LUISS

Master's Degree Course in International Management

Trade in Waste:
A Network Analysis

Luca De Benedictis
SUPERVISOR

Gianfranco Di Vaio
CO-SUPERVISOR

756771
CANDIDATE

Academic Year 2022/2023

Abstract

In the present era, the global community is confronted with a dual issue. From an environmental perspective, it is worth noting that the development of excessive garbage and the absence of an adequate disposal infrastructure have resulted in the practice of waste exportation to less developed nations by certain states. On the contrary, the global community is currently grappling with a substantial scarcity of primary resources, resulting in an escalation of their costs and impeding the efficiency of supply chains. In order to effectively tackle this twin challenge, the implementation of Circular economy models is considered a recommended approach. The objective is to engage in recycling and proper waste disposal practices in order to recover essential raw materials and initiate a new manufacturing cycle.

In order to promote and provide motivation for the adoption of the Circular economy, the European Union enacted two directives, namely 851 and 852, in 2018. These directives were designed to restrict the exportation of municipal garbage from European nations to external regions, with the aim of compelling countries to engage in waste recycling practices and perceive waste as a valuable resource rather than a burden.

The primary aim of this study is to examine the progression of municipal garbage trade over a span of 10 years and evaluate the influence of two rules on this phenomenon using a Network Analysis study model. The degrees of centrality, including outdegree, indegree, proximity, betweenness, and eigenvector, were computed, along with the network density and the potential partition into clusters, known as modularity. The temporal scope under consideration spans from 2012 to 2021, with data extraction for analysis purposes conducted using the CEPI BACII database. The specific focus was on the selection of municipal garbage, identified by the extraction of the 6-digit product code 382510 (HS 2002). The data analysis and processing procedures were performed using the R software.

This technique facilitates a comprehensive comprehension of the trading network's structure, the identification of pivotal countries involved across time, and the examination of the evolution of these dynamics after the implementation of stringent guidelines in 2018.

Table of Content

1. Introduction

1.1 The Circular Economy

1.1.1 Sustainability

The global community has witnessed a surge in environmental apprehensions over the impact of human activities on the planet in recent times. Consequently, these worries have garnered significant attention from various sectors, including mainstream media, governmental initiatives, academic research, and the general populace (Cheng, Masukujjaman, Sobhani, Hamayun, Alam, 2023). The aforementioned emphasis primarily arises from an increasing societal and ecological consciousness regarding the imperative of employing resources responsibly and making thoughtful decisions (Stanescu, 2021). Consequently, there is an increased need for environmental awareness and engagement due to this inclination. Additional studies have corroborated the notion that engagement in sustainability initiatives and the practice of disclosing relevant information can yield benefits such as increased transparency, improved reputation, enhanced branding, as well as the motivation of employees and the bolstering of competitiveness (Alshbili, Elamer, Moustafa, 2021). The issue at hand has transitioned from an ethical concern to a tangible competitive advantage. In recent years, it has increasingly been a prerequisite for organizations to prioritize aspects such as brand reputation, regulatory adherence, operational efficiency, and financial considerations. The Circular Economy is often regarded as a highly effective approach for achieving sustainability objectives, particularly when considering economic considerations.

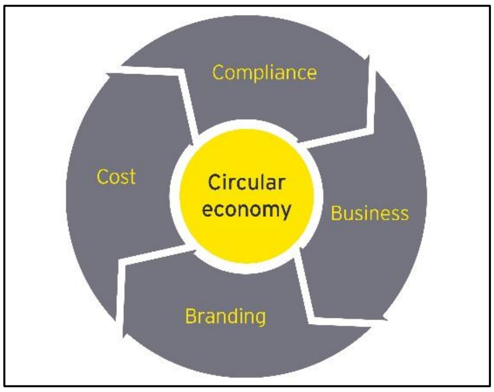


Fig 1.1 *Impact areas of the circular economy (EY, 2019)*

The Circular Economy, while providing environmental, economic, and societal advantages, specifically incentivizes economic players that effectively implement the system. According to

Geissdoerfer, Savaget, Bocken, and Hultink (2017), the concept of the Circular Economy (CE) is founded upon the principle of a regeneration cycle, enabling the effective repurposing of outdated products, components, and materials, hence enhancing economic viability and mitigating environmental issues (Khan & Haleem, 2021). While the circular economy presents targeted solutions, it necessitates the implementation of well-organized policy measures to effectively tackle key environmental and economic concerns. These concerns encompass resource and energy efficiency, supply security, waste management, the mitigation of greenhouse gas emissions, the establishment of innovative business models, and the augmentation of employment prospects (Kobza & Schuster, 2016). The primary objective of this study is to conduct an analysis of the potential of waste management practices.

1.1.2 Importance of Circularity

The growth of the economy and population, along with the process of urbanization, has resulted in a notable escalation in the generation of solid waste across most countries worldwide, with a special emphasis on emerging nations (Guerrero, Maas, Hogland, 2013). Annually, the global production of municipal solid waste amounts to 2.01 billion tonnes, a significant portion of which, at least 33%, is not subjected to environmentally responsible management practices (The World Bank, n.d.). Projections indicate that the global output of municipal solid waste is anticipated to increase by approximately 70% by the year 2050, reaching a staggering 3.4 billion metric tons. The phenomenon can be attributed to a multitude of variables, encompassing population expansion, urbanization, economic advancement, and consumer buying patterns. According to the source Statista (2023), The necessity to identify effective methods for recycling and reusing waste materials has become more apparent due to the growing diversity and volume of waste products, the limited availability of landfill space, and the scarcity of natural resources. (Li, Amirkhanian, Zhang, & Feipeng, 2019). Conventional methods of waste disposal not only result in the inefficient utilization of land resources but also pose significant risks to both the environment and the well-being of individuals in society.

In addition, the scarcity of natural and non-natural raw materials can be attributed to the extensive utilization of natural resources, non-renewable energy sources, and the substantial demand for equipment and installation materials (Av, 2021). The COVID-19 epidemic has had a significant impact on the prices of imported products, particularly precious stones, minerals, and non-ferrous and ferrous metals. These prices experienced a substantial increase throughout the latter half of 2020 and have continued to rise throughout 2021. According to Arriola, Kowalski, and van Tongeren (2022), Consequently, the trade values of these raw commodities experienced a notable increase throughout the period of the extensive trade decline. The incursion of Russia into Ukraine has resulted in more challenges for global trade, the global economy, and the international provision of agricultural and industrial raw materials, which have historically been major exports for both countries. According to Kowalski (2023), the prices of aluminum, copper, tin, gold, and zinc have recently surged to their greatest levels since the early 1990s.

Furthermore, the attainment of net zero CO2 emissions by 2050 will require a substantial augmentation in the production and global commerce of various raw materials, in addition to the aforementioned disruptions. The transition from a fossil fuel-dominated global economy to one driven by renewable energy technology will be of utmost importance. In contrast to systems reliant on fossil fuels, these particular technologies frequently exhibit a higher degree of mineral utilization. As an illustration, it can be observed that the extraction of mineral resources for the establishment of an onshore wind farm is nine times greater in comparison to a gas-fired plant. Similarly, the production of a standard electric car necessitates six times the amount of material inputs when compared to a traditional automobile. Consequently, the adoption of green transition measures would not only reduce global dependence on fossil fuels but also impose additional demands on the use of other raw materials and necessitate more efficient international trade (IEA, 2021). The escalation in prices across various raw material categories accentuates the economic and ecological significance of exploring trash recycling as a means to obtain them. The simultaneous resolution of the resource scarcity issue, environmental preservation, and the eventual formation of a circular economy can be achieved by the implementation of recycling and reuse practices for solid waste (Yang, Chen, Wang, Msigwa, Osman, Fawzy, Rooney, Yap, 2022).

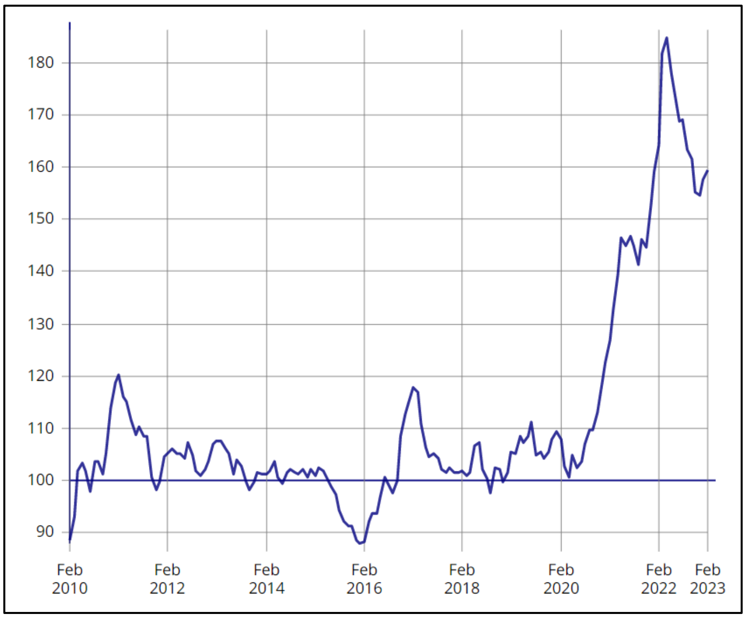


Fig 1.2 *Price trends of major raw materials from 2010 to 2023 (INSEE, 2023)*

1.1.3 EU Regulations

Over the course of its existence, the European Union has implemented a number of directives and legislative initiatives aimed at promoting sustainability, with a particular focus on the concept of Circular Economy. The Circular Economy Package encompasses two key Directives, namely Directive 2018/851/EU on trash, which modifies Directive 2008/98/EC, and Directive 2018/852/EU on packaging and packaging waste, which amends Directive 1994/62/EC. These Directives are accessible on EUR-Lex under the following references: 32018L0851 for Directive 2018/851/EU and 32018L0852 for Directive 2018/852/EU. The objectives of this directives package encompass many key aims: to optimize resource efficiency and promote the recognition of waste as a valuable resource, to reduce the Union's dependence on imported raw materials, and to facilitate the shift towards a more sustainable approach to materials management and the adoption of a circular economy model. This principle encompasses the adoption of "extended producer responsibility schemes," which refers to a collection of measures enacted by member states to ensure that product manufacturers bear the financial and operational burden of managing the phase of the product's life cycle when it becomes waste. This responsibility includes activities such as separate collection, sorting, and treatment operations.

The Waste Directive stipulates that member states are obligated to implement relevant measures to promote the advancement, manufacturing, distribution, and use of products and their components that are capable of being utilized many times. It is imperative that these materials consist of technically recyclable, long-lasting, easily repairable components. Furthermore, once these materials reach the end of their lifecycle and become garbage, they should be capable of being reused and recycled. This approach is essential for effectively adhering to the waste hierarchy. These procedures should aim to mitigate the impact of products throughout their entire life cycle, prioritize waste management strategies based on the waste hierarchy, and consider the feasibility of repeated recycling, when applicable. The study conducted by the EXSSA organization in 2020).

1.1.4 EU Directive 2018/851

The proportion of municipal garbage in the overall waste created inside the Union ranges from 7% to 10%. However, it remains a challenging sector to effectively govern, and the manner in which it is managed often serves as a reliable gauge of a nation's waste management system's overall efficacy. The management of municipal waste poses significant challenges because to its intricate and diverse composition, proximity to residential areas, extensive public visibility, and potential consequences for the environment and human well-being. Consequently, the management of municipal waste requires a well-developed framework encompassing various components such as an efficient system for waste collection, an effective mechanism for waste sorting, and accurate monitoring of waste streams. Additionally, it necessitates the active participation of citizens and businesses, infrastructure that aligns with the composition of waste, and the establishment of a comprehensive financing system. Nations that possess efficient municipal waste management systems have superior performance in overall waste management compared to other countries, including the successful attainment of recycling targets (EUR-Lex - 32018L0851).

When it comes to waste exports from the European Union, Member States are obligated to utilize their inspection powers as outlined in Article 50(4c) of Regulation (EC) No. 1013/2006 (EUR-Lex - 32006R1013). This entails requesting supporting documentation to verify whether a shipment is intended for recovery operations in accordance with Article 49 of the aforementioned Regulation. The purpose of this verification is to ensure that the waste is being managed in an environmentally responsible manner at a facility that adheres to standards for human health and environmental protection. In order to achieve this objective, Member States may collaborate with various stakeholders, including competent authorities in the receiving country and independent external verification bodies or organizations, to carry out physical inspections and other assessments on installations located in foreign countries (EUR-Lex - 32018L0851).

Consequently, it is mandatory for Member States to undertake necessary measures in order to achieve the following objectives: by the year 2025, the proportion of municipal waste that is prepared for reuse and recycling should be no less than 55% in terms of weight; by 2030, it should be no less than 60% in terms of weight; and by 2035, it should be no less than 65% in terms of weight. According to EXSSA (2020), the prescribed date for the implementation of the circular economy package recommendations is July 5, 2020. There exist notable variations in waste management practices among member countries, particularly in the domain of municipal garbage recycling. Based on data obtained from the joint OECD and Eurostat questionnaire, it is suggested that member states which exhibited a recycling rate of less than 20% for municipal waste in 2013 or a landfill rate exceeding 60% for municipal waste should be granted the authority to extend the timeframe for achieving the preparation for reuse and recycling targets set for 2025, 2030, and 2035. In order to ensure consistent advancement towards goals and timely resolution of implementation deficiencies, Member States who seek an extension should fulfill intermediate milestones and present an implementation strategy that adheres to comprehensive criteria (EUR-Lex - 32018L0851).

1.1.5 EU Directive 2018/852

The use of waste avoidance measures is a very effective approach for enhancing resource efficiency and mitigating the adverse environmental consequences associated with trash. Consequently, it is imperative for member states to adopt appropriate measures to promote the augmentation of reusable packaging introduced into the market, as well as encourage package reutilization. These approaches may encompass the implementation of deposit-refund programs and additional incentives, such as the establishment of measurable goals, the assessment of recycling progress towards predetermined targets, and the provision of varying cash compensations for reusable packaging within extended producer responsibility packaging initiatives. It is imperative for member states to implement measures aimed at promoting the adoption of reusable packaging while concurrently minimizing the utilization of non-recyclable and environmentally detrimental packaging materials. The introduction of extended producer accountability systems is warranted due to the predominant influence of manufacturers in determining the quantity and type of packaging utilized, rather than the preferences of customers. The implementation of expanded producer responsibility legislation can yield positive environmental outcomes through the reduction of packaging waste generation and the promotion of separate collection and recycling practices for such waste.

By the end of December 31, 2025, a minimum of 65% of packaging trash will undergo the process of recycling. This target will be achieved by meeting specific recycling objectives for each component of the packaging, based on their respective weights. By the conclusion of December 31, 2030, a minimum of 70% of the total weight of packaging trash will undergo the process of recycling, while more ambitious recycling targets will be established based on the specific packaging materials involved.

The establishment of a sustainable bio-economy has the potential to reduce the Union's dependence on imported raw materials. The utilization of recyclable bio-packaging and compostable biodegradable packaging provide an opportunity to promote the use of renewable materials in package production, provided that it proves beneficial when considering the entire life cycle of the packaging (EUR-Lex - 32018L0852).

1.2 The Waste Trade

1.2.1 Overview of Waste Trading

The primary objective of these trash rules is to reduce the volume of waste being exchanged between nations within the European Union. Consequently, the establishment of the Zero Waste Europe network occurred, representing a collective of European communities, local leaders, experts, and change agents with the shared objective of eradicating waste within our society (European Circular Economy Stakeholder Platform, 2022). Zero Waste Europe aims to raise awareness about the inequities associated with the waste trade, while advocating for effective waste management strategies. These strategies include discontinuing waste exports beyond the European Union, enhancing waste management practices within the Union through improved regulations, and fostering a zero-waste society by promoting waste prevention measures throughout Europe (Zero Waste Europe, 2022).

Developed countries annually export a significant number of shipping containers to underdeveloped nations, containing a substantial amount of recyclable waste. The reason for this is that the establishment of local recycling infrastructures tends to incur higher costs compared to the alternative of exporting waste. Moreover, it reduces the amount of waste sent to landfills and can provide benefits for those involved in importing goods. The exportation of recyclable materials from the European Union has had a significant increase of over 70% since the beginning of the 21st century, thereby playing a substantial role in the substantial expansion of waste exports in recent years. Illicit disposal or incineration of waste is a common occurrence in importing nations due to the insufficiency of waste infrastructure, as the traceability of waste is lost once it departs from its origin. However, it should be noted that exporting nations still incorporate these exported volumes into their national recycling rates (Tiseo, 2023).

In order to have a comprehensive understanding of the magnitude of trash trade in Europe, it is noteworthy to highlight that in the year 2021, European Union (EU) member states facilitated the transportation of over 33 million tons of rubbish to foreign countries. This figure represents approximately 16% of the total worldwide waste commerce. Furthermore, approximately 50% of the waste was transported to Turkey, a country with waste management standards that are less stringent compared to those of the European Union. According to a report by the Organization Human Rights Watch, the aforementioned circumstances have given rise to a range of health challenges inside the country, including respiratory ailments, intense migraines, and dermatological afflictions (Euronews, 2023). The following visual representation displays the primary recipients of garbage imports originating from the European Union, ranked by volume.

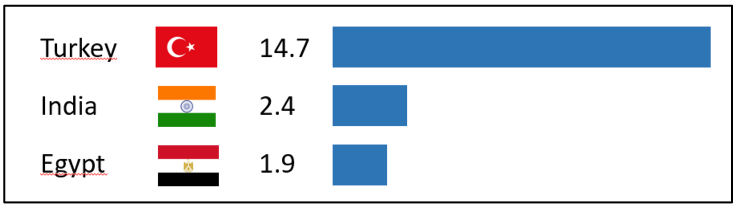


Fig 1.3 *The main destinations of EU export of waste (Eurostat, 2021)*

From a purely macroeconomic perspective, it is argued that garbage trading should not be subjected to specific limits or rules. Lawrence Henry Summers, a distinguished American economist and former

United States secretary of the treasury (1999-2001), raised a pertinent inquiry over the prudence of disposing waste in countries characterized by low wages and sparse population density. Due to the sparse distribution of inhabitants, the impact of environmental hazards on the population is negligible. The presence of low wages is associated with a heightened level of tolerance towards environmental dangers, indicating a diminished economic valuation of human life and well-being. This suggests that the costs associated with pollutants that negatively impact health are relatively minimal. According to Hayes (2022), the rule of comparative advantage suggests that toxic waste ought to be stored or managed in locations where the associated environmental costs are minimized. It is often considered that all parties involved stand to gain advantages from the implementation of free trade. Primarily, it is predicated upon voluntary exchange. Consequently, in the absence of any gains from trade, a country will refrain from engaging in trade activities. Furthermore, the international division of labor serves to improve the efficiency of resource allocation by effectively directing factors of production towards their most productive applications. Applying this logic to waste management, it can be inferred that engaging in global trade of garbage yields advantageous outcomes (Summers, 1992).

The aforementioned EU rules are based on a distinct concept, characterized by a stronger emphasis on environmental concerns. The perspective informed by environmental concerns regarding international waste trading posits that the majority of such commerce exhibits an imbalanced transactional dynamic between the Northern and Southern regions. The phenomenon of the developed world transferring its own environmental difficulties to the developing world is observed, wherein the latter has significant hurdles in managing and processing waste materials. According to Rauscher (1999), implementing a ban on the sale of rubbish would offer respite to the southern regions, while simultaneously compelling the northern regions to either cease the generation of waste or develop environmentally sustainable methods for its disposal.

1.2.2 State of the Art

Numerous studies examining the trafficking of trash have been undertaken in recent years. The study conducted by Wang, Zhao, Lim, Chen, and Sutherland (2020) shared a comparable objective to the one outlined in this research. Their work, which received support from the National Natural Science Foundation of China, focused on examining the consequences of China's import Ban on plastic trash. In relation to methodological approach, two academic papers are noteworthy. The first paper, authored by three researchers affiliated with the Department of Applied Informatics at the University of Macedonia (Petridis, Petridis, Stiakakis, 2020), and the second paper, conducted by scholars from the Department of Sociology at the University of Oregon (Theis, 2021), both employ network analysis to examine the trading patterns of e-waste, specifically Waste Electrical and Electronic Equipment.

Numerous studies have been conducted on the domestic management of municipal garbage, whereas limited attention has been given to its international trading. The analysis of municipal garbage trading was conducted by the Observatory of Economic Complexity (OEC). The calculations encompassed the identification of leading exporters, leading importers, and the changes seen between 2003 and 2021. Nevertheless, the current study offers a comprehensive depiction of trade relations between nations for the specified product category, albeit lacking in-depth analysis of its evolutionary trajectory. The primary objective of this study is to examine the evolution of trade relations, specifically for this product category. Additionally, the study does not delve into the examination of external events that could have potentially influenced the network's dynamics. The aforementioned study conducted a descriptive analysis of the pertinent entities that sequentially occurred within the examined timeframe (2012-2021). To validate and enhance the findings produced by the OEC observatory, coding procedures were employed. The novelty of this study resides in the approach employed to examine the global trade patterns of this specific commodity category and the market dynamics influenced by the implementation of two regulatory measures. A comprehensive explanation of this methodology will be provided in subsequent sections.

2. Methodology

2.1 Network Analysis

The selected approach for the study given in this paper is Network Analysis (NA), a method that has gained popularity in various fields, including those unrelated to social issues. The birth of Network Analysis has been attributed to three causes: measurements, visualization (Freeman, 2000), and tools. Over the past twenty years, the proliferation of network analysis tools has played a crucial role in the successful integration of Network Analysis into several scientific disciplines (Batagelj, Doreian, Ferligoj, Kejzar, 2014). According to Butts (2008), contemporary social network analysis is characterized by its high computational demands, surpassing those of numerous other domains within the field of social research.

In contrast to other regularly employed descriptive statistics in the field of applied international trade analysis, Network Analysis distinguishes itself by its emphasis on linkages and the relationships between them, rather than on individual organizations (Bowen, Hollander, Viaene, 2012). The focus is placed on the structural characteristics and interconnections of the network being examined. This tool facilitates the identification of prominent states and their interconnections within the domain of commodity trading. Consequently, it enhances comprehension of market dynamics and helps the recognition of potential opportunities or challenges. Furthermore, it facilitates the identification of

prominent hubs and clusters within the realm of global trade. This can facilitate a more comprehensive comprehension of the progression of trade connections and enable the identification of crucial points of vulnerability, as depicted in the illustration below.
Ultimately, it enables the discernment of nascent patterns in the realm of international commodities exchange. The assessment of countries or regions that may be appealing for future trading activity can be facilitated by this approach (De Andrade, Rêgo, 2018).

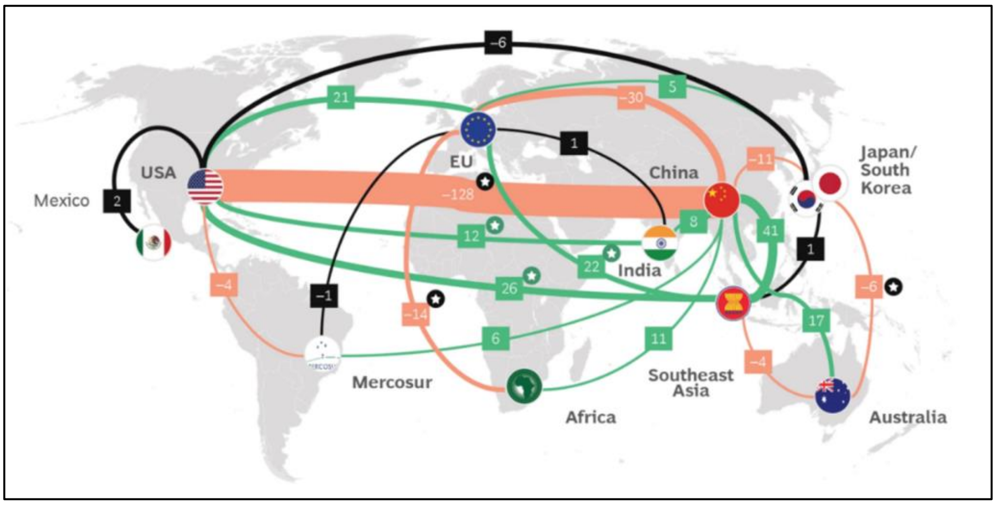


Fig 2.1 *Projection of percentage change in volume of goods traded from 2019 through 2023 (BCG, 2020)*

In essence, doing a network analysis study on interstate product trafficking proves to be advantageous in gaining a deeper comprehension of market dynamics, discerning potential business prospects, and identifying areas of susceptibility within the global trading system.

2.2 Analyze trade with Network Analysis

The World Trade Network (WTN) is a way of representing Global Trade and it is defined with the nodes as the countries in the world and with the links as the paths between them (Aller, Ductor, Herrerias, 2015). The WTN, defined as $N = (V, L, W, P)$, is made up of two independent parts: the first is the graph $G = (V, L)$, where $V = \{2, 3, ..., n\}$ is a collection of vertices (countries) and $L = \{0, 1, ..., m\}$ is a set of connections (trade flows) between pairs of vertices. The linkages are directed, flowing from the exporting nation, i, to the importing country, j, where Lij is a simple directed link and G is a simple directed graph. The second part contains all extra information about the qualities of the linkages, as represented by the line value function W, and the vertices, as represented by the vertex value function P. The positive parts of W operate as dyadic weights on G, changing its original binary structure and converting the directed graph into a weighted network, where wij represents the strength of the link between nation i and country j. Instead, the items in P include country-specific values (e.g., income, population) (De Benedictis, Tajoli, 2011). Cumulative distributions of *in-degree* and *out-degree* can be plotted to highlight the largest importers and exporters of waste. Indeed, the *out-degree* is the number of outgoing linkages created by nation *i* towards its trade partners (direct trade partners define its nearest neighborhood), while the *in-degree* is the number of incoming links to country *i* (Menichetti, Dall'Asta, Bianconi, 2014).

2.3 Data analysis

2.3.1 Data collection

The source of the data utilized for the analysis is the UN Comtrade database. The platform is widely regarded as the most comprehensive global trade data platform because to its ability to consolidate monthly and yearly statistics on international commerce, categorized by product and trading partner. This platform is utilized by various entities such as governments, educational institutions, research centers, and businesses. The United Nations Statistics Division has collected data on global merchandise trade from 1962 to 2021, encompassing about 200 nations. These statistics account for nearly 99% of the total global commerce trade (UN Comtrade, n.d.). According to the UN Comtrade Wiki (n.d.), the recording of commodities typically use the widely adopted version and classification known as HS2002. The categorization of commodities is accomplished through the utilization of the Harmonized System (HS) and the Broad Economic Categories (BEC).
The presence of a substantial amount of missing data in the original UN database posed challenges in accurately capturing information for a wide range of nations, over an extended time period, and at a highly detailed level of analysis. This limitation hindered the comprehensive utilization of the extensive data available in ComTrade. Due to this rationale, it was deemed more favorable to employ a modified version of the primary database, specifically the one generated by the French research institution CEPII (Centre d'Etudes Prospectives d'Informations Internationales): the BACI dataset. To address the issue of missing data, the methodology employed involves performing a series of operations to enhance and integrate the Comtrade database. This process is based on a mirror statistic strategy, which ensures that the reported flow remains consistent when viewed from both import and export perspectives. According to Gaulier and Zignago (2010),
In order to conduct an analysis on the global trash trade and its relationship with Directives 2018/851/EU and 2018/852/EU, the 6-digit product code 382510 (HS 2002) was retrieved, building upon the research conducted by The Observatory of Economic Complexity (OEC). The provided code pertains to waste materials categorized as waste, trimmings, and scrap originating from chemical or related industries. It serves the purpose of classifying such materials for international trade.

Specifically, the code provides a definition for municipal waste, which encompasses solid waste produced by households, commercial establishments, and public spaces located within urban or municipal regions. The alignment between the definition provided and the research issue investigated in this article is attributed to its comprehensive coverage of waste materials, encompassing packaging materials, as well as a diverse range of substances, including food, paper, glass, plastic, and textiles (OEC). Hence, it is feasible to examine the influence of two directives by means of a singular product code. Directive 2018/852/EU seeks to establish regulations pertaining to the management of packaging waste, encompassing a broader scope beyond the confines of municipal boundaries. Nevertheless, the study is based on the premise that the management of packaging trash created in urban areas serves as a representative model for all packaging waste. Future studies could focus on conducting a comprehensive examination of packaging waste, examining it in a disaggregated and isolated manner.

Finally, in terms of the selection of statistical software, the Network Analysis was performed using R within the R Studio environment. There are three notable advantages that R possesses in comparison to standalone network analysis programs. Firstly, it enables the execution of replicable research, a feat that is unattainable through the utilization of Graphical User Interface (GUI) software. Additionally, the data analysis features of R provide robust tools for manipulating data in order to effectively prepare it for network analysis. In conclusion, a continuously growing collection of packages has been developed with the intention of transforming R into a comprehensive network analysis tool (Sadler, 2017).

2.3.2 Data description

As expected, the CEPII-BACI database comprises trade data pertaining to the 238 most prominent countries. Each trade transaction is identified by a unique combination of exporter, importer, product, and year, which are represented by six variables. The variable "t" represents the reference year in this study, encompassing the years 2012 to 2021. These years were selected as they represent the most recent data available and are the focus of analysis within the designated time range. The specified time period enables an examination of the municipal trash trading landscape prior to the implementation of Directives 2018/851 and 2018/852, as well as the subsequent three-year period. On the contrary, variable k represents the product category denoted by the HS 6-digit code, specifically assigned the value 382510, as previously elucidated, signifying the HS code pertaining to municipal garbage. The variables i and j are used to denote the exporting and importing countries, respectively. According to the description of BACI (n.d.), the variable v is utilized to quantify the value of the transaction in thousands of USD, whereas the variable q is employed to express the corresponding quantity in metric tons.

The overall value of municipal garbage trade was determined by consolidating data from multiple nations throughout the specified time period. The sector under consideration exhibits an average trade value of 46.471 thousand US dollars during the examined period, which accounts for less than 0.1% of global commerce[1]. The value of this phenomenon, as a point of reference, is ranked at position 4,859 out of 5,202 in the overall analysis of product categories. It can be compared to the market for ‘Vermouth and other wine of fresh grapes, flavored with plants or aromatic substances, in containers holding more than 2 liters’, HS 6-digit code 220590 (47.045 thousands of US $)[2]. However, it is important to note that this sector is significantly less valuable than the Municipal Waste sector. When considering the quantity of traded products measured in metric tons, it is approximately 35 times larger than the Vermouth 2 liters market[3]. This highlights that its significance is primarily in terms of weight rather than value. While it may appear to have limited economic significance, it is important to note that the industry contributes to 18.9% of the global trade in 'Residual products of the chemical or associated industries' (HS code 3825)[4]. Additionally, it possesses significant environmental significance, given that municipal garbage constitutes around 16% of the total waste produced on a global scale (Gupta & Chopra, 2023).

Upon analyzing the temporal trajectory of this variable, it becomes evident that it does not adhere to a consistent pattern. Indeed, the aforementioned phenomenon experiences a continuous expansion up until the year 2014, followed by a sudden cessation between the years 2012 and 2013. Subsequently, there is a further decrease observed until 2017, after which a clear resurgence in growth is observed.

[1] Programming code in Annex (6.1), *Code for Municipal Waste % of total traded (per value)*
[2] Programming code in Annex (6.2), *Code for Municipal Waste Product Category Ranking (per value) + Comparable*
[3] Programming code in Annex (6.3), *Code for Municipal Waste Product Category Comparable (per weight)*
[4] Programming code in Annex (6.4), *Code for Municipal Waste % of all 3825- codes (per value)*

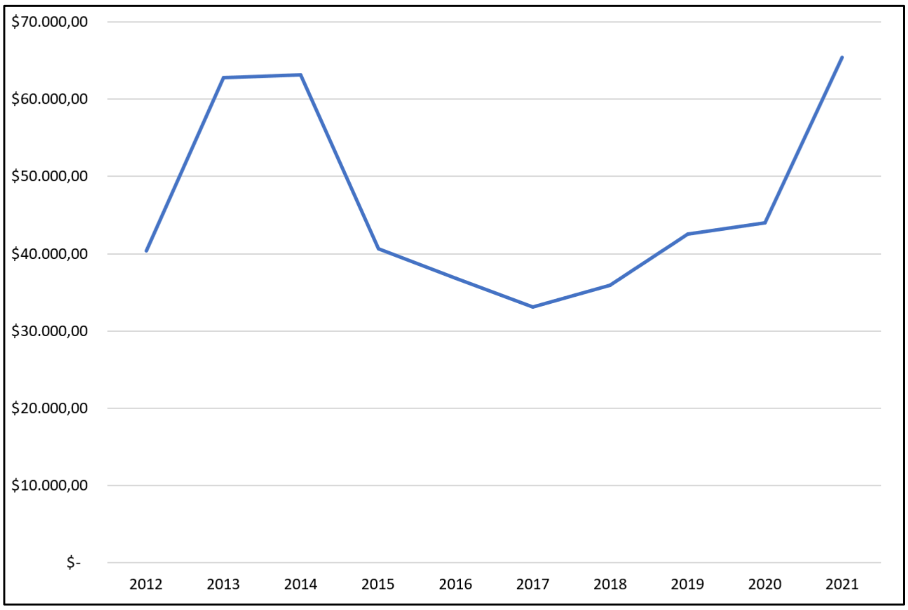


Fig. 2.2 *Imports/Exports trend value in thousands of US $ (2012-2021) of Municipal Waste trade*

Subsequently, an analysis was conducted on the Top-Exporters and Top-Importers that succeeded in the investigated time period[5]. In relation to imports, it is feasible to examine the surrounding circumstances preceding and following a specific occurrence: the imposition of an import prohibition by China in late 2017, which was enforced starting from January 2018. China's "National Sword" policy, which had been responsible for managing more than 50% of the global recyclable waste for the past quarter-century, implemented a ban on the importation of a significant portion of plastics and other materials intended for recycling processors in the country. The decision was made in order to prevent an influx of unsanitary and polluted materials from overwhelming Chinese processing facilities, thereby exacerbating the country's existing environmental concerns. Subsequent to this, the importation of waste materials by China has experienced a substantial decline of over 90%, so instigating a noteworthy transformation in the global recycling processing sites and methodologies (Yale E360, 2019). In agreement with the preceding statement, an examination of the recent importation patterns of leading nations reveals that China, which includes Hong Kong ("China, Hong Kong Special Administrative Region") for economic purposes, consistently holds significant positions on the global stage. Specifically, China accounted for an approximate average of 35% of global municipal waste imports from 2012 to 2016. In the year 2017, there was a noticeable decline in both trade shares and ranking position, although they remained within the top 10. The reason for this can likely be attributed to the announcement of China's garbage import ban in August 2017, which consequently impacted trade during that year. In the year 2018, China and Hong Kong have been excluded from the ranking, thereby indicating the efficacy of the legislative directive.

[5] Programming code in Annex (6.6), *Code for Top-10 Importers and Top-10 Exporters (2012-2021)*

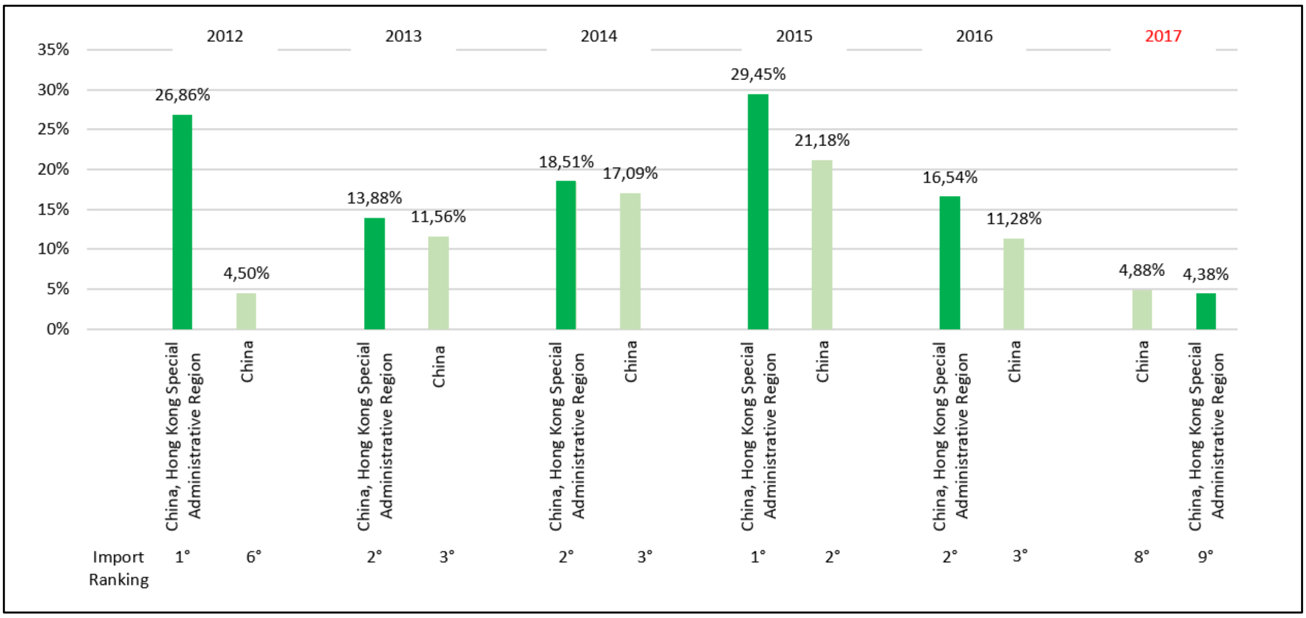


Fig. 2.3 *China and Hong Kong imports share trend (2012-2017) of Municipal Waste trade*

The United States, including Puerto Rico and the US Virgin Islands, emerged as a significant participant in the importation of municipal garbage from 2012 to 2021. During the analyzed period, the United States exhibited an average importation rate of approximately 12% in relation to the global production of municipal waste. In recent years, subsequent to reaching its highest point in 2016 and 2017, there has been a gradual decline resulting in a 6% market share in 2021. One of the contributing factors to this phenomenon can be attributed to the establishment of the Environmental Protection Agency (EPA) in 2017. The aforementioned order has superseded the preexisting regulations pertaining to the import and export of hazardous wastes to and from the United States. Consequently, this measure has effectively discouraged the practice of waste importation and exportation, including municipal garbage (Federal Register, 2016). Nevertheless, it is unsurprising that China and the United States have occupied prominent roles in the importation of this particular trash category. Indeed, both of these nations are among the largest in terms of land area globally, which subsequently grants them ample resources for waste management and landfill capacity. When examining the trend over the specified analysis period, it is advisable to take into account the trajectory of European import values in relation to the global value. The global trade of municipal garbage has experienced significant growth since 2017, with a notable increase observed between 2020 and 2021. This surge has resulted in the attainment of the highest levels recorded throughout the specified timeframe.

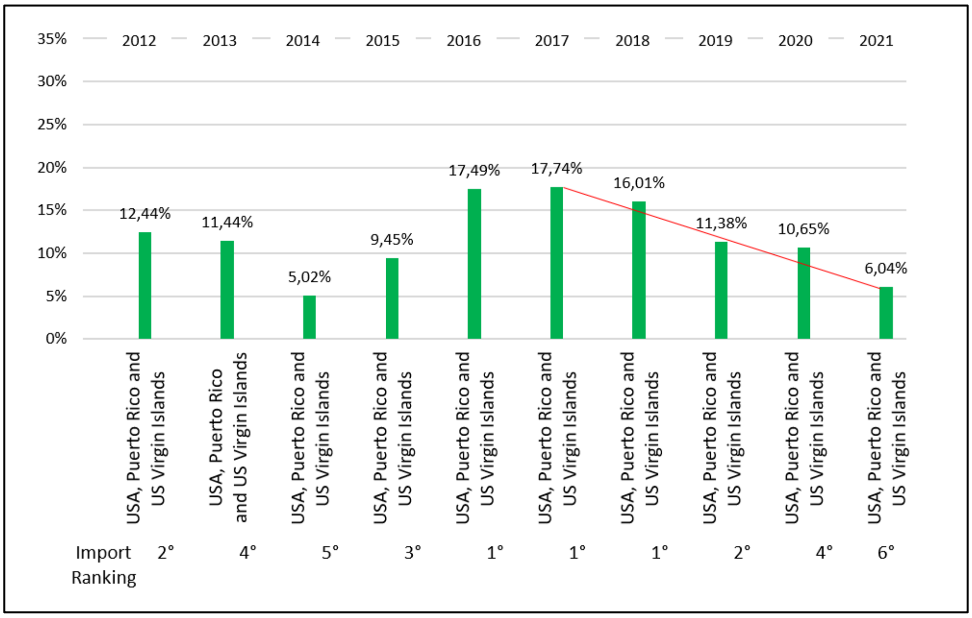


Fig. 2.4 *USA, Puerto Rico, and US Virgin Island imports share trend (2012-2021) of Municipal Waste trade*

Regarding the European Union, the focal point of our examination, it is noteworthy that the data presents a very unexpected outcome. During the specified timeframe, it is noteworthy that European Union member states consistently accounted for an average of approximately 55.49% of global municipal waste imports. This dominance was observed annually, with the exception of the biennium spanning 2014-2015, across the period from 2012 to 2021, when considering the collective data of the diverse EU nations. Furthermore, it has been observed that a number of European nations consistently rank among the top 10 importers, with an average of 7 out of 10 each year. These countries exhibit a substantial proportion of municipal trash trade, despite their comparatively smaller geographical size in comparison to other nations. In the preceding three-year period (2019-2021), Portugal, the Netherlands, and Sweden held the highest positions in the import rankings, with respective import shares of 19.58%, 13.66%, and 25.33%. These countries possess land areas of approximately 92,212 km2, 41,543 km2, and 449,964 km2, which, when combined, amount to roughly 1/15th of the land area of the United States. Undoubtedly, the European Union collectively holds a dominant position in terms of imports.

When conducting a study of the trend throughout the specified period, it is prudent to consider the evolution of the European import value in relation to the worldwide import value. The international trade of municipal waste has experienced a notable surge since 2017, with a particularly significant increase observed between 2020 and 2021, culminating in the highest recorded level throughout the examined timeframe. The European Union has consistently increased its import shares on an annual basis, culminating in a figure of 78.82% in the year 2021. Until the year 2019, the European Union has consistently pursued a trajectory of expansion by progressively augmenting its import shares on an annual basis, culminating in a notable value of 65.18%. In contrast, there has been a decline in shares over the past two years, with a reduction of 60.70% in 2020 and 50.82% in the subsequent year. Nevertheless, the aforementioned upward trajectory should not be deemed unexpected. The Directives under investigation in this study, which were implemented in 2018, have the objective of promoting the recycling of a specific waste category. Consequently, their primary intention is to restrict the exportation of garbage rather than its importation. One possible explanation for the increasing trend of European imports is the observed scarcity of raw materials in recent years. The challenge of locating specific materials and the subsequent financial burden of acquiring them has prompted a growing interest in exploring their potential through waste recycling, which is increasingly recognized as a valuable resource to be utilized.

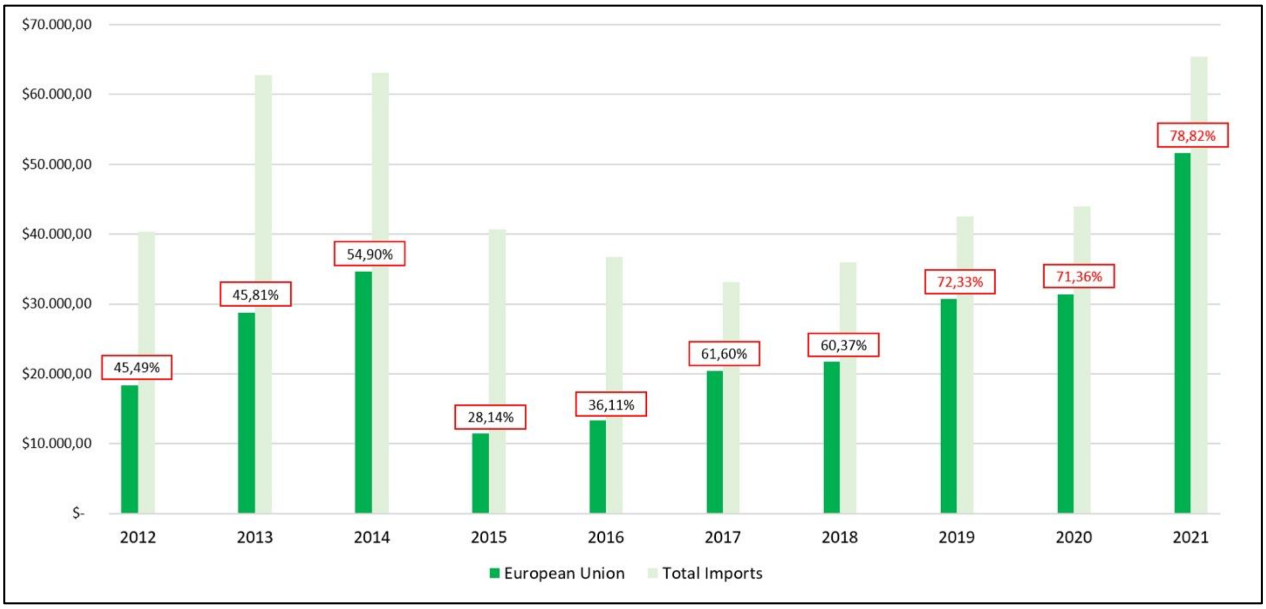


Fig. 2.5 *EU imports share trend (2012-2021) of Municipal Waste trade*

When considering the aspect of exports, it is evident that Japan, Canada, and the UK continuously exhibit prominence among the countries that are frequently placed among the top 10. Furthermore, it is obvious that European countries are strongly represented within this particular category. Japan is well acknowledged on the international stage as a significant participant in the global plastics sector. Notwithstanding its rather modest geographical extent, the nation exhibits a noteworthy population density of 381 inhabitants per square kilometer. Indeed, Japan is positioned as the ninth most densely populated country among nations with populations exceeding 10 million. During the period spanning from 2012 to 2017, it is evident that Japan consistently represented roughly 30% of the aggregate municipal waste exports. To tackle the prevailing trend observed in 2018, the Japanese Ministry of the Environment implemented the "Waste Control Law." This legislation, an amendment to existing laws, was designed to prohibit the exportation of certain categories of hazardous and non-hazardous waste (Japanese Ministry of the Environment, 2018). The discernible consequences of the intervention are seen in Japan's exclusion from the top 10 export rankings since 2019, with trade shares below 3%.

On the other hand, Canada has consistently maintained a prominent position over the whole period under examination. On average, municipal waste constituted slightly over 11% of the total global exports. In the year 2021, there was a notable dip in the percentage, falling below 10%. This decline is the first occurrence of such a decrease in the past ten years, with a recorded value of 5.94%. The successful accomplishment of this outcome can be ascribed to a series of policies enacted by the Canadian government, aimed at improving waste management and promoting the adoption of sustainable behaviors. The Canadian government introduced a legislative proposal in December 2020, referred to as the Canadian Environmental Protection Act (CEPA), aimed at implementing reforms in environmental protection. The primary objective of this reform is to strengthen the existing safeguards for environmental and public health, with a particular focus on the management of hazardous waste. This initiative is outlined in the Canadian Environmental Protection Act (CEPA) of 2020. The Zero Plastic Waste Initiative was launched by the Canadian government in 2021. Its main goal is to reduce the usage of disposable plastics and promote a circular economy by improving recycling and composting methods for waste materials (Plastic Waste Export Regulations, 2021). An essential element of this project involves the enforcement of the Plastic garbage Export Regulations, which aim to limit the transfer of plastic garbage to developing nations (Zero Plastic Waste project, 2021).

In essence, the United Kingdom is subject to a multitude of elements that are duly considered. The present study's analysis was predicated on the hypothetical situation wherein the individual under investigation was neither affiliated with, nor had any prior association with, the European Union. The present study employed a methodology to investigate the prospective consequences of Brexit on the municipal waste industry and the ramifications of European regulations. During the period under examination, barring the year 2012, the United Kingdom consistently maintained a position within the upper echelon of nations in relation to the exportation of municipal waste. This export activity constituted an estimated average of 15% of the global trade in this domain. Notwithstanding the United Kingdom's informal withdrawal from the European Union prior to the prescribed date, it underwent a period of transition until December 31, 2020, wherein it upheld the enforcement of European Union rules and regulations. This phenomena has the potential to provide an explanation for the observed export pattern in recent years. Following a period characterized by an average market share of roughly 6%, the United Kingdom observed a notable surge to 32.3% in 2021, which coincided with its withdrawal from the regulatory framework of the European Union. The waste management legislation enacted by the English government, which encompasses the Circular Economy Act 2020 (European Union Future Relationship Act, 2020) and the 2018 Resources and Waste Strategy for England (Department for Environment, Food & Rural Affairs, 2018), has not produced the expected results within a limited timeframe.

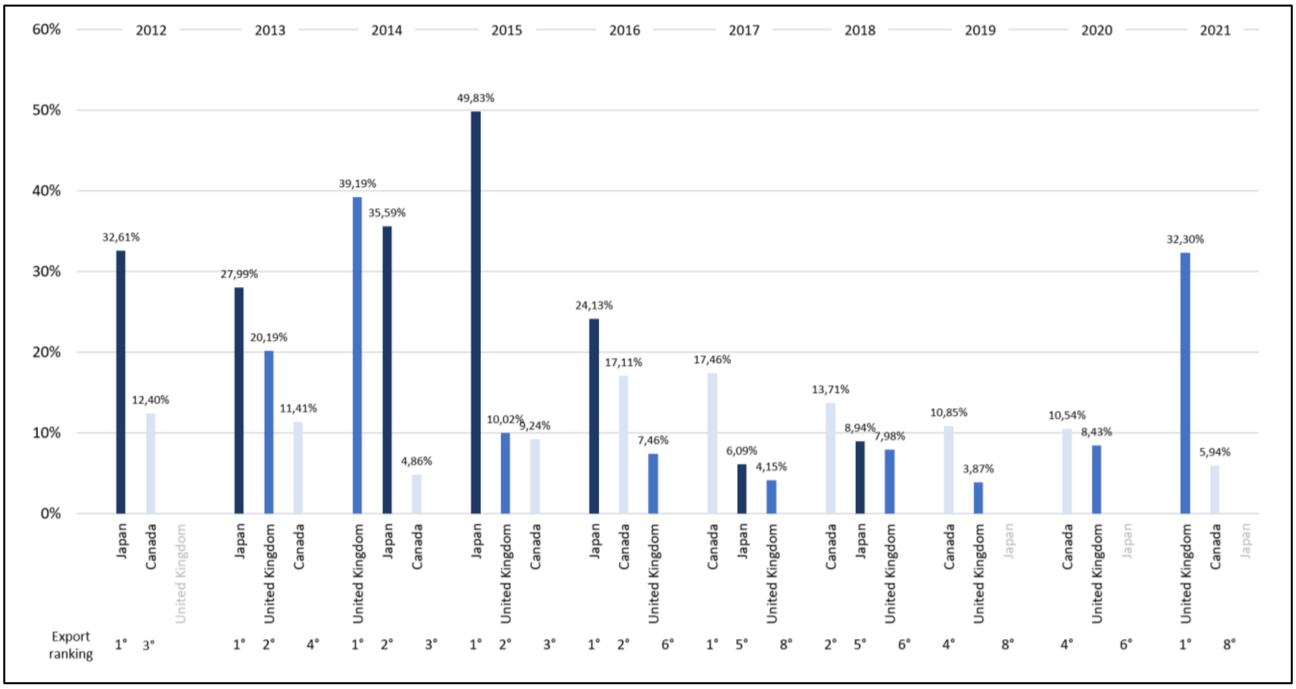


Fig. 2.6 *Japan, Canada, and UK exports share trend (2012-2021) of Municipal Waste trade*

Regarding the European Union, which encompasses its constituent member states, there was a notable increase in exports and imports from 2015 to 2019. During this period, the level of exports reached a peak of 65.18%, representing the highest value observed during the specified timeframe. Nevertheless, during the course of the past two years, there has been a notable decline in the export share, with figures dropping to 60.70% in 2020 and further decreasing to 50.82% in 2021. The observed decline can be attributed to two factors: an increasing recognition of the significance and value of garbage recycling, and the implementation of a set of directives, which are the focus of this research. Indeed, although the European Union introduced the aforementioned regulations in 2018, member states were granted a deadline until 2020 to carry out the process of transposition. Anticipated outcomes are projected to manifest in 2019, as the implementation of the directives, albeit not yet enforced, is expected to serve as a barrier to waste exports. It is evident that the import shares consistently exceed the export shares on an annual basis for this particular waste category. Consequently, it can be concluded that the European Union predominantly functions as an importer rather than an exporter of urban garbage.

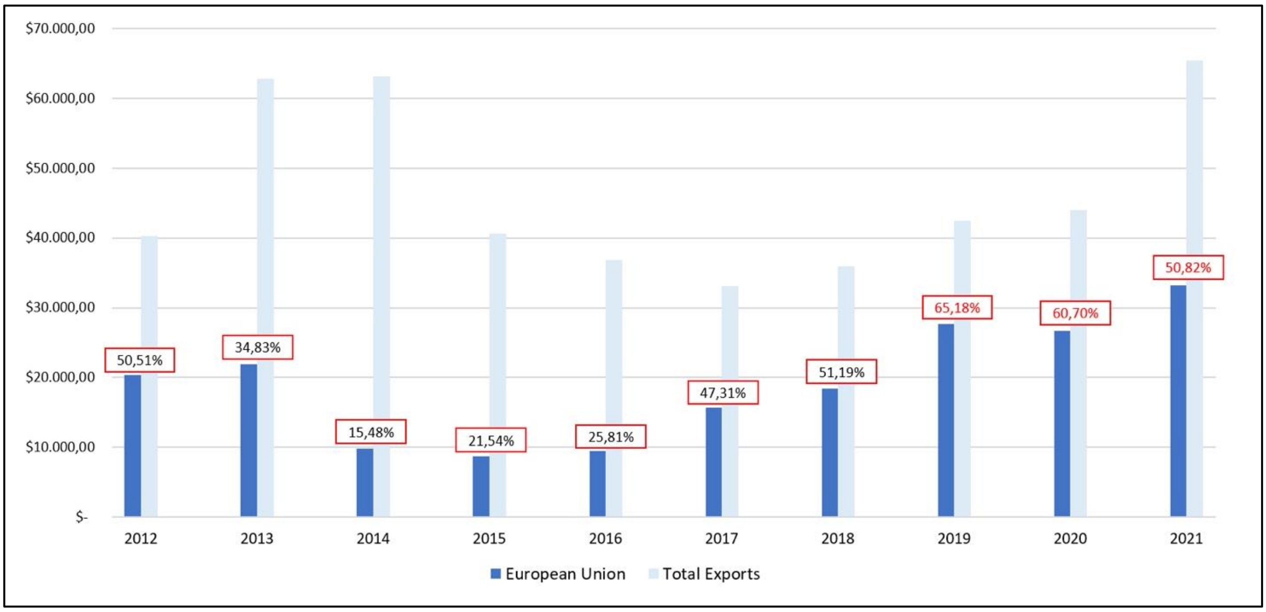


Fig. 2.7 *EU exports share trend (2012-2021) of Municipal Waste trade*

2.3.3 Application of Network Analysis

Following the completion of the dataset description, the Network Analysis was performed as part of this study. The objective was to provide a more precise elucidation of the global trade development between nations and endeavor to assess the impacts of the implementation of Directives 2018/351 and 2018/352 on both European countries and the international community.

To accurately interpret the graphical representations produced by the Network Analysis research, it is crucial to consider that the dimensions of the vertices are contingent upon the quantity of outbound links, which correspond to the number of exporting partners. The vertex sizes have been adjusted on a logarithmic scale solely for the purpose of enhancing the visual depiction and highlighting the disparities between countries. The Fruchterman-Reingold representation, which is widely recognized and commonly used, was employed for the layout of nodes. The Fruchterman-Reingold layout algorithm is a method used to position nodes within a network. It achieves this by simulating a repulsive force that acts between all nodes, as well as an attracting force that acts between nodes that are connected by an arc. The objective is to arrange the vertices in a manner that achieves equilibrium between the repulsive and attractive forces, resulting in a node layout that accurately depicts the network's structure (Analyzing Social Media Networks using NodeXL, 2020). Subsequently, the countries that are members of the European Union were depicted in the color green, while countries within the geographical boundaries of Europe but not affiliated with the EU were represented in gray. American countries were assigned the color red, African countries were denoted by the color orange, Asian countries were indicated by the color yellow, and lastly, countries in Oceania were distinguished by the color blue. This highlights the prominent role played by the continents. The links in question have a directional orientation, originating from the exporting country and terminating at the importing country. These links possess a weighting mechanism, wherein larger transaction values (represented by the variable v) are associated with darker grayscale hues.The user's text is too short to be rewritten academically.

Furthermore, an analysis was conducted to examine the outdegree, indegree, closeness, betweenness, and eigenvector centrality, as well as their trends within the specified period, in order to enhance the depth of the study6. The subsequent years were used as points of reference to delineate the progression of the network. The study focuses on three specific years: 2012, which marks the beginning of the time under examination; 2018, the year when the European regulations (2018/351 and 2018/352) were implemented, warranting an analysis of the circumstances surrounding their approval; and 2021, the final year of the period, allowing for an observation of the directives' impact three years after their introduction.

The analysis of network density, which refers to the likelihood of a connection between two randomly selected states, involved calculating the temporal evolution of this metric across the years under examination[6]. With the exception of a notable increase in density observed in 2015, the overall pattern exhibits a predominantly linear trajectory, characterized by an average value of 3.1%. According to De Benedictis and Tajoli (2011), a network exhibiting a density index below 0.50 signifies its irregularity and incompleteness. This suggests that the majority of countries do not engage in commerce with all other nations, but rather selectively choose their trading partners. The relatively low value observed can be attributed to several factors. These factors include the specific commodity being traded, considerations related to waste management, environmental impact, safety concerns, and regulatory restrictions. These considerations impose limitations on the quantity of waste that can be transferred between entities and the countries eligible for export. Furthermore, given its limited relative exchange value, it is plausible to argue that nations often opt to export waste to neighboring countries rather than engaging in lengthy and economically burdensome transportation, hence reducing the range of potential export destinations for such waste.

[6] Programming code in Annex (6.7), *Code for the Network Analysis (loop 2012-2021) + Density + Centrality Measures*

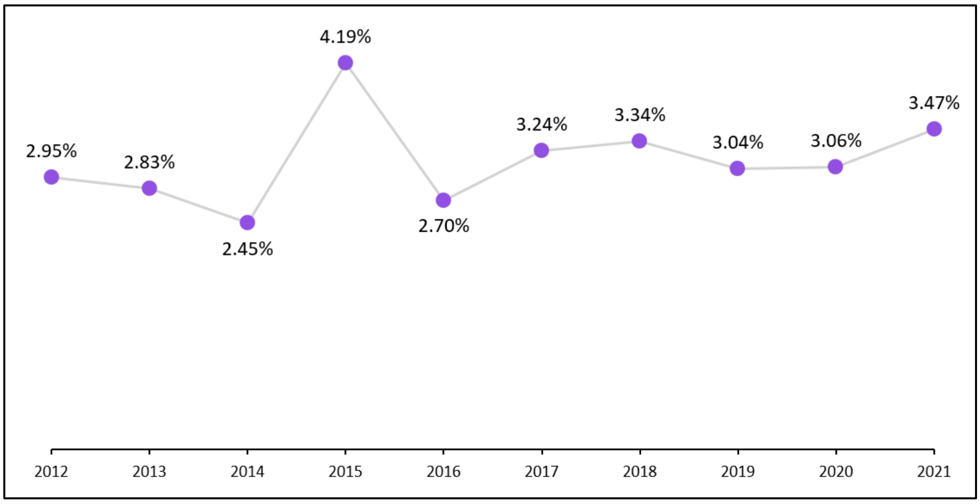


Fig. 2.8 *Network density evolution over the analysis period (2012-2021)*

2.3.4 Key players in the network

Upon analyzing the network data from 2012, it becomes evident that Europe, particularly the European Union, stands out as the continent with the highest representation. Notably, Germany (DEU), Austria (AUT), France (FRA), Italy (ITA), and Belgium (BEL) are prominent among the European Union (EU) member states, while the United Kingdom (GBR), Switzerland (CHE), and Norway (NOR) are notable among the countries outside the EU. The United States (USA) and Japan (JPN) serve as prominent representations of the American and Asian regions, respectively. In general, it may be posited that geographical proximity has a dominant role in shaping the network of international trade, leading countries to engage in trade mostly with their neighboring counterparts. Brazil stands out as an exception among countries that are geographically far from others within the same continent. The potential rationale for its site may be attributed to its function as a hub or sorting center, as it receives waste materials from Italy and Germany and subsequently sends them to Bolivia. Thailand (THA), South Korea (KOR), and China (CHN) exhibit an intriguing trading dynamic with European and other nations. Specifically, Thailand receives municipal waste from the United Kingdom (GBR) and Japan (JPN), while simultaneously exporting a significant quantity, as indicated by the dark gray arrow, to Germany (DEU). South Korea, on the other hand, receives waste from Denmark (DNK), the United Kingdom (GBR), and the United States (US). Lastly, China imports waste from Germany (DEU), the United Kingdom (GBR), and Australia (AUS), while also exporting a considerable amount to France (FRA). This observation highlights the prevailing practice since 2012 of transferring garbage from economically affluent nations to less developed ones, while acknowledging that there are exceptions to this general trend.

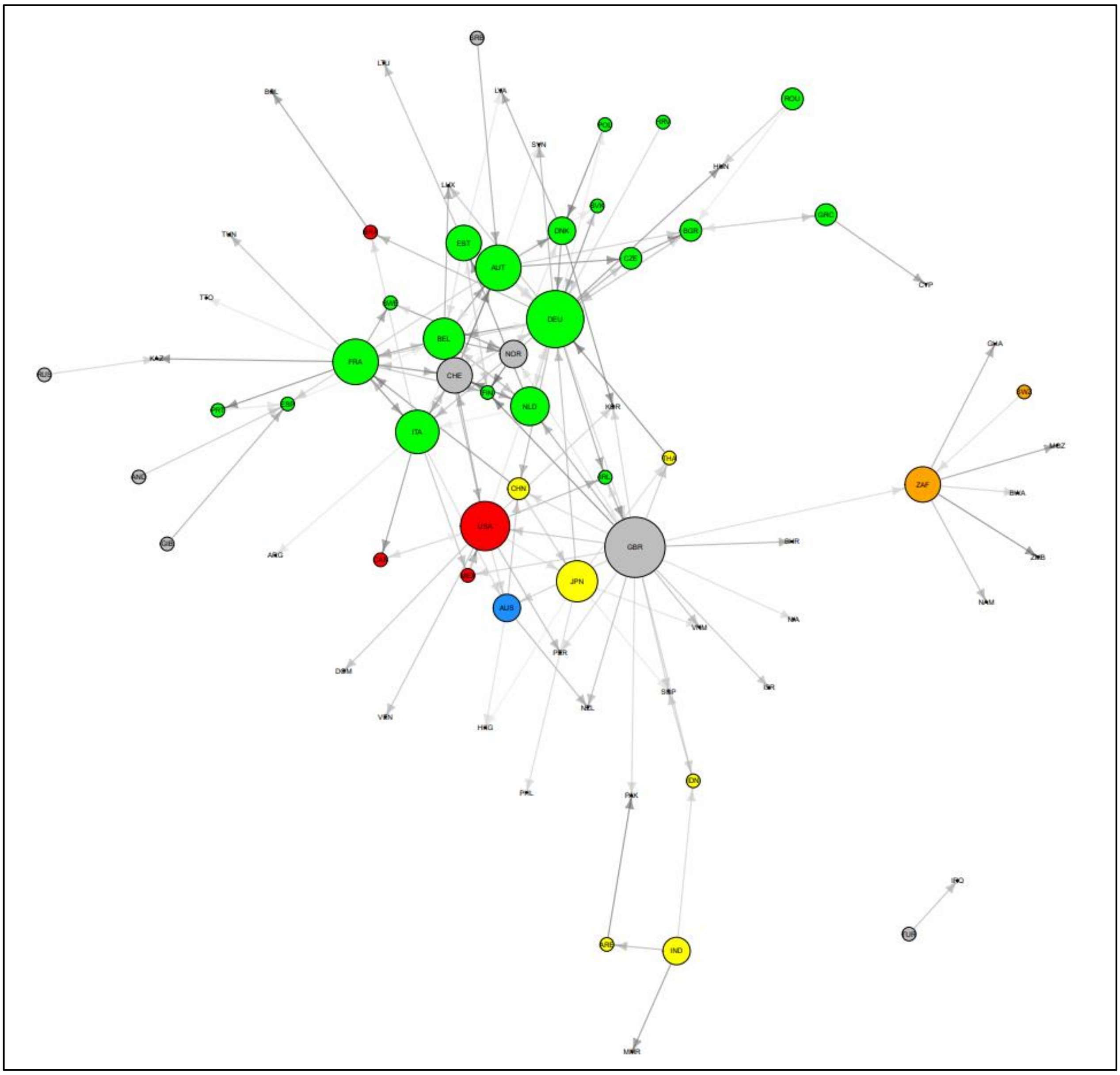


Fig. 2.9 *Representation of municipal waste exchange network (2012)*

Upon examining the network in 2018, it becomes apparent that the European Union found it necessary to introduce Directives 2018/351 and 2018/352 in response to the evolving landscape of municipal trash exchange. Indeed, a majority of the prominent entities may be identified by the color green, including the Netherlands (NLD), Austria (AUT), Italy (ITA), France (FRA), Germany (DEU), and other member states of the European Union. By examining their respective outdegrees, it becomes apparent that all 27 states within the European Union can be readily distinguished. Furthermore, when taking into account Norway (NOR), the United Kingdom (GBR), Switzerland (CHE), and Turkey (TUR), the dominant position of Europe becomes even more apparent. The United States (USA), Japan (JPN), and India (IND) are prominent participants in global trade and have a tendency to export to their respective continents. Conversely, Australia (AUS) mostly engages in exports to Asia, owing to its geographical positioning. Additionally, it is worth mentioning the significant role played by Nicaragua, since it serves as a recipient of garbage originating from all continents.

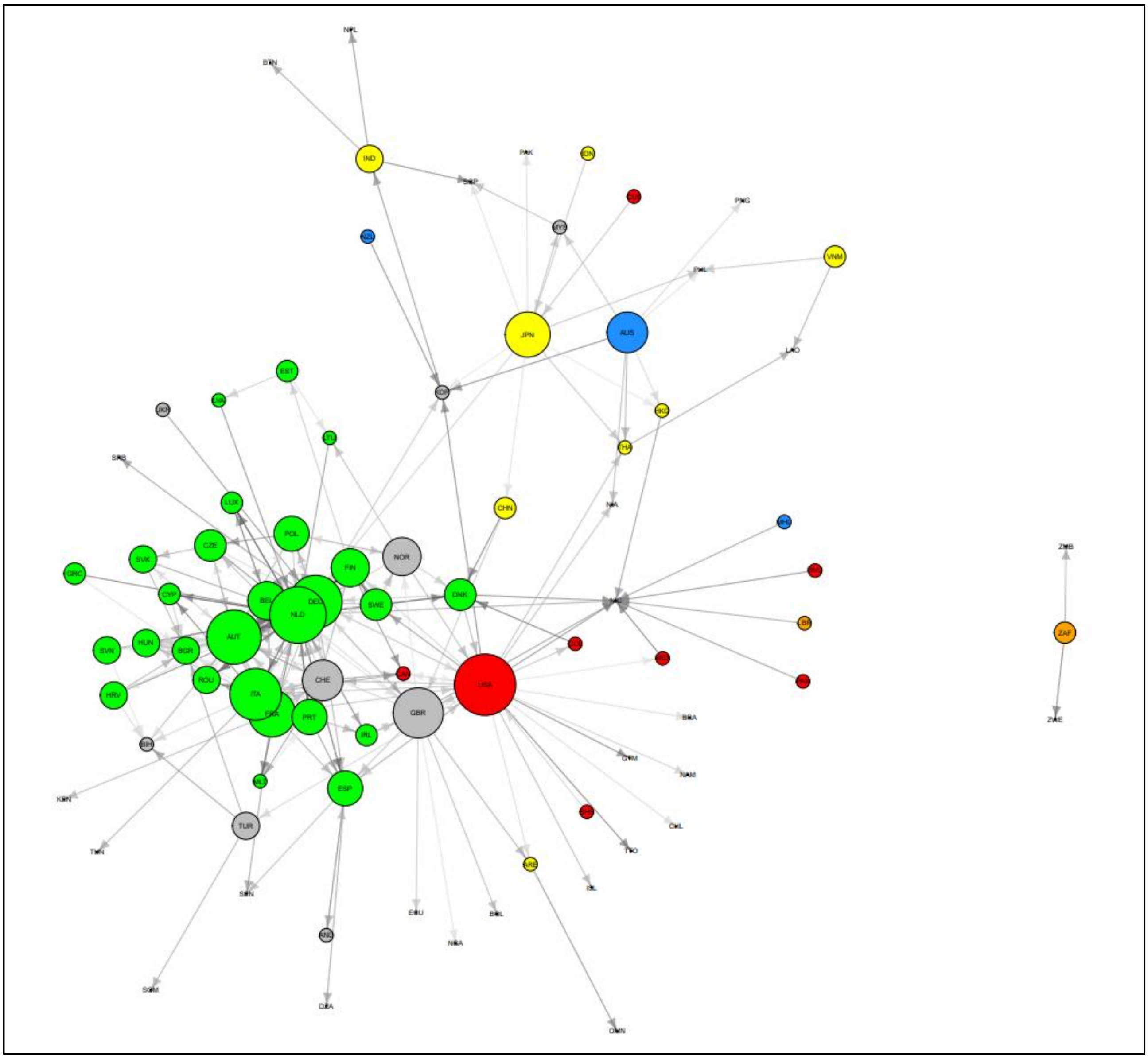


Fig. 2.10 *Representation of municipal waste exchange network (2018)*

In the year 2021, after a span of three years since the implementation of the directives, the macroeconomic landscape bears resemblance to that observed in 2018 and 2012. Europe continues to play a prominent role, with an increasing focus on nations outside the European Union. In contrast, European Union member states, which are still in the process of implementing regulations that have not been fully enforced in all countries, appear to be relatively smaller in size and have fewer export partners. The most notable instances were Slovakia (SVK), Cyprus (CYP), Lithuania (LTU), Portugal (PRT), and Bulgaria (BGR). The latter, specifically, appears to have played a significant role in the importation of municipal waste, as indicated by the presence of many incoming arrows depicted in the graph. Italy (ITA) had a reduction in size, albeit the change was less perceptible, whilst Austria (AUT) witnessed an expansion in its territorial dimensions. Overall, there is a greater level of interconnectedness observed in the global market across different continents. With the exception of the European Union, nearly all states that export garbage have established trade partnerships with at least one country outside their own continents.

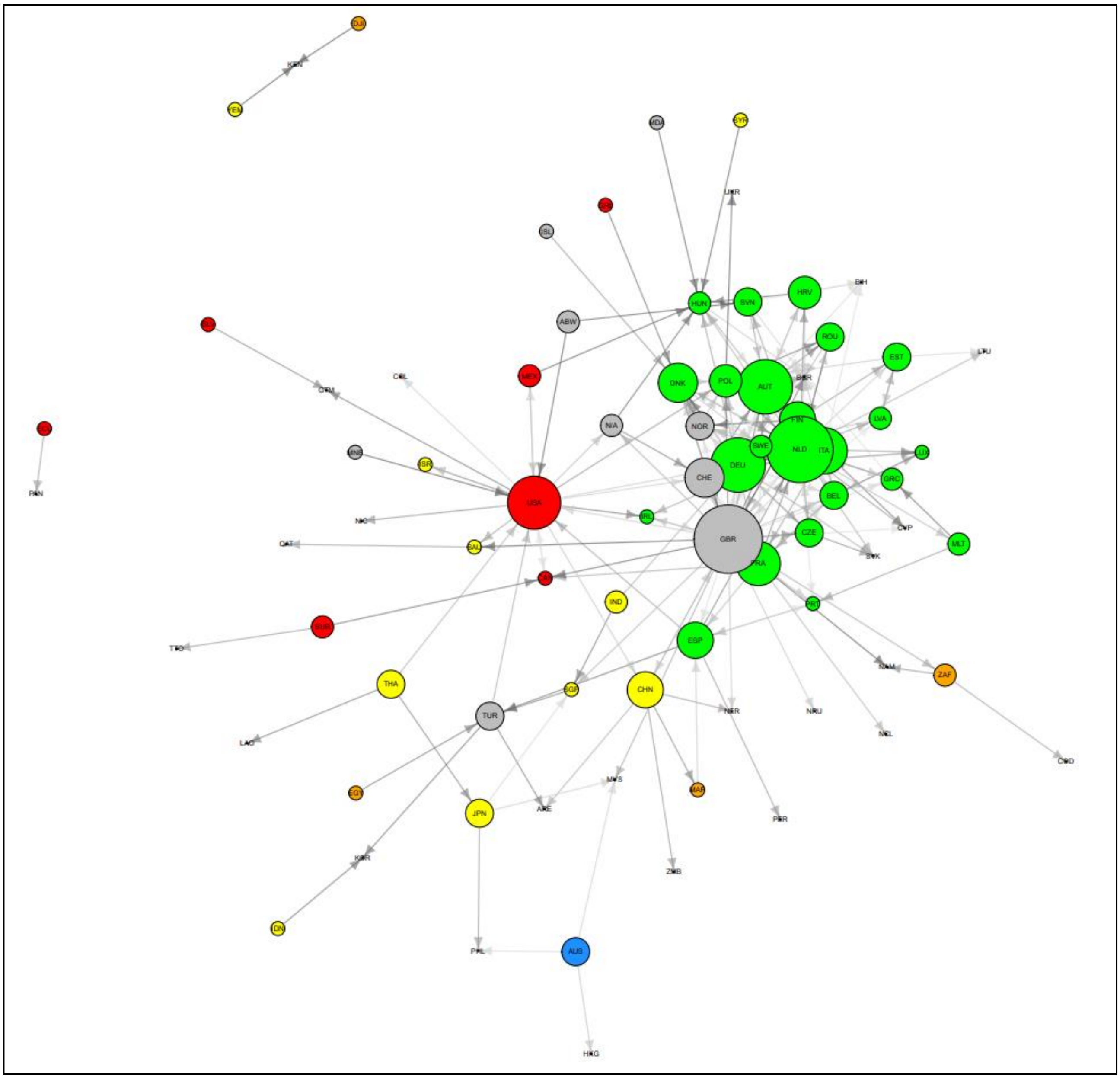


Fig. 2.11 *Representation of municipal waste exchange network (2021)*

2.3.5 Centrality measures

To comprehensively comprehend and evaluate the configuration of the network and ascertain the pivotal nodes within it, the subsequent metrics pertaining to centrality were employed. The utilization of these methods enables the identification of nodes that hold a central position in the network, exerting significant influence over trade propagation, flow dynamics, or network control.

The initial two measures of centrality utilized in the analysis are outdegree and indegree, which are then juxtaposed with the rankings of countries in the top-10 list examined in the preceding chapter. Indeed, it is noteworthy that the top 10 importers or exporters provide insight into the states that have engaged in significant import and export activities in terms of economic value. Additionally, the indegree and outdegree centrality metrics serve as indicators of the number of states from which a country receives imports or to which it sells goods.

In relation to imports, it can be inferred and visually observed in the accompanying figure that there is a notable overlap between the leading importers and the countries exhibiting the highest degree of indegree centrality. Countries that are present in both columns are visually highlighted with color in the graph. Upon examining the data from the three specified reference years, it becomes evident that the influence of the 2018 restrictions remains quite modest. Indeed, the Netherlands (NLD) and Austria (AUT), which are prominent nations in trash importation, experienced growth between 2012 and 2018. However, in 2021, their import figures declined from 27 to 14 for the Netherlands and from 15 to 8 for Austria. Despite these reductions, both countries continue to hold their positions as leading garbage importers. Both Italy (ITA) and France (FRA) were consistently ranked inside the top 10 in both 2012 and 2018. However, it is noteworthy that these countries are absent from the current ranking in 2021.

2012 Top-10 Importers	2012 Top-10 Indegree		2018 Top-10 Importers	2018 Top-10 Indegree		2021 Top-10 Importers	2021 Top-10 Indegree	
1) HKG	DEU	13	1) USA	NLD	27	1) SWE	NLD	14
2) USA	BEL	6	2) SWE	AUT	15	2) DEU	SWE	10
3) ITA	CHE	6	3) NLD	DEU	13	3) LVA	BGR	10
4) DEU	AUT	5	4) AUT	BGR	12	4) CHE	DEU	9
5) BEL	BGR	5	5) PRT	NIC	10	5) NLD	USA	9
6) CHN	FRA	5	6) BGR	USA	8	6) USA	AUT	8
7) SVK	CHN	4	7) KOR	ESP	7	7) BEL	HUN	8
8) AUT	USA	4	8) BEL	BEL	6	8) BIH	POL	8
9) UK	ITA	4	9) FIN	FRA	6	9) ITA	GBR	8
10) BGR	NLD	4	10) SVN	ITA	6	10) AUT	BEL	7
				...	...		...	...
				KOR	5		BIH	4
				SWE	4			

Fig. 2.9 *Comparison of Top-10 countries by import value and Top-10 by indegree centrality*

Regarding exports, the argument exhibits a comparable nature. The countries that rank inside the top 10 in terms of both garbage exported value and export partners continue to be noteworthy due to their vibrant characteristics. The initial aspect that warrants attention pertains to England (GBR). Following the termination of their commitments to the European Union, a notable surge of 240% was observed in their export partnerships for the year 2021. In a broad sense, prominent member states of the European Union, namely Austria (AUT), Germany (DEU), Italy (ITA), and France (FRA), experienced a decline in their export partners throughout the year 2021. However, the Netherlands (NED) diverged from this trend by observing an increase in their export partners. In conclusion, Japan's absence from the list can be attributed to its environmental measures, while the United States continues to uphold its prominent position.

2012: Top-10 Exporters	2012: Top-10 Outdegree		2018: Top-10 Exporters	2018: Top-10 Outdegree		2021: Top-10 Exporters	2021: Top-10 Outdegree	
1) JPN	GBR	20	1) AUT	USA	22	1) GBR	GBR	29
2) NLD	DEU	17	2) CAN	NLD	17	2) DNK	NLD	26
3) CAN	USA	11	3) NOR	AUT	15	3) DEU	AUT	14
4) BEL	AUT	9	4) DEU	DEU	14	4) FRA	DEU	14
5) AUT	FRA	9	5) JPN	ITA	13	5) AUT	USA	13
6) ESP	ITA	8	6) GBR	GBR	12	6) NLD	ITA	9
7) DEU	BEL	7	7) MLT	FRA	10	7) NOR	FRA	8
8) ITA	JPN	7	8) USA	JPN	9	8) CAN	DNK	6
9) EST	NLD	6	9) ROU	AUS	7	9) ITA	CHE	6
10) ROU	EST	5	10) NLD	CHE	7	10) SVN	ESP	5
				...	...			
				NOR	6			

Fig. 2.10 *Comparison of Top-10 countries by export value and Top-10 by outdegree centrality*

Furthermore, the subsequent metric of centrality under consideration is closeness centrality. The metric quantifies the degree of proximity between a given node and all other nodes in a network, based on their topological distance. In the field of network analysis, the concept of "distance" typically pertains to the quantification of steps necessary for a given node to reach another node within the network. The geodesic distance, often known as the great circle distance, refers to the shortest route between two countries, denoted as countries i and j. The following states, within the time frame under consideration in this investigation, exhibited proximity centrality ratings of 1. While nodes do not possess direct connections to every other nodes, they establish connections with them via longer paths that involve intermediate nodes. These pathways may nonetheless enable a node to establish connectivity with all other nodes in the graph, even in the absence of a direct connection. Hence, it is possible for the node to possess a closeness centrality value of 1, as stated by Zhang and Luo (2017). These nations has the potential to serve as significant hubs for garbage disposal activities or facilitate the transportation of waste across other regions. As a result of their advantageous geographical positioning, these entities possess a greater degree of authority over the allocation of waste transportation pathways and pricing mechanisms. Consequently, they exhibit enhanced accessibility to waste markets and wield a heightened level of influence on the operational dynamics of such markets. However, it is important to consider that the importance of neighboring countries in this context is contingent upon various factors, including the quantity and type of trash generated, waste management strategies employed, available infrastructure, and legal limitations. The level of participation and importance of any country in the waste trade will be determined by a unique combination of these factors.

The chart presented below illustrates that the United Arab Emirates (ARE) and Indonesia (IDN) are the sole countries that have consistently held a prominent position in this aspect throughout the years being examined. At a broad level, it can be observed that the countries represented in this context are predominantly from South America and Asia, with limited representation from European Union nations, particularly those with less robust economies. Hence, it may be argued that these nations, who maintain contacts (even if indirect) with all other countries, represent the primary recipients of international municipal trash trade.

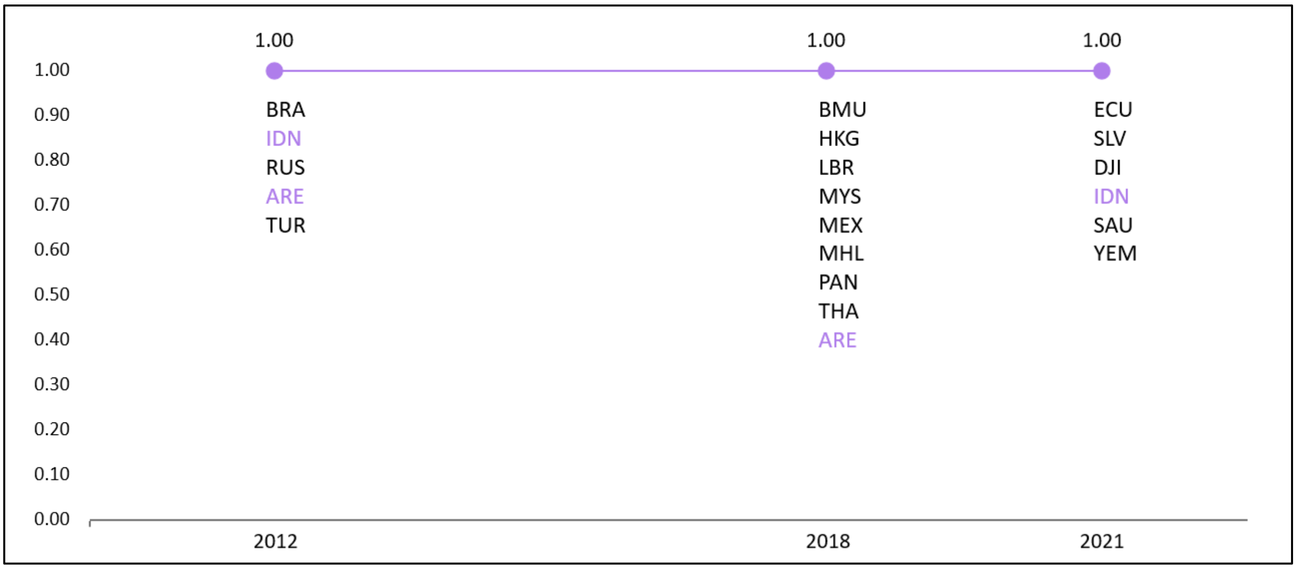


Fig. 2.11 *Top countries by Closeness centrality*

In relation to betweenness centrality, the countries that emerged within the top 5 over the analyzed period were visually represented together with their temporal patterns. These countries include the

United Kingdom (GBR), the Netherlands (NLD), the United States (USA), Germany (DEU), and Belgium (BEL). Countries that exhibit a high degree of betweenness centrality in the domain of trash trade are typically seen as significant due to their pivotal function as connectors or mediators in facilitating communication between other nations involved in waste trade (Zhang & Luo, 2017). In this particular instance, it is noteworthy because, in contrast to closeness centrality, three out of the five entities under consideration are countries that are affiliated with the European Union. This observation underscores the significant influence that our continent continues to exert on the international trade of municipal garbage, even in the year 2021, despite the implementation of regulations in 2018. However, a discernible decline in the betweenness centrality value may be observed for the Netherlands and particularly Germany starting from 2018. This suggests a potential impact of the regulations. It is imperative to bear in mind, nonetheless, that when examining aggregate or sectoral trade flows, this metric appears to be unsuitable for evaluating bilateral trade ties. Therefore, these factors should be approached with caution (De Benedictis, Tajoli, 2014).

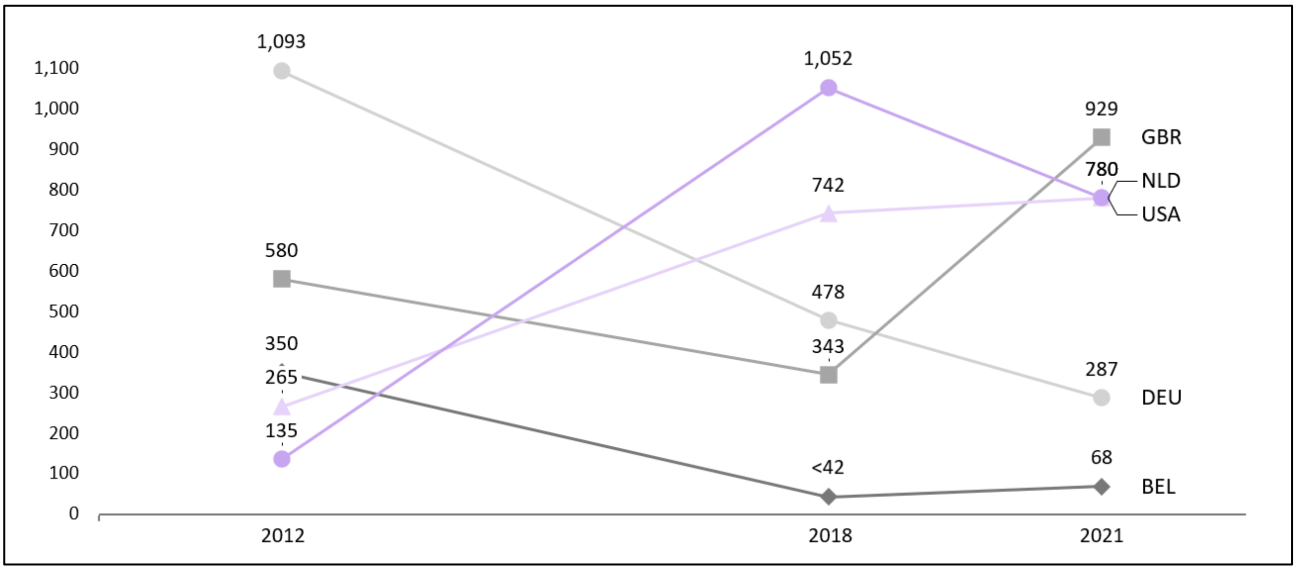


Fig. 2.12 *Top countries by Betweenness centrality*

The countries exhibiting increased eigenvector centrality have been subjected to analysis. The focal point of this centrality measure does not lie in the analysis of the country in question, but rather in the assessment of the centrality of the countries with whom it is associated. Eigenvector centrality is a metric used to assess the significance of a node by considering the significance of its neighboring nodes (De Benedictis, Tajoli, 2014). A nation exhibiting elevated eigenvector centrality is linked to other nations characterized by robust centrality or influence, indicating its advantageous standing within the waste trade network. Establishing connections with prominent nations can offer valuable prospects for accessing crucial markets, resources, and technology within the waste sector (Zhang &

Luo, 2017). Once again, the six countries that held significant roles during the analyzed period, according to this dimension, were identified as the United Kingdom (GBR), the Netherlands (NLD), Austria (AUT), Germany (DEU), Switzerland (CHE), and Belgium (BEL). Similar to the examination of betweenness centrality, the eigenvector analysis also underscores the significance of Europe within the waste exchange framework. Notably, all six prominent countries identified are of European origin, with four out of the six being members of the European Union.

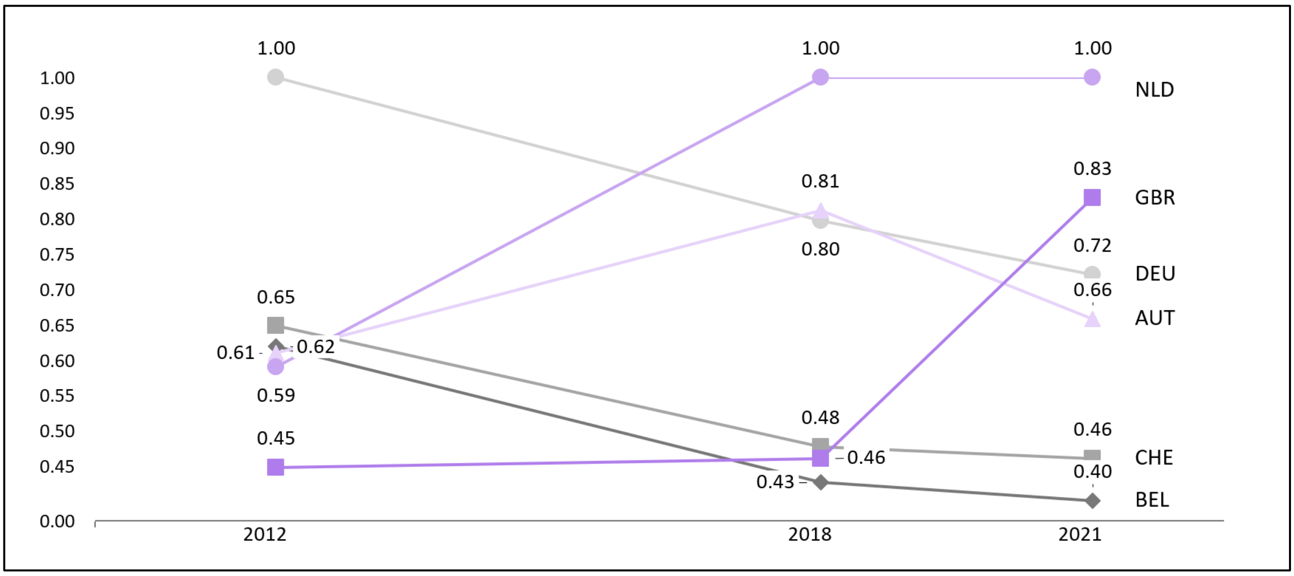


Fig. 2.13 *Top countries by Eigenvector centrality*

2.3.5 Modularity

Subsequently, the utilization of modularity indices was undertaken in order to ascertain potential clusters[7]. Modularity is a quantitative metric used to assess the organization of a network, specifically examining the extent to which the graph can be partitioned into distinct subgroups that exhibit comparable properties and behaviors. Modularity is expected to exhibit higher values within a given community. On the other hand, there will be a limited number of connections between distinct clusters, resulting in a correspondingly reduced level of intensity (Newman, 2006). The graph below illustrates the trajectory of Network Modularity measurements across the observed time period. The clusters were generated utilizing the community detection algorithm known as "Clauset-Newman-Moore". The technique employed in this study is founded on the concept of community detection, which involves the identification of cohesive groups within a graph. Specifically, it utilizes edge

[7] Programming code in Annex (6.8), *Code for the Network Analysis (loop 2012-2021) + Modularity*
Graphic representation in Annex (6.9), *Network graphic representation (modularity version) – 2012*
Graphic representation in Annex (6.10), *Network graphic representation (modularity version) – 2018*
Graphic representation in Annex (6.11), *Network graphic representation (modularity version) – 2021*

centrality measures to assess the importance of connections between pairs of nodes. The concept of modularity is quantified on a scale from -1 to 1, where higher values signify a more distinct partitioning into communities. A modularity value of 0 indicates that the partitioning of the network into distinct communities is not significantly different from what would be anticipated by random chance. According to Clauset, Newman, and Moore (2004), a negative score signifies that the subdivision is performing below the expected level based on chance.

It is evident that the value remains within the range of 0.05 to 0.2. This observation suggests that the network has a little inclination towards cluster formation, while the presence of a distinct or prominent community structure is not readily apparent. Therefore, providing commentary on the graphical outcomes yields limited utility. In a broad sense, the lack of distinct clusters suggests the presence of a highly linked network where all nodes are frequently connected by undirected links.

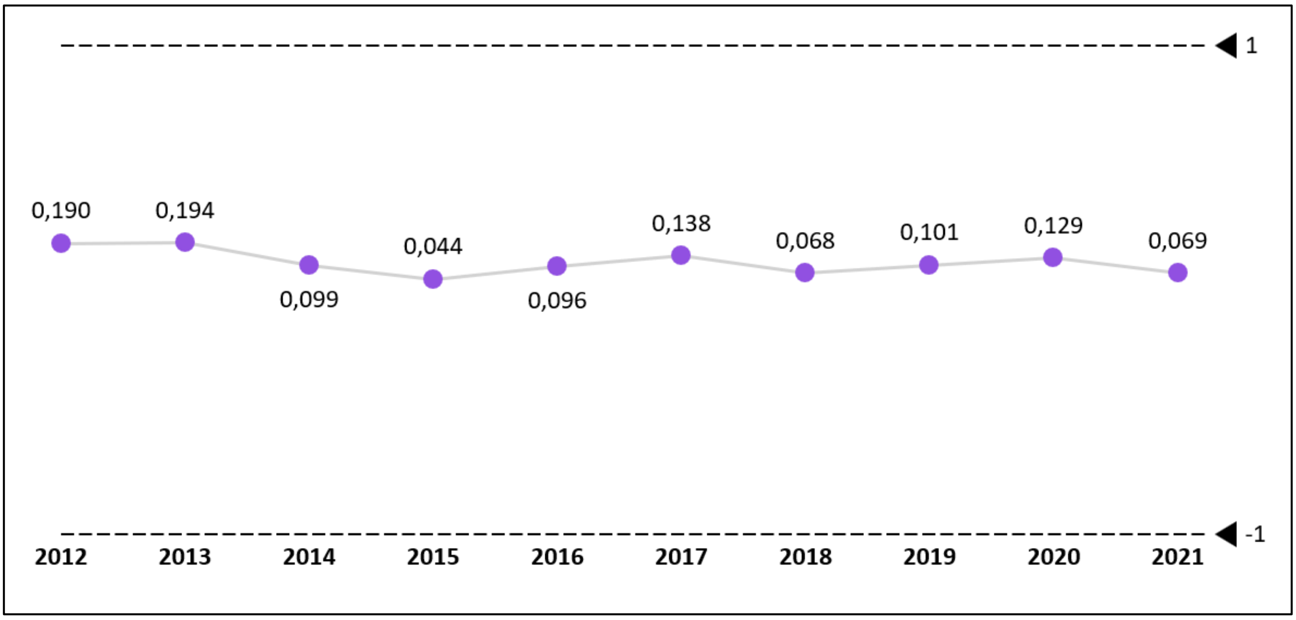


Fig. 2.14 *Network modularity evolution over the analysis period (2012-2021)*

3. Future Work

When contemplating the potential for further exploration and expansion of the aforementioned study, it is imperative to take into account the specific timeframe under examination. Directives 851 and 852 were implemented by the European Union in the year 2018. Hence, it would be intriguing to examine their effects over an extended temporal span, once data beyond the year 2021 becomes accessible. Furthermore, the European Union has granted member states an extended period until 2020 to implement the two directives. Consequently, the ability to contemplate a more extensive timeframe would undoubtedly result in more precise and conclusive findings. Over the course of time, it would also be feasible to ascertain if the ongoing objectives established by the two directives (Sections 1.1.4 and 1.1.5) will be achieved.

Another factor to consider for prospective future investigation is to the specific kind of garbage under examination. In this particular instance, the objective entailed the examination of municipal and packaging trash commerce. However, analogous investigations might be conducted on alternative waste classifications, including the garbage generated from renewable energy sources, which has garnered significant attention in recent times. Furthermore, the implementation of a distinct product code for packaging waste could facilitate a more accurate and targeted examination of this particular product category. The replication of the study can be achieved by modifying the product code that is taken from the database. The aforementioned argument is applicable to any commodity that may be subjected to a similar analytical technique.

In conclusion, from a geographical standpoint, it is possible to direct attention towards an alternative continent or state that has implemented rules akin to those of the European Union's 851 and 852. By examining the contextual factors and resultant impacts of these regulations, a comprehensive analysis can be conducted.

4. Conclusions

The primary aim of this research is to acquire a comprehensive comprehension of the municipal trash exchange market, with a specific focus on examining the underlying reasons, the contextual background of its implementation, and the resultant impacts of EU Directives 851 and 852. The utilization of Network Analysis and the computation of centrality metrics reveal the continued significance of Europe, specifically the European Union, in the worldwide Municipal Waste trade domain. Nevertheless, in the study's most recent data from 2021, a mere three years after the implementation of the aforementioned rules, noticeable shifts can already be observed. It is important to note that the European Union allows member states some degree of discretion in adopting these directives, which contributes to the observed variability. Several nations, like Austria (AUT), Italy (ITA), and France (FRA), have observed a decline in the number of their trading partners, particularly as indicated by outdegree centrality assessments. A contrasting outcome can be noticed when examining the United Kingdom (GBR). Following its withdrawal from the European Union (EU) and the associated obligations, the country has experienced a notable increase in its trading partners, resulting in its ascent to a leading position globally. Looking at measures of betweenness and eigenvector, the discourse does not change: the leading countries remain the European ones but with an overall decreasing trend, with a few exceptions such as the Netherlands (NLD).

Undoubtedly, the objectives established by the aforementioned laws for the years 2025 and 2030 exhibit a commendable level of ambition. By the year 2025, it is imperative that the proportion of municipal garbage that is appropriately processed for the purpose of reuse and recycling reaches a minimum of 55 percent in terms of weight. Furthermore, by 2030, this percentage must increase to a minimum of 60 percent, and by 2035, it must further escalate to a minimum of 65 percent. Japan and China can be regarded as exemplars. Both countries, which have been major players in the global export market, particularly in the field of plastics, have experienced a significant decline in their export rankings over the past decade. This decline can be attributed to the implementation of reforms by their respective central governments between 2017 and 2019. As a result, these countries are no longer among the top exporters in the industry.

In terms of network structure, the nodes exhibit a significant level of interconnectivity, but with a limited number of direct linkages. This observation is supported by the analysis of betweenness centrality measures and the graphical representation of the network. The observed outcomes exhibit diminished density and modularity values, hence posing challenges in identifying grouping patterns beyond those associated with continents and geographical placement.

Understanding the significance of waste as both a valuable resource and a potential hazard to the environment is of utmost importance. It is crucial to establish an efficient and environmentally conscious waste disposal and recycling system. Additionally, exporting waste to countries with inadequate economic and systemic capabilities can have detrimental effects. If garbage is created in a responsible manner and effectively handled, it has the potential to compensate for the scarcity of raw materials that has been prevalent in recent years.

5. Bibliography

1 Aller, C., Ductor, L., & Herrerias, M. (2015). The world trade network and the environment. *Energy Economics*, *52*, 55–68.

2 Alshbili, I., Elamer, A. A., Moustafa, M. W. (2021). Social and environmental reporting, sustainable development and institutional voids: evidence from a developing country. *Corp Soc Responsib Environ Manag*, 28(2), 881–895.

3 Analyzing Social Media Networks with NodeXL. (2020). In Elsevier eBooks. https://doi.org/10.1016/c2018-0-01348-1.

4 A Rogue Historian - Introduction to Network Analysis with R. *Jesse Sadler*. (2017). https://www.jessesadler.com/post/network-analysis-with-r/.

5 Arriola, C., P. Kowalski and F. van Tongeren (2022), Understanding structural effects of COVID-19 on the global economy: First steps.

6 Av, A. (2021, September 2). The reason for the shortage of raw materials and its impact on the industrial sector – blog.AngelVillarroya.com.

7 Aylor, B., DeFauw, M., Gilbert, M., Knizek, C., Lang, N., Koch-Weser, I., & McAdoo, M. (2021). Redrawing the Map of Global Trade.
BCG Global. https://www.bcg.com/publications/2020/redrawing-the-map-of-global-trade.

8 Batagelj, V., Doreian, P., Ferligoj, A., Kejzar, A. (2014). Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution. *Wiley.com*.

9 Bowen, H., Hollander, A., Viaene, J. (2012). Applied International Trade. *Palgrave Macmillan*

10 Butts, C. T. (2008). Social Network Analysis with sna. *Journal of Statistical Software*, *24*(6).

11 Canadian Environmental Protection Act (CEPA) - 2020 Reform Proposal. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/modernizing-cepa.html.

12 Cheng, Y., Masukujjaman, M., Sobhani, F. A., Hamayun, M., & Alam, S. S. (2023). Green Logistics, Green Human Capital, and Circular Economy: The Mediating Role of Sustainable Production. *Sustainability*, *15*(2), 1045.

13 Clauset, A., Newman, M. E. J., & Moore, C. (2004). Finding community structure in very large networks. Physical Review E, 70(6).

14 De Andrade, R. L., & Rêgo, L. C. (2018). The use of nodes attributes in social network analysis with an application to an international trade network. *Physica D: Nonlinear Phenomena*, 491, 249–270.

15 De Benedictis, L., Nenci, S., Santoni, G., Tajoli, L., Vicarelli, C. (2014). Network analysis of world trade using the BACI-CEPII dataset. *Global Economy Journal*.

16 De Benedictis, L., Tajoli, L. (2011). The World trade network. *The World Economy*.

17 Department for Environment, Food & Rural Affairs. (2018). Resources and waste strategy for England. GOV.UK. https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england.

18 Description of BACI. (n.d.). http://www.cepii.fr/DATA_DOWNLOAD/baci/doc/DescriptionBACI.html#country-codes.

19 DIRECTIVES 2018/851 ON WASTE AND 2018/852 ON PACKAGING AND PACKAGING WASTE. (2020, December 21). - www.exssa.com.

20 EUR-Lex - 31994L0062 - EN - EUR-Lex (europa.eu).

21 EUR-Lex - 32006R1013 - EN - EUR-Lex (europa.eu).

22 EUR-Lex - 32008L0098 - EN - EUR-Lex (europa.eu).

23 EUR-Lex - 32018L0851 - EN - EUR-Lex. (europa.eu).

24 EUR-Lex - 32018L0852 - EN - EUR-Lex (europa.eu).

25 Euronews. (2023, January 17). *"This is a true victory for the next generations": EU takes step towards limiting export of waste*. https://www.euronews.com/my-europe/2023/01/17/this-is-a-true-victory-for-the-next-generations-eu-takes-step-towards-limiting-export-of-w.

26 Freeman, L. (2000). *Visualizing Social Networks*.

27 Gaulier, G., Zignago, S. (2010). BACI: International Trade Database at the Product-Level. The 1994-2007 Version. *CEPII Working Paper*.

28 Geissdoerfer, M., Savaget, P., Bocken, N., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768.

29 Guerrero, L. A., Maas, G. G., & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. Waste Management, *33(1)*, 220–232.

30 Gupta, A., Chopra, A. (2023). Solid Waste Management Market Size - By Waste (Municipal, Industrial), By Treatment (Open Dumping, Disposal {Landfill, Recycling, Incineration/Combustion, Composting & AD}), By Material (Paper & Paperboard, Metals, Plastics, Food, Textiles), 2023 - 2032. In Global Market Insights Inc. https://www.gminsights.com/industry-analysis/solid-waste-management-market.

31 Hayes, A. (2022, August 29). What Is Comparative Advantage? *Investopedia*. https://www.investopedia.com/terms/c/comparativeadvantage.asp#:~:text=Comparative%20advantage%20is%20one%20of%20the%20most%20important,foundational%20principle%20in%20the%20theory%20of%20international%20trade.

32 *Hazardous Waste Export-Import Revisions*. (2016, November 28). Federal Register. https://www.federalregister.gov/documents/2016/11/28/2016-27428/hazardous-waste-export-import-revisions.

33 IEA (2021), Net Zero by 2050: A Roadmap for the Global Energy Sector, International Energy Agency, *OECD TRADE POLICY PAPER N°270 (oecd-ilibrary.org).*

34 INSEE (2023), *International price indices of imported raw materials - All commodities* - https://www.insee.fr/en/statistiques/3532430?sommaire=3530679.

35 Japanese Ministry of the Environment (2018). *Waste Control Law* https://www.env.go.jp/en/index.html.

36 Khan, S., Haleem, A. (2021). Investigation of circular economy practices in the context of emerging economies: a CoCoSo approach. *International Journal of Sustainable Engineering*, *14*(3), 357–367.

37 King's Printer of Acts of Parliament. (n.d.). European Union (Future Relationship) Act 2020. https://www.legislation.gov.uk/ukpga/2020/29/contents/enacted.

38 Kobza, N., Schuster, A. M. (2016). Building a responsible Europe - the value of circular economy. *IFAC-PapersOnLine*, *49*(29), 111–116.

39 Kowalski, P. (2023). Raw materials critical for the green transition: Production, international trade and export restrictions.

40 Li, J., Amirkhanian, S. N., Zhang, L., & Feipeng, X. (2019). Life cycle assessment and life cycle cost analysis of recycled solid waste materials in highway pavement: A review. Journal of Cleaner Production, 233, 1182–1206.

41 Menichetti, G., Dall'Asta, L., & Bianconi, G. (2014). Network Controllability Is Determined by the Density of Low In-Degree and Out-Degree Nodes. Physical Review Letters, 113(7).

42 Nelson, M. (2019). Can responding to resource scarcity help your business grow? *www.ey.com*.

43 Newman, M. E. J. (2006). Modularity and community structure in networks. Proceedings of the National Academy of Sciences of the United States of America, 103(23), 8577–8582.

44 OEC (visited 14/04/2023). *Municipal waste* OEC - the Observatory of Economic Complexity. https://oec.world/en/profile/hs/municipal-waste#exporters-importers.

45 Petridis, N., Petridis, K., & Stiakakis, E. (2020). Global e-waste trade network analysis. Resources Conservation and Recycling, 158, 104742.

46 Piling Up: How China's Ban on Importing Waste Has Stalled Global Recycling. (2019). Yale E360. https://e360.yale.edu/features/piling-up-how-chinas-ban-on-importing-waste-has-stalled-global-recycling.

47 Plastic Waste Export Regulations - May 2021 press release:

https://www.canada.ca/en/environment-climate-change/news/2021/05/canada-announces-new-measures-to-reduce-plastic-waste-and-pollution.html.

48 Rauscher, M. (1999). *International Trade in Hazardous Waste*.

49 Stanescu, M. D. (2021). State of the art of post-consumer textile waste upcycling to reach the zero waste milestone. *Environmental Science and Pollution Research*, *28*(12), 14253–14270.

50 Summers, L. H. (1992). Let Them Eat Pollution, *The Economist*, 66.

51 Theis, N. (2021). The Global Trade in E-Waste: A Network Approach. Environmental Sociology, 7(1), 76–89.

52 Tiseo, I., (2023, February 8). Topic: Global waste trade. *Statista*. https://www.statista.com/topics/7943/global-waste-trade/#topicOverview.

53 Topic: Waste generation worldwide. (2023, February 8). *Statista*. https://www.statista.com/topics/4983/waste-generation-worldwide/#topicOverview.

54 Trends in Solid Waste Management. (n.d.). https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html#:~:text=The%20world%20generates%202.01%20billion%20tonnes%20of%20municipal,but%20ranges%20widely%2C%20from%200.11%20to%204.54%20kilograms.

55 *UN Comtrade*. (n.d.). https://comtradeplus.un.org/.

56 *UN Comtrade Wiki - UN Comtrade - UN Statistics Wiki*. (n.d.). https://unstats.un.org/wiki/display/comtrade.

57 Wang, C., Zhao, L., Lim, M. K., Chen, W., & Sutherland, J. W. (2020). Structure of the global plastic waste trade network and the impact of China's import Ban. Resources Conservation and Recycling, 153, 104591.

58 Waste Trade - Zero Waste Europe. (2022, July 27). Zero Waste Europe. https://zerowasteeurope.eu/our-work/eu-policy/waste-management/waste-trade/.

59 What are the main destinations of EU export of waste? - *Products Eurostat News - Eurostat (europa.eu) - Bing*. (n.d.).

60 Yang, M., Chen, L. X., Wang, J., Msigwa, G., Osman, A., Fawzy, S., Rooney, D., & Yap, P. (2022). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters*, *21*(1), 55–80.

61 Zero Plastic Waste Initiative - February 2021 press release: https://www.canada.ca/en/environment-climate-change/news/2021/02/government-of-canada-launches-zero-plastic-waste-initiative-to-address-plastic-pollution-and-protect-the-environment.html.

62 Zero Waste Europe. (2022b, November 28). European Circular Economy Stakeholder Platform. https://circulareconomy.europa.eu/platform/en/dialogue/existing-eu-platforms/zero-waste-europe.

63 Zhang, J., Luo, Y. (2017). Degree Centrality, Betweenness Centrality, and Closeness Centrality in Social Network.

6. Appendix

6.1 Code for Municipal Waste % of total traded (per value)

```
#Create an empty vector to store trade data for product category k=382510
 trade_k <- c()
 #Loop through the csv files from 2012 to 2021
  for (year in 2012:2021) {
 #Read the current csv file
  filename <- paste0("BACI_HS12_Y", year, "_V202301.csv")
  data <- read.csv(filename)
 #Select only the data for product category k=382510
  data_k <- subset(data, k == 382510)
 #Sum the trade value for product category k=382510 for the current year
  trade_k[year-2011] <- sum(data_k$v)
 }
 #Calculate the total trade value from 2012 to 2021 for all product categories
 combined
 total_trade_all <- 0
 #Loop through the csv files from 2012 to 2021
  for (year in 2012:2021) {
 #Read the current csv file
  filename <- paste0("BACI_HS12_Y", year, "_V202301.csv")
  data <- read.csv(filename)
 #Sum the trade value for all product categories for the current year
  total_trade_all <- total_trade_all + sum(data$v)
 }
 #Calculate the trade value from 2012 to 2021 for product category k=382510
 sum_trade_k <- sum(trade_k)
 #Calculate the percentage of the trade value for product category k=382510
 compared to the total trade value from 2012 to 2021 for all product categories
 combined
 percent_trade_k <- sum_trade_k / total_trade_all * 100
 #Print the results
 cat("The total trade value for product category k=382510 from 2012 to 2021 is"
 , sum_trade_k, "thousand USD.\n")

 ## The total trade value for product category k=382510 from 2012 to 2021 is
 464713.7 thousand USD.

 cat("The total trade value from 2012 to 2021 for all product categories combin
ed is", total_trade_all, "thousand USD.\n")

 ## The total trade value from 2012 to 2021 for all product categories combined
is 179500640939 thousand USD.

 cat("The percentage of the trade value for product category k=382510 compared
to the total trade value from 2012 to 2021 for all product categories combined
is", percent_trade_k, "%.")

 ## The percentage of the trade value for product category k=382510 compared to
the total trade value from 2012 to 2021 for all product categories combined is
0.0002588925 %.
```

6.2 Code for Municipal Waste Product Category Ranking (per value) + Comparable

```
# Load the required library
library(dplyr)

# Create an empty list for the data of each year
data_list <- list()

# Read the data for each year and save it in the list
for (year in 2012:2021) {
  filename <- paste0("BACI_HS12_Y", year, "_V202301.csv")
  data_list[[year-2011]] <- read.csv(filename)
}

# Merge the data for all years into a single data frame and calculate the avera
ge trade value for each product category
prod_val_mean <- bind_rows(data_list) %>%
  group_by(k) %>%
  summarize(total_value = sum(v), mean_value = total_value / 10^6) %>%
  arrange(desc(mean_value)) %>%
  mutate(ranking = row_number())

# Find the position of HS code 382510 in the ranking
position <- prod_val_mean %>%
  filter(k == "382510") %>%
  pull(ranking)

# Find the top and bottom 10 product categories surrounding HS code 382510 in t
he ranking
top_bottom_10 <- prod_val_mean %>%
  filter(ranking %in% (position-10):(position+10))

# Print the ranking of product categories by average trade value, the position
of HS code 382510 in the ranking, and the top and bottom 10 product categories
surrounding HS code 382510
cat("Ranking of product categories by average trade value between 2012 and 2021
:\n")
```

6.3 Code for Municipal Waste Product Category Comparable (per weight)

```
# Load the required library
library(dplyr)

# Create an empty data frame to store the total values for each product
total_data <- data.frame(k = character(), sum_q = numeric(), year = numeric(),
stringsAsFactors = FALSE)

# Loop through years 2012 to 2021
for (year in 2012:2021) {
  # Read the data for the current year
  file_name <- paste0("BACI_HS12_Y", year, "_V202301.csv")
  data <- read.csv(file_name)
```

```r
  # Replace NA values in 'q' with 0
  data$q[is.na(data$q)] <- "0"

  # Convert 'q' values to numeric
  data$q <- as.numeric(as.character(data$q))

  # Calculate the sum of values in 'q' for product k=382510
  sum_k_382510 <- sum(data$q[data$k == "382510"], na.rm = TRUE)

  # Calculate the sum of values in 'q' for product k=220590
  sum_k_220590 <- sum(data$q[data$k == "220590"], na.rm = TRUE)

  # Calculate the sum of values in'q' for all products and create a ranking tab
le based on the average weight of trade from 2012 to2021
  ranking_table <- data %>%
    group_by(k) %>%
    summarize(avg_weight = sum(q, na.rm = TRUE) / length(unique(year))) %>%
    arrange(desc(avg_weight))

  # Add the total values for each product to the 'total_data' data frame
  total_data <- rbind(total_data, data.frame(k = ranking_table$k, sum_q = ranki
ng_table$avg_weight, year = year))
}

# Calculate the average weight (sum divided by number of years) for product k=3
82510
avg_weight_k_382510 <- sum(total_data$sum_q[total_data$k == "382510"], na.rm =
TRUE) / length(unique(total_data$year[total_data$k == "382510"]))

# Calculate the average weight (sum divided by number of years) for product k=2
20590
avg_weight_k_220590 <- sum(total_data$sum_q[total_data$k == "220590"], na.rm =
TRUE) / length(unique(total_data$year[total_data$k == "220590"]))

# Print the results
cat("The average weight (sum divided by number of years) for product k=382510 i
s:", avg_weight_k_382510, "\n")

## The average weight (sum divided by number of years) for product k=382510 is:
1351277

cat("The average weight (sum divided by number of years) for product k=220590 i
s:", avg_weight_k_220590, "\n")

## The average weight (sum divided by number of years) for product k=220590 is:
38894.09
```

6.4 Code for Municipal Waste % of all 3825- codes (per value)

```r
# Load the required library
library(dplyr)

# Create an empty list for the data of each year
data_list <- list()
```

```
# Read the data for each year and save it in the list
for (year in 2012:2021) {
  filename <- paste0("BACI_HS12_Y", year, "_V202301.csv")
  data_list[[year-2011]] <- read.csv(filename)
}

# Merge the data for all years into a single data frame and calculate the total
trade value for product categories starting with "3825"
prod_val_total <- bind_rows(data_list) %>%
  filter(as.character(k) %>% startsWith("3825")) %>%
  summarize(total_value = sum(v))

# Calculate the total trade value for category k=382510 between 2012 and 2021
cat_val_total <- bind_rows(data_list) %>%
  filter(k == 382510) %>%
  summarize(total_value = sum(v))

# Calculate the percentage of trade for category k=382510 from 2012 to 2021 rel
ative to the total trade value for all product categories starting with "3825"
from 2012 to 2021
percentage_trade <- (cat_val_total$total_value / prod_val_total$total_value) *
100

# Print the average trade value for product categories starting with "3825" and
the percentage of trade for category k=382510
cat("Average trade value for product categories starting with 3825 between 2012
and 2021: ", prod_val_total$total_value, "\n")

## Average trade value for product categories starting with 3825 between 2012 a
nd 2021:  2454838

cat("Percentage of trade for category k=382510 from 2012 to 2021 relative to th
e total trade value for all product categories starting with 3825: ", percentag
e_trade, "%")
```

6.5 Code for Importers and Exporters (2012-2021)

```
# Definition of the years of interest
years <- 2012:2021

# Initialization of lists for exporters and importers of each year
all_exporters <- list()
all_importers <- list()

# For loop to iterate overall years of interest
for(year in years) {
  # Reading data for the current year
  data <- read.csv(paste0("BACI_HS12_Y", year, "_V202301.csv"))
  # Reading files with country codes
  country_codes <- read.csv("country_codes_V202301.csv")
  # Counting the number of countries
  n_countries <- nrow(country_codes)
  # Extracting country names
  country_names <- country_codes[, "country_name_full"]
```

```
  # Definition of the product of interest (k = 382510)
  k <- 382510
  data_product <- data[data["k"] == k, ]
  # Initialization of the total export/import matrix
  matrix_tot <- data.frame(matrix(0, n_countries, n_countries), row.names = cou
ntry_names)
  colnames(matrix_tot)

  # Nested for loop to iterate over all country pairs
  for(i in 1:nrow(country_codes)) {
    for(j in 1:nrow(country_codes)) {
      # Extracting country codes i and j
      country_code_i <- country_codes[i, "country_code"]
      country_code_j<- country_codes[j, "country_code"]
      # Extracting country names i and j
      country_name_i <- country_names[i]
      country_name_j <- country_names[j]
      # Extracting data corresponding to country pair i and j and product k
      data_subset <- data_product[(data_product["i"] == country_code_i) & (data
_product["j"] == country_code_j), ]
      # Calculating total exports/imports between countries i and j
      tot <- sum(data_subset[,"v"])
      # Updating the total export/import matrix
      matrix_tot[country_name_i, country_name_j] <- tot
    }
  }

  # Calculating total exports/imports for each country
  tot_exports <- t(t(rowSums(matrix_tot)))
  colnames(tot_exports) <- c("tot")
  tot_imports <- t(t(colSums(matrix_tot)))
  colnames(tot_imports) <- c("tot")

  # Extracting all exporters and importers for the current year
  all_exporters_year <- tot_exports[order(tot_exports[,"tot"], decreasing = TRU
E) & tot_exports[, "tot"] != 0, , drop = FALSE]
  all_importers_year <- tot_imports[order(tot_imports[,"tot"], decreasing = TRU
E) & tot_imports[, "tot"] != 0, , drop = FALSE]

  # Adding all exporters and importers to the list of all years
  all_exporters[[year - 2011]] <- all_exporters_year
  all_importers[[year - 2011]] <- all_importers_year

  # Printing all exporters and importers for the current year
  cat(paste0("Exporters for year ", year, ":\n"))
  print(all_exporters_year)
  cat("\n")

  cat(paste0("Importers for year ", year, ":\n"))
  print(all_importers_year)
  cat("\n")
}
```

6.6 Code for Top-10 Importers and Top-10 Exporters (2012-2021)

```
# Definition of the years of interest
years <- 2012:2021

# Initialization of the lists for the top importers and exporters for each year
all_top_exporters <- list()
all_top_importers <- list()

# For loop to iterate over all the years of interest
for(year in years) {

  # Reading the data for the current year
  data <- read.csv(paste0("BACI_HS12_Y", year, "_V202301.csv"))

  # Reading the file with the country codes
  country_codes <- read.csv("country_codes_V202301.csv")

  # Counting the number of countries
  n_countries <- nrow(country_codes)

  # Extracting the names of the countries
  country_names <- country_codes[, "country_name_full"]

  # Definition of the product of interest (k = 382510)
  k <- 382510
  data_product <- data[data["k"] == k, ]

  # Initialization of the total matrix of exports/imports
  matrix_tot <- data.frame(matrix(0, n_countries, n_countries), row.names = cou
ntry_names)
  colnames(matrix_tot) <- country_names

  # Nested for loop to iterate over all the country pairs
  for(i in 1:nrow(country_codes)) {
    for(j in 1:nrow(country_codes)) {

      # Extraction of the country codes i and j
      country_code_i <- country_codes[i, "country_code"]
      country_code_j <- country_codes[j, "country_code"]

      # Extraction of the names of the countries i and j
      country_name_i <- country_names[i]
      country_name_j <- country_names[j]

      # Extraction of the data corresponding to the country pair i and j and th
e product k
      data_subset <- data_product[(data_product["i"] == country_code_i) & (data
_product["j"] == country_code_j), ]

      # Calculation of the total exports/imports between countries i and j
      tot <- sum(data_subset[,"v"])

      # Updating the total matrix of exports/imports
      matrix_tot[country_name_i, country_name_j] <- tot
```

```
    }
  }

  # Calculation of the total exports/imports for each country
  tot_exports <- t(t(rowSums(matrix_tot)))
  colnames(tot_exports) <- c("tot")
  tot_imports <- t(t(colSums(matrix_tot)))
  colnames(tot_imports) <- c("tot")

  # Extraction of the top 10 importers and exporters for the current year
  top_exporters <- tot_exports[order(tot_exports[,"tot"], decreasing = TRUE), ,
drop = FALSE][1:10, , drop = FALSE]
  top_importers <-tot_imports[order(tot_imports[,"tot"], decreasing = TRUE), ,
drop = FALSE][1:10, , drop= FALSE]

  # Addition of the top 10 importers and exporters to the list for all years
  all_top_exporters[[year - 2011]] <- top_exporters
  all_top_importers[[year - 2011]] <- top_importers

  # Printing the top 10 importers and exporters for the current year
  cat(paste0("Top 10 importers for year ", year, ":\n"))
  print(top_importers)
  cat("\n")

  cat(paste0("Top 10 exporters for year ", year, ":\n"))
  print(top_exporters)
  cat("\n")
}
```

6.7 Code for the Network Analysis (loop 2012-2021) + Density + Centrality Measures

```
# Load the necessary libraries
library(igraph)

##
## Attaching package: 'igraph'

## The following objects are masked from 'package:stats':
##
##     decompose, spectrum

## The following object is masked from 'package:base':
##
##     union

# Load the country data
country_codes <- read.csv("country_codes_V202301.csv", stringsAsFactors = FALSE
)

# Load the product data
product_codes <- read.csv("product_codes_HS12_V202301.csv", stringsAsFactors =
FALSE)

# Set the product category of interest
k_waste <- "382510"
```

```
# Create an empty list for plots
plots <- list()

# Create an empty list for densities
densities <- list()

# Iterate through the years from 2012 to 2021
for (year in 2012:2021) {

  # Construct the data file name for the current year
  filename <- paste0("BACI_HS12_Y", year, "_V202301.csv")

  # Load the data for the current year
  data <- read.csv(filename)

  # Select only the data for the product category of interest
  data_k <- subset(data, k == k_waste)

  # Select only the data for exporting and importing countries of the product o
f interest
  data_k_ij <- subset(data_k, i %in% country_codes$country_code & j %in% countr
y_codes$country_code)

  # Create a directed graph for the current year
  graph <- graph_from_data_frame(data_k_ij[, c("i", "j", "v")])

  # Set the node names as ISO 3DIGIT country codes
  V(graph)$name <- country_codes$iso_3digit_alpha[match(V(graph)$name, country_
codes$country_code)]

  # Add ISO 3 DIGIT code as node labels
  V(graph)$label <- V(graph)$name

  # Set node labels to bold, size 1.2, and color black
  V(graph)$label.font <- 2
  V(graph)$label.cex <- 1.2
  V(graph)$label.color <- "black"

  # Assign colors to nodes based on the continent they belong to
  eu_countries <- c("AUT", "BEL", "BGR", "CYP", "CZE", "DEU", "DNK", "ESP", "ES
T", "FIN", "FRA", "GRC", "HRV", "HUN", "IRL", "ITA", "LTU", "LUX", "LVA", "MLT"
, "NLD", "POL", "PRT", "ROU", "SVK", "SVN", "SWE")
  europe_countries <- c("ALB", "AND", "ARM", "AZE", "BIH", "BLR", "CHE", "GEO",
"ISL", "KAZ", "LIE", "MDA", "MCO", "MKD","MNE", "NOR", "RUS", "SMR", "SRB", "TU
R", "UKR")
  asia_countries <- c("AFG", "ARE", "BGD", "BHR", "BRN", "BTN", "CHN", "HKG", "
IDN", "IND", "IRN", "IRQ", "ISR", "JPN", "JOR", "KWT", "KGZ", "LAO", "LBN", "LK
A", "MAC", "MDV", "MNG", "MMR", "NPL", "OMN", "PAK", "PHL", "PRK", "QAT", "SAU"
, "SGP", "SYR", "THA", "TJK", "TKM", "TLS", "ARE", "UZB", "VNM", "YEM")
  america_countries <- c("ATG", "ARG", "BHS", "BRB", "BLZ", "BMU", "BOL", "BRA"
, "CAN", "CHL", "COL", "CRI", "CUB", "DMA", "DOM", "ECU", "SLV", "GRL", "GRD",
"GLP", "GTM", "HTI", "HND", "JAM", "MTQ", "MEX", "SPM", "MSR", "NIC", "PAN", "P
RY", "PER", "PRI", "KNA", "LCA", "VCT", "SUR", "TTO", "TCA", "USA", "URY", "VEN
")
```

```
  oceania_countries <- c("ASM", "AUS", "COK", "FJI", "PYF", "GUM", "KIR", "MHL"
, "FSM", "NRU", "NCL", "NZL", "NIU", "NFK", "MNP", "PLW", "PNG", "PCN", "WSM",
"SLB", "TKL", "TON", "TUV", "VUT", "WLF")
  africa_countries <- c("DZA", "AGO", "BEN", "BWA", "BFA", "BDI", "CMR", "CPV",
"CAF", "TCD", "COM", "COD", "DJI", "EGY", "GNQ", "ERI", "ETH", "GAB", "GMB", "G
HA", "GIN", "GNB", "CIV", "KEN", "LSO", "LBR", "LBY", "MDG", "MWI", "MLI", "MRT
", "MUS", "MYT", "MAR", "MOZ", "NAM", "NER", "NGA", "STPierre and Miquelon", "S
HN", "SYC", "SLE", "SOM", "ZAF", "SSD", "SDN", "SWZ", "TZA", "TGO", "TUN", "UGA
", "ESH", "ZMB", "ZWE")
  other_countries <- setdiff(country_codes$iso_3digit_alpha, c(eu_countries, eu
rope_countries, asia_countries, america_countries, oceania_countries, africa_co
untries))

  # Set node color based on the continent
  V(graph)$color <- ifelse(V(graph)$name %in% eu_countries, "green",
                           ifelse(V(graph)$name %in% europe_countries, "gray",
                                  ifelse(V(graph)$name %in% asia_countries, "ye
llow",
                                         ifelse(V(graph)$name %in% america_coun
tries, "red",
                                                ifelse(V(graph)$name %in% ocean
ia_countries, "dodgerblue",
                                                       ifelse(V(graph)$name %in
% africa_countries, "orange", "gray"))))))

  # Set node size based on the out-degree of nodes
  out_deg_cen <- degree(graph, mode = "out")
  V(graph)$size <- log10(out_deg_cen + 1) * 9

  # Set link color in grayscale based on the value of v
  E(graph)$color <- gray.colors(length(E(graph)$v), alpha = 0.6)[rank(E(graph)$
v)]

  # Set link width to 2
  E(graph)$width <- 2

  # Set the name of the graph as "Network <year>"
  name <- paste0("Network ", year)

  # Add the graph to the list of plots
  plots[[name]] <- graph

  # Calculate the density of the graph
  density <- edge_density(graph)

  # Add density to the list of densities
  densities[[name]] <- density

  # Set the size of the figure and draw the graph with the Fruchterman Reingold
layout
  set.seed(12345)
  pdf(paste0("graph", year, ".pdf"), width = 20, height = 20)
  plot(graph, layout = layout_with_fr,
       vertex.label= V(graph)$label,
       vertex.label.cex = 0.7,
```

```
       vertex.label.family = "sans",
       vertex.label.font = 10,
       vertex.label.color = "black",
       vertex.size = V(graph)$size,
       vertex.color = V(graph)$color,
       edge.width = E(graph)$width,
       edge.color = E(graph)$color,
       main = name)

  # End the figure
  dev.off()

}

# Print the densities to the screen
for (i in 1:length(densities)) {
  cat(names(densities[i]), ": ", round(densities[[i]], 4), "\n")
}
```

6.8 Code for the Network Analysis (loop 2012-2021) + Modularity

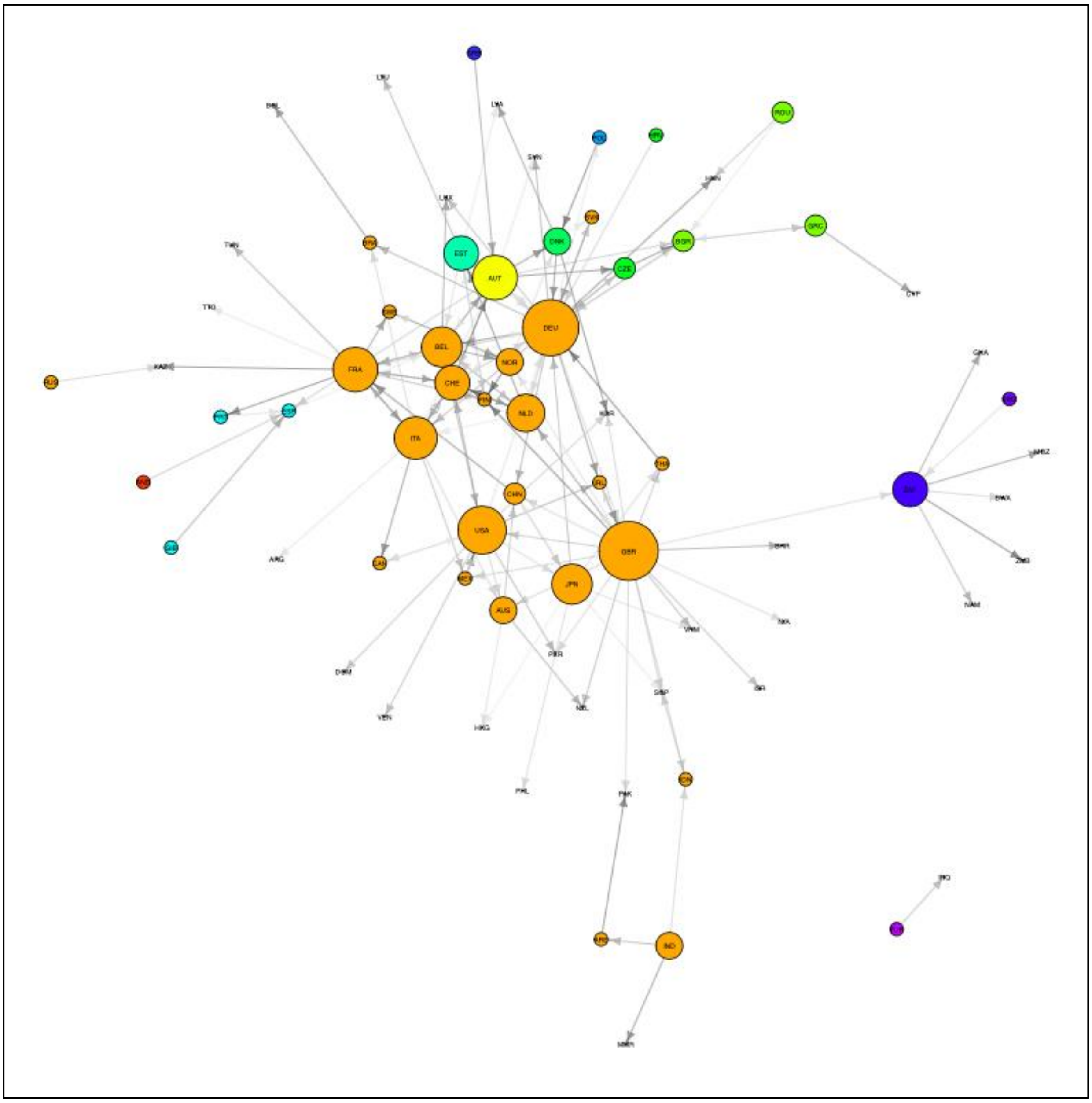
```
# Load the necessary libraries
library(igraph)

##
## Attaching package: 'igraph'

## The following objects are masked from 'package:stats':
##
##     decompose, spectrum

## The following object is masked from 'package:base':
##
##     union

# Load country data
country_codes <- read.csv("country_codes_V202301.csv", stringsAsFactors = FALSE
)

# Load product data
product_codes <- read.csv("product_codes_HS12_V202301.csv", stringsAsFactors =
FALSE)

# Set the product category of interest
k_waste <- "382510"

# Create an empty list for plots
plots <- list()

# Create an empty list for densities
densities <- list()

# Create an empty list for modularities
modularities <- list()
```

```
# Iterate through the years from 2012 to 2021
for (year in 2012:2021) {

  # Construct the data file name for the current year
  filename <- paste0("BACI_HS12_Y", year, "_V202301.csv")

  # Load data for the current year
  data <- read.csv(filename)

  # Select only data for the product category of interest
  data_k <- subset(data, k == k_waste)

  # Select only data for exporting and importing countries of the product of in
terest
  data_k_ij <- subset(data_k, i %in% country_codes$country_code & j %in% countr
y_codes$country_code)

  # Create a directed graph for the current year
  graph <- graph_from_data_frame(data_k_ij[, c("i", "j", "v")])

  # Set node names as ISO 3DIGIT country codes
  V(graph)$name <- country_codes$iso_3digit_alpha[match(V(graph)$name, country_
codes$country_code)]

  # Add ISO 3 DIGIT code as node labels
  V(graph)$label <- V(graph)$name

  # Set node labels to bold, size 1.2, and color black
  V(graph)$label.font <- 2
  V(graph)$label.cex <- 1.2
  V(graph)$label.color <- "black"

  # Assign colors to nodes based on the continent they belong to
  eu_countries <- c("AUT", "BEL", "BGR", "CYP", "CZE", "DEU", "DNK", "ESP", "ES
T", "FIN", "FRA", "GRC", "HRV", "HUN", "IRL", "ITA", "LTU", "LUX", "LVA", "MLT"
, "NLD", "POL", "PRT", "ROU", "SVK", "SVN", "SWE")
  europe_countries <- c("ALB", "AND", "ARM", "AZE", "BIH", "BLR", "CHE", "GEO",
"ISL", "KAZ", "LIE", "MDA", "MCO", "MKD","MNE", "NOR", "RUS", "SMR", "SRB", "TU
R", "UKR")
  asia_countries <- c("AFG", "ARE", "BGD", "BHR", "BRN", "BTN", "CHN", "HKG", "
IDN", "IND", "IRN", "IRQ", "ISR", "JPN", "JOR", "KWT", "KGZ", "LAO", "LBN", "LK
A", "MAC", "MDV", "MNG", "MMR", "NPL", "OMN", "PAK", "PHL", "PRK", "QAT", "SAU"
, "SGP", "SYR", "THA", "TJK", "TKM", "TLS", "ARE", "UZB", "VNM", "YEM")
  america_countries <- c("ATG", "ARG", "BHS", "BRB", "BLZ", "BMU", "BOL", "BRA"
, "CAN", "CHL", "COL", "CRI", "CUB", "DMA", "DOM", "ECU", "SLV", "GRL", "GRD",
"GLP", "GTM", "HTI", "HND", "JAM", "MTQ", "MEX", "SPM", "MSR", "NIC", "PAN", "P
RY", "PER", "PRI", "KNA", "LCA", "VCT", "SUR", "TTO", "TCA", "USA", "URY", "VEN
")
  oceania_countries <- c("ASM", "AUS", "COK", "FJI", "PYF", "GUM", "KIR", "MHL"
, "FSM", "NRU", "NCL", "NZL", "NIU", "NFK", "MNP", "PLW", "PNG", "PCN", "WSM",
"SLB", "TKL", "TON", "TUV", "VUT", "WLF")
  africa_countries <- c("DZA", "AGO", "BEN", "BWA", "BFA", "BDI", "CMR", "CPV",
"CAF", "TCD", "COM", "COD", "DJI", "EGY", "GNQ", "ERI", "ETH", "GAB", "GMB", "G
HA", "GIN", "GNB", "CIV", "KEN", "LSO", "LBR", "LBY", "MDG", "MWI", "MLI", "MRT
", "MUS", "MYT", "MAR", "MOZ", "NAM", "NER", "NGA", "STPierre and Miquelon", "S
```

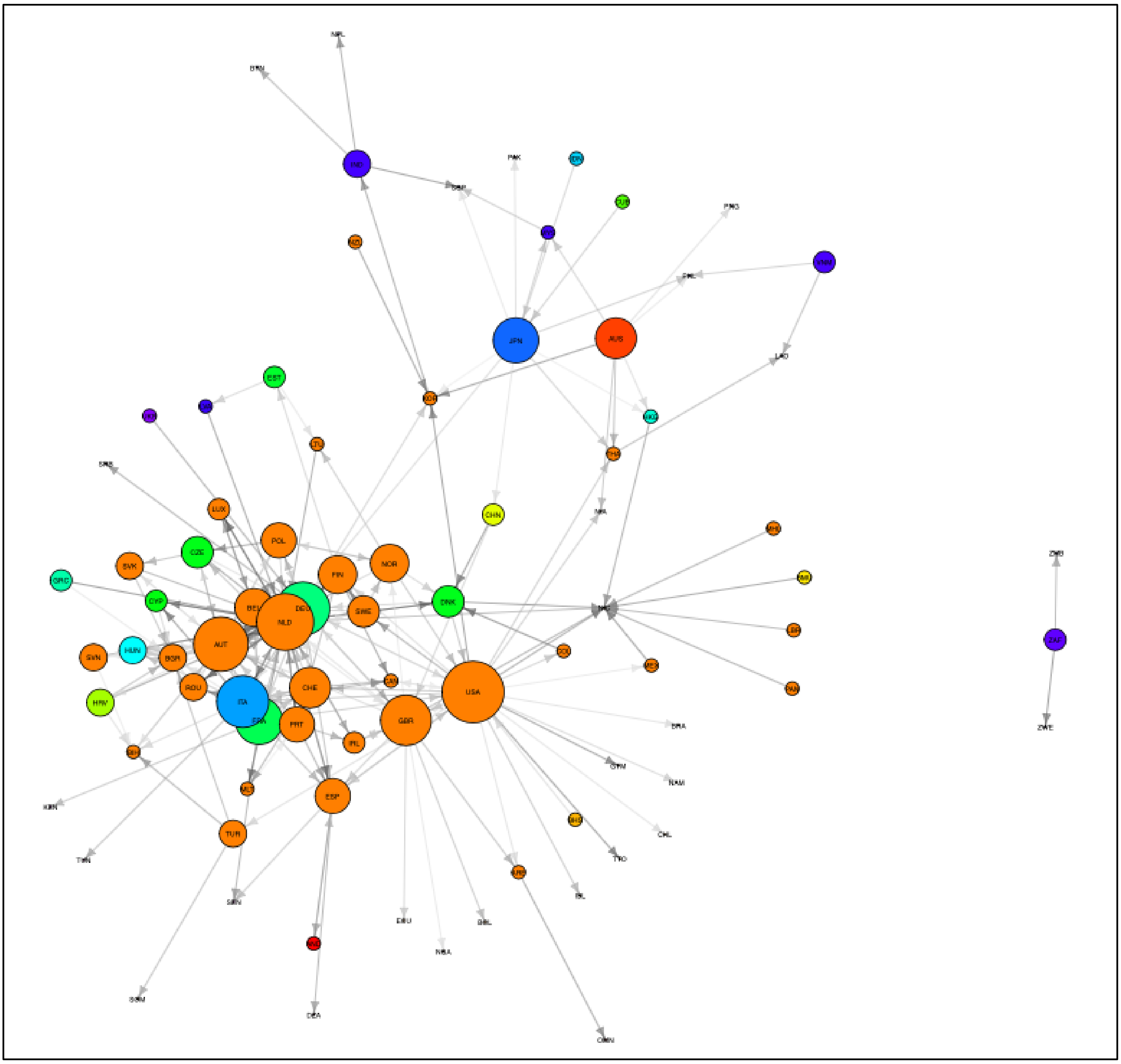
```
HN", "SYC", "SLE", "SOM", "ZAF", "SSD", "SDN", "SWZ", "TZA", "TGO", "TUN", "UGA
", "ESH", "ZMB", "ZWE")
  other_countries <- setdiff(country_codes$iso_3digit_alpha, c(eu_countries, eu
rope_countries, asia_countries, america_countries, oceania_countries, africa_co
untries))

  # Set node color based on the continent
  V(graph)$color <- ifelse(V(graph)$name %in% eu_countries, "green",
                         ifelse(V(graph)$name %in% europe_countries, "gray",
                                ifelse(V(graph)$name %in% asia_countries, "ye
llow",
                                       ifelse(V(graph)$name %in% america_coun
tries, "red",
                                              ifelse(V(graph)$name %in% ocean
ia_countries, "dodgerblue",
                                                     ifelse(V(graph)$name %in
% africa_countries, "orange", "gray"))))))

  # Set node size based on the out-degree of nodes
  out_deg_cen <- degree(graph, mode = "out")
  V(graph)$size <- log10(out_deg_cen + 1) * 9

  # Set link color in grayscale based on the value of v
  E(graph)$color <- gray.colors(length(E(graph)$v), alpha = 0.6)[rank(E(graph)$
v)]

  # Set link width to 2
  E(graph)$width <- 2

  # Set the name of the graph as "Network <year>"
  name <- paste0("Network ", year)

  # Add the graph to the list of plots
  plots[[name]] <- graph

  # Calculate the density of the graph
  density <- edge_density(graph)

  # Add density to the list of densities
  densities[[name]] <- density

  # Calculate communities in the graph using the Clauset-Newman-Moore algorithm
  communities <- cluster_edge_betweenness(graph)

  # Calculate the modularity of the graph
  modularity <- modularity(graph, communities$membership)

  # Add modularity to the list of modularities
  modularities[[name]] <- modularity

  # Set the size of the figure and draw the graph with the Fruchterman Reingold
layout
  set.seed(12345)
  pdf(paste0("graph", year, ".pdf"), width = 20, height = 20)
```

```
  # Assign a different color to nodes based on their community membership
  node_colors <- rainbow(max(communities$membership) + 1)
  V(graph)$color <- node_colors[communities$membership + 1]

  plot(graph, layout = layout_with_fr,
       vertex.label= V(graph)$label,
       vertex.label.cex = 0.7,
       vertex.label.family = "sans",
       vertex.label.font = 10,
       vertex.label.color = "black",
       vertex.size = V(graph)$size,
       vertex.color = V(graph)$color,
       edge.width = E(graph)$width,
       edge.color = E(graph)$color,
       main = name)

  # End the figure
  dev.off()
}
# Print the densities and modularities to the screen
for (i in 1:length(densities)) {
  cat(names(densities[i]), ": ", round(densities[[i]], 4), ", Modularity: ", ro
und(modularities[[i]], 4), "\n")
}
```

6.9 Network graphic representation (modularity version) – 2012



6.10 Network graphic representation (modularity version) - 2018



6.11 Network graphic representation (modularity version) - 2021