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Strategies in Energy Supply: A Social Network Analysis on the Energy Trade of the European Union

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Abstract: As energy is vital in the sustainability of almost every part of daily life, energy security has become more crucial than ever before. One of the main threats to energy security is a possible disruption along the trade network, which jeopardizes the constant energy supply. The purpose of this research is to identify the relation ties between EU countries in order to clarify the characteristics of the network, such as its crucial actors, vulnerabilities, structural holes, etc., to help achieve some proposals for a more sustainable and secure energy supply. This will help identify the underlying causes of recurring energy crises in the EU and provide insight into developing management strategies for further studies. Following this purpose, we examined the trade network density to clarify typical characteristics of the network, applied degree centrality measures to identify the most central importer and exporter countries, and found the dominance and critical vulnerabilities of actors in the network by using domestic import data of the EU countries. Finally, we recommend some policies and management strategies according to the obtained results and previous literature for further discussion.

Keywords: strategic management; energy supply; diversification strategies



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1. Introduction

Besides the dependence of economic superiority and welfare on energy, energy security, which means uninterrupted and affordable energy flow, has gained strategic importance with the energy crises since the early 1970s [1]. Economies that are not rich in fossil energy resources, especially the European Union (EU), have to manage the supply of these resources primarily through imports. Regulations during the crude oil crises in the 1960s and 1970s and market liberalization packages in the 1990s to 2000s aimed to mature the energy sector in the context of energy security, sustainability, competitiveness, and economy. After the oil crisis of the 1970s, Europe did not face any crisis-grade energy supply shortages for more than 30 years. This situation led the EU to pay insufficient attention to the issue of energy security until 2006, at the time the Russian–Ukrainian natural gas dispute occurred. Despite the several solid steps taken on energy security after the first Russia–Ukraine dispute, another energy crisis emerged in 2009 for the same reason. As of January 7, the natural gas transmitted throughout the Russia–Ukraine–EU chain was out of service until January 20 in the mentioned year [2]. The complete cessation of 30% of the total gas imported into Europe for two weeks has enabled the EU to take new steps on energy security. It has shown that measures such as increasing energy diversification on the basis of both resources and imports, expanding storage and reserve capacities, and providing the

necessary infrastructures for the development of the energy transmission mechanism in the domestic market became a top priority and led to the preparation of required policies in this regard [3,4]. Nevertheless, despite all these initiatives, the European Energy Security Stress Tests conducted in 2014 revealed that it is not yet sufficiently prepared for a possible natural gas interruption from the east [5]. Eventually, another wave of crises emerged with the COVID-19 pandemic, severely affecting energy supply [6]. The EU has lucrative potential in many aspects, including energy, because of its position [7–9]. However, its success mainly depends on whether it fulfills its capability or not, as focusing on international crises such as pandemics or international conflicts will prevent the identification of the underlying problems. Accordingly, it was clear that the electricity generation sources of the EU still relied on fossil fuels in 2021. Approximately half (48%) of the total generation of electricity was sourced from combustible fuels and natural gas, which mainly depended on imports from non-EU countries. For instance, the EU imported 90% of its gas consumption, while more than 40% of it was solely supplied from Russia. Also, Russia accounted for 46% of coal imports and 27% of oil imports in 2021 [10].

The main purpose of this paper is to clarify the steps that should be taken by the EU in order to avoid recurring energy crises or downsizing the negative effects of various global conditions by applying a social network analysis to the domestic energy trade network of the EU.

Determining the density rate and exposing the central and mediator countries by social network analysis will help to understand the characteristics of the network. Thus, factors that jeopardize the network and increase the vulnerability of the member countries will be more apparent. This study focuses on the EU since the regulations and relationships between the member countries and other non-EU European countries may significantly differ.

The social network analysis focuses on the ties between the actors of the network. While traditional social science perspectives ignore relational knowledge and focus on the actors in the network, social network analysis focuses on existing connections and interactions between the actors. In other words, it is assumed that actors in a network are never independent, and their ties determine their positions and actions [11]. Examining the domestic energy trade, where there is substantial interdependence and connection between actors in terms of scope and intensity, will help to bring a superior strategic management viewpoint for the energy security of the EU into discussion. This will enlighten further research to examine other feasible options to establish new energy trade strategies and policies. Therefore, this paper will bring a distinct viewpoint to the literature.

The results showed that the domestic energy trade of the EU is controlled by a tiny percentage of the member countries, which endangers the sustainability of the energy trade network. Moreover, it is known that the energy trade of the EU is highly dependent on imports from a few countries, which brings another vulnerability.

From this point, any committed development in domestic energy channels may significantly contribute to the diversification strategies, in other words, the energy security of the EU. Further discussion regarding the management and strategy of energy trade is included in Section 6.

2. Literature Review

Energy trade has strategic significance as it does not appear solely as a for-profit trade but also as an influential instrument in national political goals. Therefore, it has as a mechanism that governments constantly intervene as part of the national strategies of states [12]. Energy trade mainly refers to trading primary energy resources. Therefore, it covers sources that have energy production value. However, it is well-known that among these sources, oil, natural gas, and coal dominate almost the entire market [13–16]. Therefore, the mentioned sources still have significant value in the energy trade of the EU compared to other types.

Especially since the 90s, energy demand, supply, and trade relations have become more complicated. Storage and transportation of energy is a capital-intensive sector, which means high costs are required to store and transport energy [17]. From the point of view of crude oil, it is clear that geopolitical and diplomatic relations are the main factors affecting the trade. Also, ordinary commercial cooperation and mutual interest relations are key structural motivations of international energy trade.

Furthermore, overseas investments, technological processes, energy efficiency, and global incidents are the other key factors affecting the energy trade network. For instance, events such as the 2004–2005 Iraq–American war, the 2008 financial crisis, significant progress in shale technology, and the COVID-19 pandemic emerge as turning points that play a critical role in shaping the trade network [12,18,19]. Moreover, the armed conflict in Ukraine increased the urgency of providing affordable energy globally [20], especially from the perspective of Europe, as it has been highly dependent on imports of energy sources from Russia [21].

2.1. Energy Supply and Demand in the EU

According to the latest data, Germany has the largest population, with 83.2 million people, constituting 18.6% of the total EU population. Secondly, France constitutes 15% with 67.1 million; thirdly, Italy constitutes 13.5% with 60.2 million, followed by Spain constituting 10.6% with 47.3 million, and Poland constituting 8.5% with 38 million. Fourteen of the remaining member states have population ratios between 1 and 5%, while the other eight member states have a population ratio of less than 1% [22]. Germany, aka the locomotive of the EU [23], ranks first place in the economy as well as the population, and it alone constitutes about a quarter (24.7%) of the gross domestic product (GDP) of the EU. Other leading countries in GDP ranking are France (17.4%), Italy (12.8%), Spain (8.9%), and the Netherlands (5.8%). The countries lowest in the GDP ranking of the union are Slovakia, Luxembourg, Croatia, Bulgaria, Slovenia, Lithuania, Latvia, Cyprus, and Estonia, followed by Malta, with the lowest share of 0.1% [24]. Germany's geographical location and size ensure its vital role in the energy sector of the EU. Germany, the leader in indicators such as population and GDP, ranked first in the EU in the highest energy consumption in 2019 [25]. With these attributes, it also ranked seventh in the world's highest energy consumption and fifth in GDP. However, Germany meets a very high part of its energy demand through imports. As of 2019, the country provided 71% of its energy supply through imports [26]. France, the second largest energy-consuming country in the EU, is a net electricity exporter and the second country to produce the most electricity via nuclear energy in the world. Conversely, the country meets a large part of its demand via imports due to the limited capability for oil and natural gas production [27]. Italy, the third country in the highest energy consumption ranking, has an import dependency of 75%, which is above the EU average [22]. Spain ranks fourth in highest energy consumption and possesses nearly no crude oil or natural gas production due to geographical constraints. As almost all the oil and natural gas are supplied via imports, there is an upper-limit regulation for imports from each country to diversify the sources [28]. It is noteworthy that in Spain, where approximately 38% of renewable resources are used in electricity generation as of 2019, 11.4% of the total electricity produced is provided by cogeneration systems (the use of thermal energy produced for other purposes to generate electricity concurrently). Furthermore, 21.4% of the total electricity production in the country was met by nuclear power plants [29]. The potential of the overall renewable energy resources in terms of geographical availability and technological capacity in Spain is more than sufficient for the total domestic demand, including the need for fossil fuels [30]. On the other hand, Poland, the fifth highest energy consumer in the EU, is also a significant producer among the EU countries. However, it is a net importer of oil and natural gas due to the scarce crude oil and natural gas resources. Poland met 45% of its energy needs from coal, 31% from petroleum and its derivatives, 17% from natural gas, and 7% from renewable energy sources. Poland, which is trying to alleviate its excessive dependence on Russia regarding

energy, is attempting to adapt to the regulations of the EU and create its energy policies in that direction [31]. The following Figure 1 shows the sum of electricity generation in the EU by source in 2021 [32]:

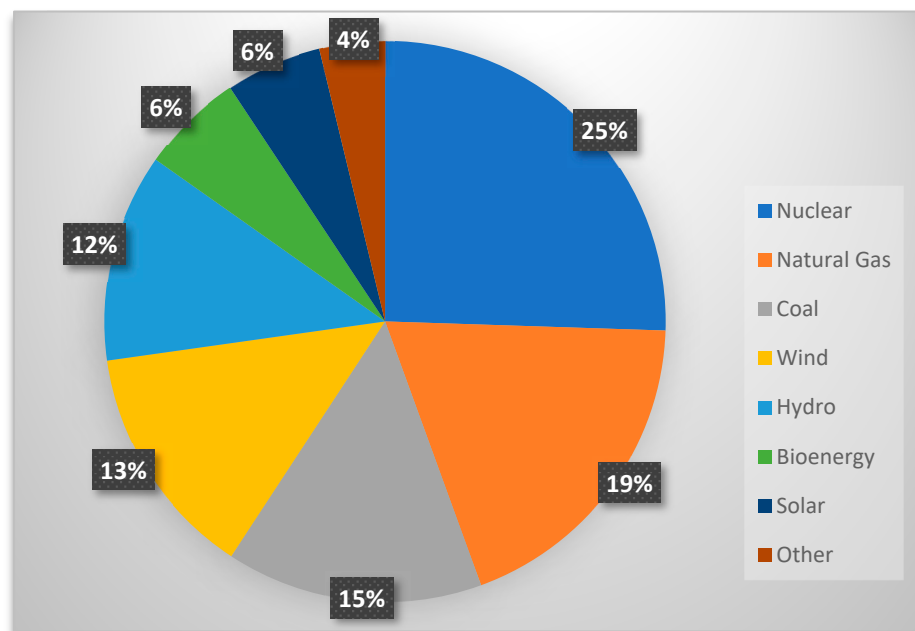


Figure 1. Electricity generation in the EU by source in 2021.

Figure 1 shows the major sources of electricity generation in the EU. According to the graph, it is clear that nuclear power became the primary source, which constitutes 25% of the total electricity generation in the EU. Natural gas is the second most-used resource to generate electricity in the EU, with 19%. It is also remarkable that renewables such as wind, solar, bioenergy, and hydro have a total share of 35%. A noteworthy point on the graph is that the sum of combustible fuels and natural gas still constitutes a significant share of the total electricity generation of the union. Furthermore, as mentioned for the specific countries before, energy sources are highly dependent on imports from non-EU countries [33].

2.2. Social Network Analysis

Networks are becoming more influential as the contemporary knowledge economy increases the significance of non-material variables [34]. For instance, it is typical that the individual investors tend to act in unison with the other investors and behave in parallel with the large majority of investors in the market [35]. Accordingly, many studies focus on networks in various disciplines. For instance, Praet, Martens, and Van Aelst [36] performed a large-scale comparison of parliamentary Twitter networks in 12 countries to investigate the influence of the countries' democratic systems on network behavior and elite polarization. Castor et al. [37] combined bibliometric and social network analysis methods to map the scientific publications associated with tuberculosis produced by the BRICS. Madhusanka and Kumaraswamy [38] examined energy and carbon policy networks of buildings in developing countries.

The social network analysis is a method that allows examining the structures, which can be in the behavioral, social, political, or economic fields [11] (p. 10). Moreover, the method used for analyzing networks, where individuals, species, teams, or organizations of all types and sizes can be actors, has been used in various studies examining interstate interaction and trade [39] (pp. 1–2).

Some fundamental theories constitute a basis for social network analysis. The strong ties theory, proposed by James Samuel Coleman [40], focuses on the closure attribute of

social networks. The theory argues that stronger relations are consequential and emphasizes the positive effect of the social ties of the actors with close relations [41,42] (p. 184, pp. 37–38). The existence of strong ties means that the actors are in close contact. In addition, the actors in a network with strong ties have similar characteristics, thus showing the feature of closure [40]. It is argued that a crucial advantage of strong ties is that they reduce uncertainty in the exchange relations between actors. Therefore, communication and cooperation in the network are strong, the relationship is reliable, and mutual interests exist [41] (p. 184). In the context of the strong ties theory, having strong ties in the network of countries will provide a significant advantage in the energy trade network. In other words, a country should be in strong ties with at least some of the countries in the network, and if a country has no strong ties, it is unlikely to have a significant position in the structure.

On the contrary, the weak ties theory put forward by Mark S. Granovetter [42] (p. 202) refers to a circumstance where the density of relationships between actors in any social network is low. Although these ties are weak, they cannot be considered insignificant as these weak ties can be a key bridge between different groups with strong bonds. In fact, it is obvious that the number of actors that can be reached through weak ties is considerably higher than the number of actors that can be reached through strong ties.

Therefore, having a large number of weak ties in the energy trade is as important as the existence of strong ties in a country's network.

In the structural holes theory put forward by Ronald Burt [43], the weak ties theory has been expanded and rearranged. While the point emphasized in Granovetter's theory of weak ties was about the poor quality of the tie, Burt's theory of structural holes was about bridging different groups. Burt [42–44] (pp. 34–35, pp. 341–343, pp. 353–354) emphasizes the strategic advantage created by the intermediary position of the actors by building bridges, and he states that the existence of actors that are not connected with each other in a network reveals the structural holes and that the actors who fill these structural holes can establish competitive advantage. Considering this in terms of energy trade, the countries in an intermediary position can gain influence in the network.

3. Method

In this study, the social network analysis method, which allows investigation of the relations between the actors rather than the actors themselves, is implemented on the domestic energy trade network of the EU. The network approach is based on patterning ties in which actors are embedded and has significant effects on those actors. The analysis is established on systematic empirical data and mathematical models [45,46].

The aim of this research is to identify the relation ties between the EU countries in order to clarify the characteristics of the network, such as its crucial actors, vulnerabilities, structural holes, etc., to help achieve some proposals for a more sustainable and secure energy supply. In line with this aim, we assumed that EU energy trade security can be measured by applying social network analysis according to the previous literature.

The data were obtained from the dataset published by the UN Comtrade Database. Raw data from 2021 were used in the study as they were the most recent available data during the study. Tables and graphics are based on the products with the code "27", which expresses the "fuels" group according to the "HS 1988/92" customs product classification since the study is on the trade of energy commodities. The group also includes direct electricity trade under "27.16". The data indicate the yearly trade volumes of the selected product group in USD. Although both export and import data are available separately in the source used, only import data were taken into account in the study since the import data reflect reality more consistently [47]. The relationship matrix of the network was formed weighted in order to examine the strength of the ties. In the energy trade, volume is important, as well as the existence of imports. Also, the import data were entered asymmetrically since the mutual import and export volumes may not be equal. For

example, it is not expected that Poland's total trade rate with Germany will be the same as Germany's total trade rate with Poland [48].

Figure 2 shows a simple example, which A and B are the actors of a network. It is clear that actor A and actor B are in a relationship. If the volume of the relation matters, as well as the existence thereof, the data should be weighted. Also, the relation weights are different for actors A and B. For instance, actor A imports 100 USD, while actor B imports 300 USD of goods. In such a case, the matrix should be asymmetrical.

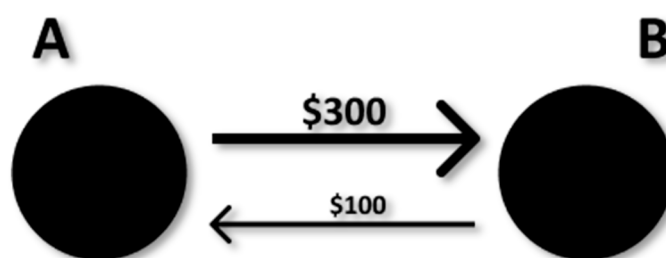


Figure 2. Weighted and asymmetric relation example.

4. Results

In order to reveal the structure of the network and determine the degree of importance of the countries in the network, the amount of energy trade between the actors, the density values of the network, and the degree of centrality of the countries were examined. Network density is found by dividing the number of ties available in the network by the number of all relationships that have the potential to occur [11] (pp. 101–103). The number of all possible ties can be found with the formula $n(n-1)/2$ in a symmetric and with $n(n-1)$ in an asymmetric matrix, where “ n ” is the number of actors [49,50] (pp. 216–217, p. 95). Hence, the density of the network is calculated by dividing the number of ties in the network by the number found by this formula. The density measurement shows whether the network is knitted or whether the actors are intensely connected to each other [49] (p. 254). It helps to clarify some typical characteristics of a network. For example, network structures with high density are considered to be more advantageous in terms of coordination in the network [51].

However, only some of the ties in the network are meaningful. Therefore, dichotomizing, which refers to converting valued data to binary data with a certain threshold level, is implemented on the matrix data [39] (p. 97). Especially when examining the energy trade, tiny values make no sense, but they are still constituting ties. In this case, we set a minimum threshold level at 100 million USD, which is a much lower value (1/7) than the lowest importer country's (Estonia) total import. The threshold level is very low in an energy trade network worth around 192.8 billion USD. However, setting a threshold level this low is meant to identify all relation ties at first glance no matter they are significant.

Table 1 shows the energy trade relations equal to or greater than 100 million USD. According to the table, there are 301 ties in the energy trade network of the EU as of 2021. By applying the cited formula, the density is 0.429 (301/702). The interpretation of the density results is usually subjective [39] (p. 170), such as asserting that the density rate is acceptable for the EU, as it may arise because of low-volume trades of micro-states. Nevertheless, the total internal trade value is around 192.8 billion USD according to the data. Therefore, setting a threshold level at 100 million USD may not reflect a true image of the network. Indeed, it is advised to dichotomize at multiple levels before conducting the analyses on each of the resulting datasets. This method preserves the richness of the data and can provide network structure insights that are difficult to obtain from methods that deal directly with valuable data. It also helps to determine the reliability of the results [49] (p. 146). The following table shows the dichotomized tie numbers in the energy trade network of the EU at the second threshold level (1 billion USD).

Table 1. Ties of the energy trade network in the EU (equal to or greater than 100 million USD).

	AT	BE	HR	CY	CZ	DK	EE	FI	FR	DE	GR	IT	LV	LT	LU	NL	PL	PT	RO	SK	SI	ES	SE	HU	BG	IE	MT	Sum
AT	0	1	0	0	1	0	0	0	1	1	0	1	0	0	0	1	1	0	1	1	1	0	0	1	0	0	0	11
BE	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1	1	0	0	1	0	15
HR	1	1	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	11
CY	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1	7
CZ	1	1	0	0	0	0	0	0	1	1	0	1	0	0	0	1	1	0	0	1	0	0	0	1	0	0	0	9
DK	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	9
EE	0	1	0	0	0	1	0	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	8
FI	0	1	0	0	0	1	1	0	1	1	0	1	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	10
FR	1	1	0	0	1	1	0	1	0	1	1	1	0	0	1	1	1	1	0	0	0	1	1	0	1	1	0	16
DE	1	1	0	0	1	1	1	1	1	0	1	1	1	1	0	1	1	0	1	1	0	1	1	1	0	0	1	19
GR	1	1	1	0	0	0	1	0	1	1	0	1	0	0	0	1	1	0	1	0	1	1	1	1	1	0	1	16
IT	1	1	1	1	1	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	22
LV	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	5
LT	0	1	0	0	0	0	1	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	8
LU	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4
NL	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1	0	1	0	18
PL	0	1	0	0	1	1	0	1	1	1	0	1	1	1	0	1	0	0	0	1	0	1	1	1	0	0	0	14
PT	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	8
RO	1	1	0	0	1	0	0	0	1	1	1	1	0	0	0	1	1	0	0	1	0	1	0	1	1	0	0	13
SK	1	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	7
SI	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	0	1	0	0	1	0	1	0	0	1	12
ES	0	1	0	0	0	1	0	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	1	0	1	0	0	14
SE	0	1	0	0	0	0	0	1	1	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	9
HU	1	1	1	0	1	0	0	0	1	1	0	1	0	0	0	1	1	0	1	1	1	0	0	0	1	0	0	13
BG	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	6
IE	0	1	0	0	0	1	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	8
MT	0	1	1	0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	9
Sum	11	23	4	1	10	10	8	13	20	23	12	20	8	9	2	23	18	6	8	9	5	15	14	12	7	5	5	301

Table 2 shows the energy trade relations equal to or greater than 1 billion USD. At the second threshold, there exist 42 ties in the energy trade network of the EU. According to the formula $(42/702)$, the density is found to be around 0.0598, which is an extremely low rate. Moreover, it is clear that only 16 out of 27 countries made energy trade at this volume. At this point, if a third threshold level is set at 10 billion USD, the density will be much lower. Consequently, it is obvious that the density of the energy trade network of the EU is not high, so this circumstance creates structural gaps and facilitates a small percentage of the actors to dominate the network.

Centrality metrics reveal the importance level of the actors within the network. A high degree of importance indicates that the actor is in a strategic role due to his position in the network. The metrics of centrality are most widely used in measuring economic issues such as authority and degree of access to resources and knowledge [11] (pp. 169–174). In implementing the degree centrality on asymmetric data, it is essential to distinguish the concepts of inner and outer degree centrality. While internal degree centrality refers to the number of connections toward the actor, external degree centrality expresses the number of connections from the actor to the others. It is argued that the actors with high internal centrality are dominant or highly prestigious in the network, while those with high external degree centrality possess a high level of trade [50] (p. 147). Therefore, both positions provide a strong authority in the network. Table 3 shows the degree centrality results.

Table 3 shows the inner and outer degree centrality levels of the actors within the energy trade network of the EU. At first glance, it is remarkable that certain countries possess first rankings, both in inner and outer degree centrality results. For instance, Germany, the Netherlands, Belgium, France, Italy, and Spain are placed high in the ranks in both lists. Thus, it is apparent that these countries dominate the EU energy trade network. Furthermore, the first ranking in the outer degree centrality of the Netherlands by a large margin shows that it has a strong dominance of energy export in the network.

The results of the centrality analysis confirm the density analysis, as it shows that certain countries, which are only a tiny percentage of the EU, hold the network. This means that any opportunity first falls into the hands of one of these countries, and other countries are more likely to be dependent on them.

Table 2. Ties of the energy trade network in the EU (equal to or greater than 1 billion USD).

	AT	BE	HR	CY	CZ	DK	EE	FI	FR	DE	GR	IT	LV	LT	LU	NL	PL	PT	RO	SK	SI	ES	SE	HU	BG	IE	MT	Sum
AT	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
BE	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
HR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CZ	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
DK	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2
EE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
FR	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	5
DE	1	1	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	6
GR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IT	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LU	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
NL	0	1	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	7
PL	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
RO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
SK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	4
SE	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
HU	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3
BG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	2	4	1	0	2	2	0	1	5	8	0	3	0	0	0	5	0	1	0	1	0	3	3	0	1	0	0	42

Table 3. Inner and outer degree centrality results in the energy trade network of the EU.

Inner Degree		Outer Degree	
Germany	4.80%	The Netherlands	8.20%
Belgium	4.60%	Belgium	4.60%
France	4.10%	Germany	4.00%
The Netherlands	3.60%	France	1.70%
Italy	1.50%	Spain	1.30%
Spain	1.20%	Sweden	1.20%
Hungary	1.10%	Italy	1.10%
Austria	1.00%	Austria	0.80%
Czech Republic	0.70%	Czech Republic	0.70%
Poland	0.70%	Poland	0.60%
Sweden	0.60%	Slovakia	0.60%
Finland	0.60%	Finland	0.50%
Denmark	0.50%	Denmark	0.40%
Portugal	0.50%	Greece	0.40%
Romania	0.40%	Hungary	0.30%
Croatia	0.30%	Portugal	0.30%
Slovenia	0.30%	Lithuania	0.30%
Slovakia	0.20%	Romania	0.20%
Greece	0.20%	Croatia	0.20%
Lithuania	0.20%	Slovenia	0.20%
Bulgaria	0.20%	Bulgaria	0.20%
Latvia	0.20%	Latvia	0.10%
Cyprus	0.20%	Estonia	0.10%
Luxembourg	0.20%	Cyprus	0.00%
Estonia	0.10%	Luxembourg	0.00%
Ireland	0.10%	Ireland	0.00%
Malta	0.10%	Malta	0.00%

5. Limitations

The unit price and amount purchased for Energy Resources are sometimes kept confidential by the states for various reasons. For instance, item “Areas NES (not elsewhere stated)” in the database refers to low-value trade, or the partner designation was unknown to the country. The reporting country does not share the details of the trading partner in some specific cases. Therefore, deviations may occur in the results depending on the unknown import source. Also, the import data of energy commodities regarding Bulgaria, Ireland, and Malta for 2021 was unavailable. Therefore, the import values of these countries were found from the export data of other countries within the network. However, the trade links “Malta—Ireland—Bulgaria” were impossible to show. On the other hand, we argue that the unavailable data does not jeopardize the reliability of the study since these countries are not energy-intense actors like the Netherlands, Germany, or France.

6. Conclusions and Discussion

This study showed that certain countries are intensely dominant within the energy trade network of the EU. On the export side, the position of the Netherlands is remarkable, as it is the net export leader of the EU. The findings support that the Netherlands is a crucial transit and energy hub for oil, natural gas, coal, and electricity. The country has extensive cross-border and subsea oil and gas pipelines and electrical interconnections. The ports take a critical role in regional and global energy trade and maintain one of Europe’s most considerable concentrations of oil refining and marine bunkering fuels. Also, the Netherlands is home to a major liquefied natural gas (LNG) terminal, called GATE (Gas Access to Europe), and to the largest gas-trading hub, called Title Transfer Facility (TTF), in Europe. On the other side, the Netherlands imported 99 billion USD in energy commodities while exporting 85 billion USD as of 2021. Thus, it is clear that the country’s exports depend on its imports. Moreover, 19% of energy import solely belongs to Russia,

which is a fact that increases the vulnerability of the Netherlands [52]. As for Germany, the highest energy importer of the EU, the circumstance is nearly the same. Germany realized 16% of its imports from the Netherlands (which has a significant dependency on Russia and other non-EU countries) and approximately 14% directly from Russia. Belgium, which has the second centrality rank on both sides of the trade, imports 56% of its energy commodities solely from the Netherlands. Germany takes steps against the risks to energy supply security, such as intensifying its energy transition progress with the implementation of new policies. The policies aim to ensure energy productivity and a progressive transition from fossil fuels to renewable energy sources [53]. The import rates are nearly the same for France and Italy, which shows high dependency. Countries such as Poland and Slovakia are more vulnerable in energy supply as more than 50% of their imports directly depend on Russia. Accordingly, we argue that the energy dependency of the EU still needs to be lowered. The recent COVID-19 pandemic [19] and the recurring conflict between Russia and Ukraine in 2022 resulted in crises for the EU [54], which support the argument. Indeed, the crisis that emerged because of the war led the EU to shift its import shares to other countries such as Norway. The share of Norway increased to 13.4% in petroleum products and 44.3% in natural gas in 2023. Furthermore, it is remarkable that the UK has a 17.8% share in the natural gas import of the EU [55]. At this point, despite this being a solution for the short term, it may bring another import dependency for the EU; especially since the disintegration processes between the EU and the UK after Brexit cause significant uncertainties for the future [56,57].

Conversely, Spain might be considered an exception. The country has significant rates of imports from African and North American countries (more than 45%), less than 15% of its total imports are from the EU, and around 10% of its imports are from Russia. Spain's diversification in the energy trade is clearly better than many other EU countries. The upper-limit regulation of Spain may have worked well for this conclusion. At this point, it is advisable for other EU countries to follow upper-limit policies.

Nevertheless, this would be more possible if the EU developed its internal trade network infrastructure. According to the findings, the strong dominion of a small percentage of the members within the network shows that most of the EU countries are incapable of reaching opportunities in energy trade. Also, the domination of a few actors causes vulnerability for the trade network as it prevents the diversification of trade routes. Therefore, higher density in the trade network will provide diversification in energy sources, trade routes, and strategic reserves. This will significantly soften the energy crises within the EU.

Globalization increased the interdependence of states via the trade of products, capital transfers, technological development, and knowledge sharing [58]. Therefore, it became highly possible that regional issues would turn into broader crises because of the extent of liberalization in trade. In this line, geopolitical conflicts that cause volatility in fossil fuel prices in global markets expose the vulnerability of energy trade [59]. Hence, it is vital to comprehend the risks of such crises and develop safe and sustainable policies to ensure energy security, which refers to the supply of uninterrupted and affordable energy sources [60].

Apart from the external or global risks of being highly dependent on non-EU countries in energy trade, possible internal issues within the central countries (The Netherlands, Germany, etc.) pose a high risk for the overall network. For instance, the transition program called "Energiewende" involved the phase-out of nuclear energy production facilities. Even though it is a welcoming step against global warming and other environmental threats, it significantly increased Germany's reliance on natural gas because of the raised concerns after the Fukushima Daiichi nuclear accident in Japan resulted in the acceleration of phasing-out [61]. Such a situation decreased Germany's energy supply capacity for the domestic market and the EU network. Eventually, the country had to return to the coal energy production facilities and became the highest at a +19% increase [62]. The rising prices of natural gas and increasing demand for energy sources caused coal consumption to increase by 11% in Western Europe despite all environmental concerns [63]. Therefore,

internal issues such as management activities, national strategies, domestic policies, and new regulations of the few hub countries are always possible [64] and can considerably affect the EU trade network.

Identifying the underlying causes of conflicts is vital [65] for solving problems before they become a crisis. Diversity (capability of providing energy sources from various supply chains) and dependence (production capacity to fulfill domestic energy needs) concepts are two of the most critical terms for the energy security of the EU. Therefore, diversifying energy resources and import routes by developing an internal trade network is vital, in addition to the other main objectives the EU has to implement in the long term, such as reducing dependence, applying efficiency and decarbonization policies and raising renewable energy production [64,66,67].

Subsequently, combining the previous literature and the results of the social network analysis brings the following conclusions in brief:

1. The Netherlands is the primary energy hub for the EU, with a huge margin, and its sources mainly come from imports from non-EU countries, specifically from Russia.
2. There are very few other significant energy hubs and they are highly dependent on the Netherlands. Apart from the external risks, internal issues such as faulty new policies and regulations or a possible domestic crisis within the hub countries would jeopardize the overall network.
3. Therefore, the EU is inadequate in diversification strategies, and the union has to weigh on this.
4. Diversification strategies can take place more successfully if the EU significantly increases the number of new hubs for energy markets by encouraging other member states. This step may conflict with the profitable interests of the current hub countries, but it will bring convenience, such as energy security or stability, to the whole network.

Future studies may focus on the costs and benefits of intensifying the EU energy trade network. A feasibility study throughout the EU boundaries may expose the strategic points for reserves, import options, and the amount of capital for the required infrastructure for a sustainable energy flow.

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