risks through shared responsibilities. Establishing localized production and supply chains in Europe could help circumvent tariff barriers and improve operational responsiveness. For instance, constructing manufacturing facilities in Germany, Belgium, and Central and Eastern European countries like Hungary and Slovakia would enhance supply chain adaptability and regional market responsiveness.

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