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ORIGINAL PAPER

Modelling and analysing the relationship between innovation and the European Regulations on hazardous waste shipments

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Abstract

In Europe, there are different regulations regarding hazardous waste management with which European Union Member States must comply. On the one hand, Member States must meet the recovery targets that are set in the different waste Directives, and they have two options here: material recovery facilities in the country of origin, or recovery through the shipment of waste. In addition, EU Member States must comply with the regulations governing the shipment of hazardous waste (HW), that is, the Basel Convention and the European Regulation on the shipment of waste. Two main questions arise: where is hazardous waste sent, and why? We analyse the European regulation on the shipment of waste, and we consider the above questions by combining network analysis methodology, to examine which countries in the network can be grouped in HW-trading communities, and ANOVA technique to study how the groups created in the network behave in different contexts. These HW-trading communities can be assessed according to European Innovation Indicators, GDP, and other variables. The results allow us to understand the drivers behind the shipment of HW for recovery in Europe. First, this study provides a descriptive overview of the relationships between European countries, the way in which they cooperate and describes how each country is positioned in the joint network. Second, the study is able to identify the most relevant countries in the network. Third, the HW-trading communities are analysed to discover whether they behave differently from the other groups according to GDP and other variables, amongst which we have included the following Europe Innovation Indicators: innovation index, research systems, innovation friendly environment, or innovators. The results show that the Nordic countries are outstanding in the way in which their waste is managed with other countries and reveal a community that works both in the context of hazardous waste shipment and innovation.

Keywords Regulation on the shipment of waste · Network analysis · Innovation context · ANOVA · HW-trading communities and political relationships

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1 Introduction

The world population has reached 7 billion and is expected to grow to 9 billion people (Gerland et al., 2014; Lee, 2011), and wealth per capita will also grow in countries like China, India, and some African countries (Tukker & Butter, 2007); therefore, the need for raw materials will also grow (Allwood et al., 2011; Rosenau-Tornow et al., 2009). Another need that will increase in the future is the demand for energy, as there is a correlation between the increase of wealth and energy consumption (Malinauskaite et al., 2017).

Higher wealth per capita is closely related to increases in waste, particularly e-waste (Awasthi et al., 2018; Kusch & Hills, 2017) but also solid industrial waste (Yanrong et al., 2011). With this increase of waste, waste management has been a subject of increased interest all over the world (Andersson & Stage, 2018; C. Callao et al., 2019a, 2019b; Sakai, 2017; Um et al., 2018), leading to policies targeting the circular economy (McDowall et al., 2017; Zhu et al., 2019). The term circular economy refers to the transformation of the function of resources in the economy (Prescton 2012) so that waste has to be processed close to the point of origin (Kama, 2015) and in accordance with the principles of the 3Rs (reduce, reuse, recycle) (Ranta et al., 2018). In this new policy framework, it is important to take into account whether waste is managed in the place where it is produced, or whether it is shipped to another country for treatment.

The shipment of hazardous waste has been studied from different environmental perspectives. The shipment of HW from the north to the south has been thoroughly studied (Cotta, 2020; Lucier & Gareau, 2016; Renckens, 2015; Sonak et al., 2008) as it represents a risk for developing countries. Waste shipment is not always from north to south as researchers have proven that the USA exports more HW to Canada than to Mexico (Moore et al., , 2018, 2019).

Route visualisation can help in understanding the socio-economic characteristics of waste destinations and in decision making (Moore et al., , 2018, 2019; Rosenfeld et al., 2018; Vincent et al., 2019). Waste shipments have been examined with a view to aiding the process of route optimisation, that is, routing problems (Laurence and Wynne, 1989; Nema and Gupta, 1999; ReVelle et al., 1991) as authors look for the best model for planning and routing in HW management systems to minimize the risks. Waste transport is also important because of emissions, and transport emissions have been studied in the case of air transport (Morrell, 2007), road transport (Ong et al., 2011) and maritime transport (Viana et al., 2014).

Regarding the regulations that apply, the shipping of waste is controlled and regulated in the case of HW by the Basel Convention ("Basel Convention," 1989), and the OECD Decision Control System for waste recovery (OECD Council, 2004). Both these regulations have been implemented in Europe by Regulation (EC) No 1013/2006 on shipments of waste (European Parliament, 2007).

In Europe, there is one regulation for waste management and another for waste transport. Waste transport is regulated in Europe by Regulation (EC) No. 1013/2006. The definition and types of waste, the actors involved with waste and the way in which waste must be managed and treated are regulated by the Waste Framework Directive (WFD) (European Parliament & the Council of the European Union, 2008). Waste Framework Directive aims "to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use" (Article 1).

WFD defines hazardous waste (HW) as "waste which displays one or more of the hazardous properties listed in Annex III". Hazardous wastes pose a danger to human health and the environment (Sonak et al., 2008; Yilmaz et al., 2017). Therefore, depending on the waste stream there are different protocols and possible treatments (Nema & Gupta, 1999).

Taking into account that facilities that process HW generate externaities and are controversial (Hamilton, 1993), it is important to study HW exports for recovery in Europe, in order to find the elements of these shipments of HW and to develop better policies. Waste transport has been studied on the basis of the Basel Convention and of GHG emissions, and from the point of view of its routing, but it has not been studied by looking at the links and relations it creates between different European countries as a form of further cooperation. It is important to fill this gap, as the transport of waste gives us information about how each country manage its waste, but also shows the informal coalitions or alliances between countries; a thorough analysis can therefore lead to better policies and to a better understanding of the relationships between European countries.

This paper analyses the shipment of HW for recovery from the complex networks perspective and looks at how this relates to Regulation (EC) No 1013/2006 and Europe innovation indicators. Network analysis has been used in waste management, as, municipal waste collection and the optimisation of transporting and routing HW have been analysed through networks (Cerqueti et al., 2021; Jennings & Sholar, 1984; Karadimas & Loumos, 2007; Seadon, 2010). These studies showed the importance of finding not only the optimal routes but also the best waste collection and management systems. Network analysis has also been used to study HW shipments between Canada, Mexico, and the USA (Moore et al., 2018).

HW shipments can be for disposal or for recovery, none of the previous research has studied HW exports for recovery in Europe from a network analysis perspective, and neither has the network structure, that is created in HW shipment for recovery, been studied.

This research has a twofold target: To analyse two different waste trading networks obtained with two different analytical techniques, and to analyse the role of EU countries in managing waste from a political perspective.

To achieve the set objectives, in section two we will analyse and study the recovery[1] targets and how hazardous waste is recovered. In section three, we will present Europe Innovation Indicators. The methodology will be presented in section four, and finally we will analyse the results of the network and see if there is a relation between the network results and innovation in European countries.

2 Common recovery targets for hazardous and non-hazardous waste

Waste trade has been documented since 1970 (O´Neill 2001). It is a symptom of the problems faced by the waste management sectors in industrialised countries (O'Neill, 1998). Researchers have reported how even within Europe there are substantial differences in levels of waste trade. The United Kingdom and France were identified as the largest importers of HW within the EU, while Germany was a waste exporter (Bernard & Chang, 1994; O'Neill, 1997). Waste trade is conducted to minimise disposal costs (Bernard & Chang,

[1] The definition that will be used for recovery, will include recycling as it is based on the recovery definition included in the WFD.

1994) and to meet the demands of the regulatory system (O'Neill, 1997). Waste exports may play an important role in the transition towards a circular economy. This process (including the associated policies, such as circular economy, and actions of the European countries involved) has been studied by a number of scholars (Domenech & Bahn-Walkowiak, 2019; Hartley et al., 2020).The circular economy package has introduced new recycling targets for the different waste streams (Official Journal of the European Union, L 150, 14 June 2018), but these targets do not consider if the wastes are hazardous or not. According to European regulations, if the wastes are shipped, for recovery or recycling, to other European countries then they must be counted in the country where they were collected from. Waste shipment regulations state that hazardous waste for recovery can be exported to non-European Union States (European Parliament, 2007).

In waste shipment for recovery, more developed countries have better recycling rates, but studies do not indicate if there is a difference depending on whether or not the waste is hazardous (Higashida and Managi, 2008; van Beukering & Bouman, 2001). The high recycling rates in developed countries may be due to the value of the wastes (Cucchiella et al., 2015) and the obligation for European Union member states to reach the objectives of the different waste directives.

Different reports have also shown that recovery is beneficial for the GDP, European Commission states that private investment for a circular economy was estimated to be around 0.1% of GDP in Europe (European Commision, 2018). Also, the Ellen McArthur Foundations calculated that a circular economy will grow the European economy by 7% (Ellen MacArthur Foundation and the McKinsey Center for Business and Environment, 2015). Apart from the positive economic impact of recovery, it has become necessary, as there is also a relation between GDP and waste generation, the higher the GDP is, the more wastes a country produces (Lee et al., 2017; Malinauskaite et al., 2017).

According to Eurostat, the top treatment recovery operations for hazardous waste in 2014 were R4 (recycling/reclamation of metals and metal compounds—1.635 (1000 tonnes), R5 (recycling/reclamation of other inorganic materials—807 (1000 tonnes), R1 (use as a fuel other than in direct incineration) or other means to generate energy—649 (1000 tonnes), and R12 (Exchange of wastes for submission to any of the operations numbered R1-R11- 448 (1000 tonnes). When there are no metals or inorganic materials to recover, waste to energy (R1) seems to be the most used recovery operation. Waste to energy diverts waste from landfill and turns it into energy, thus saving emissions (Porteous, 2001; Psomopoulos et al., 2009; Tan et al., 2014).

Recovery must be done safely, and innovation can contribute towards this aim, as has already been shown (Gohlke & Martin, 2007; Potdar et al., 2016).

3 Europe innovation indicators

Innovations and environmental issues are closely related, (Porter and Van der Linde 1995). The Porter hypothesis highlighted the importance of strict environmental regulations for the introduction of innovation in cleaner technologies and environmental improvements. The relationship between policies and innovation has been widely studied (Ashford and Hall, 2011; Cecere and Corrocher, 2016; Chen et al., 2017; Fankhauser et al., 2013; Guo et al., 2017; Jo et al., 2015; Melece, 2015) as technological innovations can help with reaching environmental targets (Jordaan et al., 2017), and therefore with sustainable development (Ashford and Hall, 2011). Taking this into account, the authors use different terminology such as green growth (Guo et al., 2017) or eco-innovation (Chen et al., 2017; Jo et al., 2015; Melece, 2015; Nill and Kemp, 2009) when talking about innovation that is connected to sustainability or environmental improvements.

Regulation and innovation can help with decoupling economic growth and environmental damage (Mazzanti and Nicolli, 2011; Nill and Kemp, 2009). Environmental regulation can be done through subsidy schemes (Georg et al., 1992) and analysing the impact on firms in order to reduce it (Hernandez-Sancho et al., 2000). To achieve this purpose, innovation and eco-innovation must be measured (Basso et al., 2013).

Regarding innovation, the European Commission has created the European Innovation Scoreboards (EIS), whereby innovation indicators can measure not only innovation but also other important results, such as an innovation friendly environment. From 2011, Europe elaborated on its innovation index whereby 27 different indicators are used to analyse the performance in different innovation areas.

The results from 2014 are summarised in the following cloropeth maps: innovation index, innovators, innovation friendly environment, and research systems.

- Innovation index represents the results from the 27 indicators used by the European Commission in its report (Directorate-General for Enterprise and Industry).
- Innovators index shows the results from four indicators: share of firms that have introduced innovations onto the market or with their organisations, covering both product and process innovators, marketing and organisational innovators, Small and medium-sized enterprises (SMEs) that innovate in house.
- Innovation friendly environment uses two indicators: broadband penetration among enterprises and opportunity driven.
- Research systems shows the results from three indicators: scientific publications, most cited publications, and doctorate students.

The values of each of the four groups are represented in the following choropleth maps (Fig. 1).

We investigate the relationship between HW trade and innovation. Using ANOVA, the aforementioned indicators are studied in relation to the HW-trading communities that emerge from the network analysis of HW shipments for recovery. This has enabled us to examine the behaviour of these HW-trading communities with regard to HW.

4 Methodology and network representation

All the data in this research are published in Eurostat ("Eurostat—Data Explorer"), the statistical office of the European Union as this is the official information European countries provide to the European Commission.

We have built and analysed the network of hazardous waste shipment for recovery by applying the tools and methodologies of the discipline of Complex Networks (Boccaletti et al., 2006). The advantages of using network analysis in our research are threefold: (1) it allows a better understanding of the European scenario on HW shipment, (2) it can be used as a resource to allow individual countries to study their own relationships, and (3) we can identify the HW-trading communities and see what characterises them.

Network analysis has its origin in graph theory (Barnes, 1983; Butts, 2009), vertices/nodes and edges are common elements in both, and networks are represented by graphs.

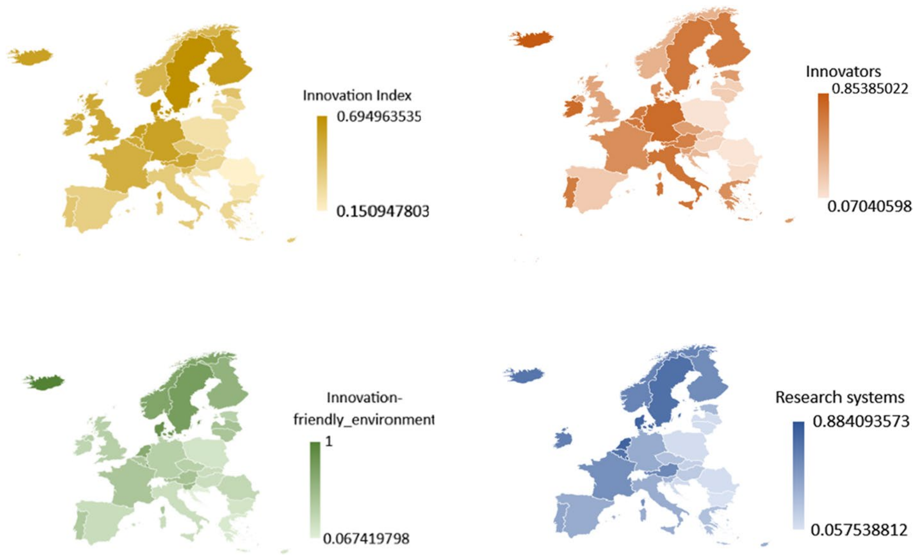

Fig. 1 Choropleth maps of Innovation index, Innovators index, Innovation friendly environment and Research systems. Own elaboration based on European Commission has created the European Innovation Scoreboards

Network analysis can show meaningful relations (Prell et al., 2009a) by using different network concepts, such as centrality, density, or modularity. In this research, we have used directed graphs (Börner et al., 2007) centrality, and modularity.

The concept of centrality was extensively developed by Freeman (Freeman, 1977, 2004) who made a compendium and analysed the following types of centrality: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. These concepts and its measures have been extensively developed and used in social network analysis (Brandes, 2001; Hage & Harary, 1995; Yan & Ding, 2009).

Regarding degree centrality, we will see which country holds the majority of ties with others in the network (Prell et al., 2009b), and through degree centrality we will see how the countries are connected to each one of the actors and which one has more connections and therefore plays a major role. For this purpose, we will also use eigenvector centrality to establish the importance of a country in the network (Bonacich, 1987). As Bonacich stated "eigenvector is an appropriate measure when one believes that actors status is determined by those with whom they are in contact".

Outdegree centrality shows to how many countries each member exports hazardous wastes. The results will show which countries occupy the most relevant positions.

Let $G = (V, E)$ be a graph in which V represents the set of countries (we use the term nodes, countries with the same meaning) participating in recovery shipment and E represents the set of links of shipment between them. Let $(vi, vj) \in E$, with $vi, vj \in V$, as an edge in G that represents any kind of shipment between countries vi and vj.

The observations of the degree centrality reveal that four countries have the highest centrality: Germany, Belgium, Netherlands, and France. With the exception of Germany, the rest of the countries are between the countries that export the largest amounts for recovery.

The results of the centrality metrics are shown in Table 1, which provides some interesting findings. Indegree centrality shows how many nodes/countries each member receives

Table 1 Results obtained using centrality metrics

Id	Label	Export	GDP	Generated	Indegree	Outdegree	Modu-larity_ class	Eigencentrality
1	Belgium	524,650	33,800	2,946,195	18	12	1	0.876125
2	Bulgaria	2,374	5,500	12,206,169	6	3	3	0.184315
3	Czech Republic	33,728	15,400	1,162,342	6	6	0	0.298495
4	Denmark	129,744	44,900	1,718,394	7	8	4	0.370225
5	Germany	366,725	34,000	21,812,660	29	16	2	1.000000
6	Estonia	1,699	13,200	10,410,321	5	6	4	0.159824
7	Ireland	180,826	41,300	482,907	1	9	4	0.070881
8	Greece	9,093	17,000	221,041	2	10	3	0.021239
9	Spain	38,608	22,300	2,984,518	12	9	1	0.595103
10	France	1,075,755	31,300	10,783,405	19	11	1	0.857168
11	Croatia	9,276	10,300	130,239	0	9	0	0.000000
12	Italy	373,152	25,400	8,923,548	11	11	2	0.610052
13	Cyprus	2,585	20,400	173.377	1	5	3	0.003652
14	Latvia	18,093	10,300	104,142	2	5	2	0.033515
15	Lithuania	20,291	11,300	16,.477	5	6	0	0.153449
16	Luxembourg	69,824	80,600	237,180	4	5	2	0.292839
17	Hungary	28,704	10,700	596,554	4	11	0	0.122130
18	Malta	11,016	17,900	36,654	0	6	1	0.000000
19	Netherlands	574,261	38,600	4,830,495	18	12	2	0.847686
20	Austria	253,438	36,200	1,272,288	18	9	2	0.843815
21	Poland	23,634	10,500	1,679,051	19	5	0	0.764753
22	Portugal	53,355	16,300	701,228	3	6	1	0.063085
23	Romania	25,164	7,000	590,300	6	6	3	0.223013
24	Slovenia	27,560	17,500	155,229	7	5	0	0.406910
25	Slovakia	11,947	13,600	371,214	3	7	0	0.143415
26	Finland	99,442	34,200	1,998,693	6	10	4	0.377701
27	Sweden	139,340	40,500	2,568,154	16	13	4	0.650768
28	United King-dom	217,259	31,000	5,755,258	16	13	1	0.718951
29	Iceland	12,272	33,800	36,250	0	4	1	0.000000
30	Liechtenstein	3,835	100,000	5,744	0	2	2	0.000000
31	Norway	887,507	67,400	1,368,049	7	11	4	0.301826

hazardous wastes from. In this case, Germany (29), France (19), Poland (19), Belgium (18), Netherlands (18) and Austria (18) are the countries with the highest indegree. Again, Belgium, Netherlands, and France appear in this list, that is, not only do they produce the largest amounts of hazardous wastes, but they also receive wastes from more than half of the countries in the table.

According to the degree eigenvector centrality, countries with the highest eigenvector centrality are Germany (1), Belgium (0.87), France (0.85), Netherlands (0.84), and Austria (0.84). All of these countries belong to HW-trading communities 1 (Belgium and France) and 2 (Germany, Netherlands and Austria), as it is shown in Table 1.

Table 2 Modularity Class—HW-trading communities

Modularity class	Countries (Eigencentrality)
0	Czech Rep, Croatia, Lithuania, Hungary, Poland, Slovenia, Slovakia
1	Belgium, Spain, France, Malta, Portugal, United Kingdom, Iceland
2	Germany, Italy, Latvia, Luxembourg, Netherlands, Austria, Liechtenstein
3	Bulgaria, Greece, Cyprus, Romania
4	Denmark, Estonia, Ireland, Finland, Sweden, Norway

Fig. 2 Hazardous waste shipment flow for recovery

As was previously mentioned, Belgium, Germany, France, and Netherlands are the countries that export the largest amounts of hazardous wastes for recovery and also have the highest indegree and degree values regarding centrality.

We will also look for modularity in the network. This concept has been widely used in biology when looking for “connected molecular components” (Yoon et al., 2006) or “loosely linked islands of densely connected nodes” (Sauro, 2008). Modularity has been widely used in health sciences (Alexander et al., 2009; Stevens et al., 2012; Taylor et al., 2009). It has also been applied in social network analysis and was defined by Newman (Newman & Girvan, 2004) as “the detection and characterization of community structure in networks, meaning the appearance of densely connected groups of vertices”.

Table 2 shows that five HW-trading communities emerge in this network, as we mentioned before, is related to the emergence of densely connected groups.

Figure 2 displays HW shipment flows for recovery, we emphasize two different metrics, firstly, the number of tonnes generated by each country is represented by the size of the node. Secondly the GDP is represented by the colour of the node, that is, countries with a higher GDP are represented in a darker colour. The thickness of the link represents the quantity of HW shipment flows between countries, and the edge colour indicates the node of origin. According to this figure, countries with the highest GDP are not the countries that produce the largest amount of hazardous wastes.

In Fig. 3, we can observe the modularity of the network, that is, its structure and which HW-trading communities are formed. The size of the node represents the number of tonnes

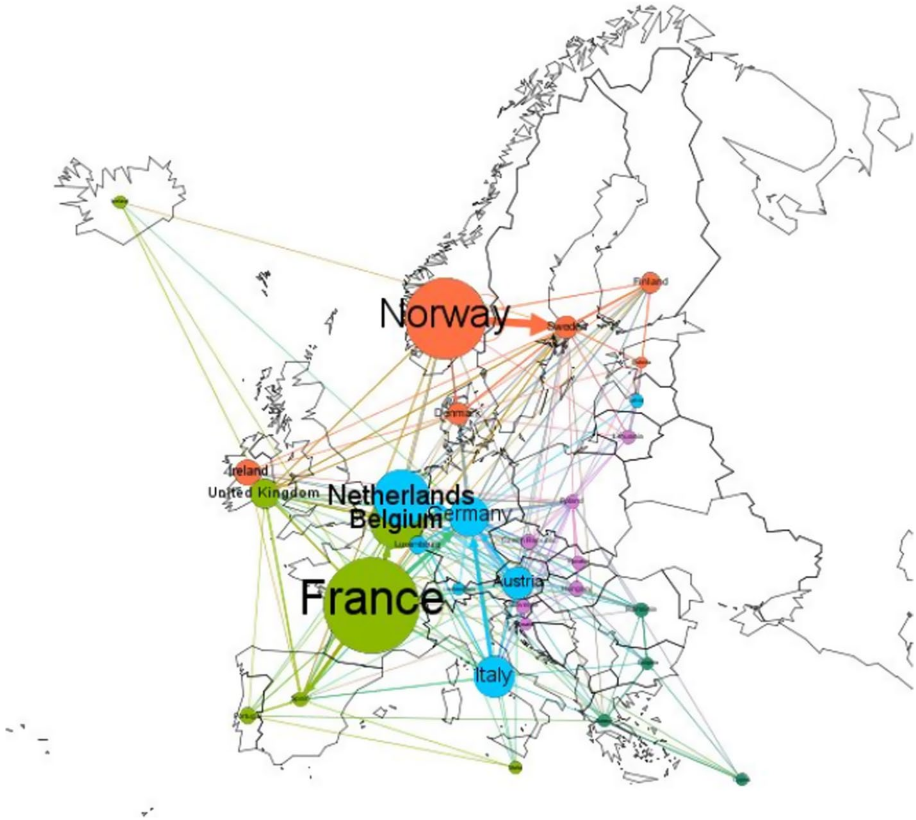

Fig. 3 Network displaying the modularity

that each country exports. The thickness of the lines represents the amount of wastes sent to another country; a high amount of exports is represented by a thick line between the nodes. In this figure, the thickest line is between Norway and Sweden, where both countries have a GDP above 40.000 euros/capita, and with a high degree of centrality (29) and also a high indegree (16). The colours in Fig. 3 represent the HW-trading communities that arise in the network.

5 Discussion

Every three years, the European Commission publishes reports on the implementation of Regulation (EC) No 1013/2006 of 14 June 2006 on shipments of waste; reports have been published in the years 2018, 2015, 2012, 2009 and 2006. These reports contain an analysis of waste shipments based on the data. It is interesting to discover how Regulation (EC) No 1013/2006 of 14 June 2006 on shipments of waste works from another perspective, based not only on the data provided by the European countries but also taking into account other variables such as GDP, the nodes we find in network analysis, and the HW-trading communities that arise in this analysis.

The HW-trading communities obtained are analysed below to see how they behave. Matching those HW-trading communities with other variables could be relevant to understand how waste shipment takes place. The discussion will lead us to look at our results in the light of these waste politics.

We use a new perspective to analyse Regulation (EC) No 1013/2006 of 14 June 2006 on shipments of waste, with data from 2014 and using network analysis we have generated two networks (Figs. 2 and 3) in which we can evaluate hazardous wastes exports for recovery between European countries. In Table 1, we present the results obtained for centrality metrics, as well as other data, such as GDP or the amount of wastes exported for recovery. Both networks are formed by 31 countries and 251 edges, which represent the number of exports of hazardous waste shipments for recovery.

If we compare the countries that generate the largest amounts of hazardous wastes, Germany (21,812,660 tonnes), Bulgaria (12,206,169 tonnes), France (10,783,405 tonnes), and Estonia (10,410,321 tonnes) with the countries that export the largest amount of wastes, France (1,075,755 tonnes), Norway (887,507 tonnes), Netherlands (574,261 tonnes) and Belgium (524,650 tonnes), we can observe that the countries that generate the largest amounts of hazardous wastes are not the countries that export the largest amounts for recovery.

If we analyse the percentage of hazardous wastes exports, we find that the countries with the higher percentages are Liechtenstein (66.76%), Norway (64.87%), and Iceland (33.85%).

The data show the importance of the hazardous waste market in Europe, in which safety is guaranteed by compliance with the Regulation for the shipment of waste and the WFD. They also show the importance of waste transport in meeting the targets of the circular economy, since not all the countries have the technology or capacity for waste treatment in the place of origin. This gives rise to a market that, no doubt, contributes to creating employment and wealth in different sectors, from waste management machinery, to trucks, drivers and mechanical workshops.

6 Analysis of network HW-trading communities

The next step is to understand the main characteristics of the five HW-trading communities generated by the network and represented in Table 2 and in different colours in Fig. 3. The first approach is to know if these groups/communities behave as such and differently from the rest of the groups according to the different variables we are studying for year 2014. We want to know what their behaviour is regarding the GDP per capita, the total hazardous waste generated, greenhouse gases generated, recovery (energy recovery), and Waste to energy plants by classified countries. It is also of interest to know their behaviour regarding the indicators defined by the EU for innovation. We have also studied the cloropeth maps in Fig. 1 that are linked to innovation and research, with a special emphasis on eco-innovation.

For this purpose, as a second stage, the analysis of variance (ANOVA) of a factor has been studied. This analysis allows the comparison of several groups as a quantitative variable. This test is a generalisation of the equality of means contrast for two independent samples. It is applied to contrast the equality of means of three or more independent populations. This analysis is inter- and intragroup, that is, no individual country's behaviour

Table 3 One-factor ANOVA

Dependency relationship		DOF	F Value	Significant relationship (*p*-value)
GDP	Inter-groups	4	5.126	Yes
	Intra-groups	25		0.004
	Total	29		
Hazardous Waste Generated	Inter-groups	4	1.027	No
	Intra-groups	25		0.413
	Total	29		
Innovation Index	Inter-groups	4	7.343	Yes
	Intra-groups	25		0.000
	Total	29		
Research Systems	Inter-groups	4	6.563	Yes
	Intra-groups	25		0.001
	Total	29		
Innovation Friendly Environment	Inter-groups	4	3.706	Yes
	Intra-groups	25		0.017
	Total	29		
Innovators	Inter-groups	4	4.474	Yes
	Intra-groups	25		0.007
	Total	29		
Greenhouse Gases	Inter-groups	4	1.556	No
	Intra-groups	25		0.217
	Total	29		
Recovery	Inter-groups	4	1.029	No
	Intra-groups	25		0.412
	Total	29		
Waste to Energy	Inter-groups	4	1.507	No
	Intra-groups	24		0.232
	Total	28		

NO: There is no functional relationship. YES: There is a functional relationship. Number in parentheses corresponds to the critical level of test

DOF Degree of Freedom

is assessed. These groups are the five HW-trading communities, shown in Table 2, that emerge from the network analysis carried out in this work.

This index requires *k* independent samples of the variable of interest. This grouping variable is called a factor and it seeks to classify the observations of the variable in the different samples. Table 3 shows the possible two-to-two combinations between the levels of the factor variable and the differences between the categories of the variable in each group. The groups whose means differ significantly (at the 0.05 level of p-value) are those that show statistically significant differences from each other. As a Post Hoc contrast, the Scheffé Test has been used.

As given in Table 3, there are five variables highlighted in bold that can be defined as independent indicators. Therefore, these groups, the five HW-trading communities shown in Table 2, behave significantly differently in the GDP per capita and in the innovation and

Table 4 Descriptive analysis based on flow characterisation

	N		Mean	Standard deviation	Minimum	Maximum
GDP (Euros/capita)	G0	7	12,757.14	2,818.90	10,300.00	17,500.00
	G1	7	26,628.57	7,587.21	16,300.00	33,800.00
	G2	**6**	**37,516.67**	**23,490.46**	**10,300.00**	**80,600.00**
	G3	4	12,475.00	7,346.37	5,500.00	20,400.00
	G4	**6**	**40,250.00**	**17,482.65**	**13,200.00**	**67,400.00**
	Total	30	26,406.67	17,433.12	5,500.00	80,600.00
Innovation Index*	G0	7	0.32264	0.08471	0.23679	0.46926
	G1	7	0.48315	0.09901	0.34375	0.59994
	G2	**6**	**0.50168**	**0.14564**	**0.26923**	**0.60740**
	G3	4	0.26517	0.10194	0.15094	0.38527
	G4	**6**	**0.57168**	**0.11488**	**0.41447**	**0.69496**
	Total	30	0.43805	0.15126	0.15094	0.69496
Research Systems*	G0	7	0.17099	0.08694	0.08551	0.31377
	G1	**7**	**0.51737**	**0.19334**	**0.20568**	**0.71193**
	G2	**6**	**0.51727**	**0.29703**	**0.09052**	**0.88409**
	G3	4	0.19228	0.14876	0.05754	0.37277
	G4	6	0.60452	0.16908	0.30591	0.79567
	Total	30	0.41061	0.25504	0.05754	0.88409
Innovation Friendly Environment*	G0	7	0.27839	0.15256	0.06742	0.50461
	G1	**7**	**0.45512**	**0.24894**	**0.23101**	**1.00000**
	G2	**6**	**0.46233**	**0.17159**	**0.22029**	**0.65506**
	G3	4	0.18011	0.06400	0.12029	0.27079
	G4	**6**	**0.59257**	**0.23586**	**0.29009**	**0.87500**
	Total	30	0.40615	0.22834	0.06741	1.00000
Innovators*	G0	7	0.27716	0.15159	0.07829	0.47336
	G1	**7**	**0.56806**	**0.20118**	**0.22007**	**0.85385**
	G2	**6**	**0.62298**	**0.21933**	**0.18915**	**0.78538**
	G3	4	0.30771	0.24840	0.07041	0.54855
	G4	**6**	**0.58621**	**0.14399**	**0.35731**	**0.75259**
	Total	30	0.48008	0.23204	0.07041	0.85385

Functional relationship are given in bold

*For definition see Directorate-General for Enterprise and Industry (European Commission), 2014 In bold Groups with higher means in each variable

research indicators: innovation index, research systems, innovation friendly environment, innovators.

Next, in Table 4, a descriptive analysis of the network HW-trading communities is carried out according to the factors that characterise the sample, based on the results in Table 3.

As shown in Table 4, the groups G4 formed by Denmark, Estonia, Ireland, Finland, Sweden, and Norway, and G2 formed by Germany, Italy, Latvia, Luxembourg, Netherlands, Austria, and Liechtenstein are the ones that have higher means for all the analysed variables. The G4 group has typical deviations that are smaller than the G2, so the behaviour of these countries is more homogeneous. This group has higher average values, except for the innovator indicator. It should be noted that the G1 group (Belgium, Spain, France, Malta, Portugal, United Kingdom, Iceland), has a similar behaviour to the G2 Group regarding the research systems and innovation friendly environment variables.

7 Discussion of ANOVA analysis

Hazardous waste management has always been analysed in great depth (Chang & Wang, 1995; Cucchiella et al., 2015; He et al., 2006; Marques et al., 2012). For this reason, it is important to go beyond data and carry out a deeper analysis to understand not only how hazardous wastes move, but also what other variables, such us GDP or the hazardous waste generated, affect these exports. It is also important to establish which HW-trading communities are formed, and how they go beyond HW exports to interact through innovation. These issues are examined using network analysis, the European Innovation Scoreboard (2020), and the ANOVA technique, providing information that arises from the implementation of Regulation (EC) 1013/2006 on the transport of waste.

The analysis of the HW shipments for recovery network revealed 251 connections between European countries. From the network analysis, it is observed that exports between them produce HW-trading communities. These HW-trading communities are made up of countries with common characteristics. An ANOVA analysis was carried out in order to identify variables that lead to common behaviours within each community and that distinguish them from other HW-trading communities. The results show the importance of countries like France, Germany, Netherlands, or Belgium, but the HW-trading communities formed show that GDP may be an important variable; the proximity of the HW-trading communities also appears to be an important factor.

Germany is the country with the highest degree, as it receives HW from 29 countries (indegree 29) and sends HW to 16 countries (outdegree 16), showing how powerful it is in relation to the shipment of HW for recovery. Its leadership and importance in Europe has been subject to research (Bulmer & Paterson, 1996, 2010; Hyde-Price & Jeffery, 2001).

However, HW-trading communities, and the countries within them, can also be analysed from other political perspectives; these perspectives arise as a consequence of the shipment of HW for recovery but may have their roots in other forms of cooperation such as coalitions or cooperation in European macro-regions.

Coalitions show power distributions (Aleskerov et al., 2002). Our results demonstrate that HW-trading communities are formed by countries that are not distant. Proximity has already been signalled as one of the roots of coalitions, as coalitions may be culturally based, associated with geographical proximity or show a division between north and south (Elgstrom et al., 2001). HW-trading communities therefore show cooperation that may go beyond the exchange of HW for recovery.

Coalitions also show how "greener countries" in Europe work together towards a common target (Liefferink & Andersen, 1998) and the importance of the Nordic block is shown in the results of this research.

Denmark, Sweden, Finland and Norway, all members of G4 and leaders in innovation, also cooperate in two other fields—in the Baltic Sea macro-region, and in two important forums, the Nordic Council of Ministers and the Nordic Council.

Once more, network analysis has revealed the importance of cooperation, and shows how cooperation in other domains leads to cooperation in HW shipment and how countries work with countries that are partners in other fields.

It is not only the Baltic Sea macro-region that has its reflection in these HW-trading communities; other macro-regions (such as the Alpine macro-region) are formed by countries that belong to G2 (Austria, Germany, Italy and Liechtenstein), with the exception of France in community 1.

In this line, the results also show the importance of and the relation between HW-trading communities and innovation. In fact, the countries in community 4 (Denmark, Estonia, Ireland, Finland, Sweden, Norway) are the countries with the highest innovation scores in all fields.

When analyzing the HW-trading communities obtained by the network according to their modularity, this highlights how the GDP per capita characterizes them, since those with a higher GDP per capita perform better regarding the innovation and research indicators. Although the networks generated may be justified by their proximity, there are other variables that characterize them and suggest that they also influence this type of exchange. The operation of the groups regarding the innovation friendly environment show very differentiated behaviours between groups G1, G2, G4 with values greater than 45% compared to groups G0 and G3 with values below 30%. This same behaviour is also observed for the research systems and innovators indicators. Therefore, the networks that are generated are characterised by geographical proximity but also by the proximity in their levels of innovation and research, and their capacity for an innovation friendly environment.

Finally, as was previously mentioned, waste to energy was the most used recovery option, which is an important novelty as other studies, only focused on Municipal Solid Waste (not exclusively for HW) (Scarlat et al., 2019), conclude that MSW as an energy source is underexploited as only 6% was sent to incineration, including energy recovery in incineration. However, further research should be done as this does not explain the amount of exports between Norway and Sweden, or the high indegree of Poland.

8 Conclusions

The first conclusion is that the implementation of Regulation (EC) 1013/2006 goes beyond the quantities of HW that are shipped, creating a network of different HW-trading communities, and showing the importance of relations between European countries.

This research can contribute to different debates in the scholarly community. On the one hand, it can improve the regulation of waste transport, as it may be possible through regulation to influence HW-trading communities in order to extend the benefits of such regulation. On the other hand, it can help to give an understanding of how different policies, such as innovation policies, influence the behaviour of countries in different areas such as waste transport, and vice versa.

The study also shows how cooperation in other domains and proximity between countries may be relevant in HW management.

All European countries export hazardous wastes in different percentages because they lack the innovation needed or because they do not have enough treatment facilities or because of legislative barriers to HW recovery facilities. If we want European countries to improve their HW recovery, it is not only prevention and innovation that are important;

a limit on hazardous waste exports may push countries to innovate and look for recovery options at home.

France and Germany have a high indegree: Germany (29), France (19), and in 2014 both had a high number of waste to energy plants, (Germany 99 plants and France 126 plants according to CEWEP), however, we cannot state that hazardous waste recovery operation is energy recovery, so further research should be done.

Countries with a high GDP are also countries with high scores in the different innovation indexes, especially Scandinavian countries (Finland, Sweden, and Norway), even if their eigenvector centrality is not very high in this network, which not only highlights the relationship between GDP and innovation, but also how countries that form HW-trading communities when trading in HW shipment for recovery interact. Based on the ANOVA results, we can conclude that the countries with similar levels of eco-innovation share similar behaviours in HW exports for recovery. In the different HW-trading communities we can observe that they share proximity, similar GDP levels, and also similar innovation environments and policies, see for example Nordic countries. It is important to note that Nordic countries have always been concerned about wastes and the environment (Richter & Koppejan, 2016; Watson et al., 2013; Ylä-Mella et al., 2014). In particular, Norway is the most efficient country regarding HW management (Carmen Callao et al., 2019a, 2019b). The amount of HW produced or greenhouse gases do not affect the behaviour of the HW-trading communities. Consequently, the transfer of knowledge between countries and groups should be encouraged in Europe.

This analysis of Regulation (EC) 1013/2006 can give a new perspective on the development of policies to achieve the new Green Deal and the sustainable development goals. It shows the importance of HW-trading communities, not only in the transport of waste, but also in cooperation and in the context of innovation, where funding is necessary to promote innovation and development in line with these objectives. In the context of the new European Green Deal and Horizon Europe, hazardous waste management seems to be of great relevance, and policies should not ignore the importance of waste transport.

It must be noted that this research began before the publication of the European Green Deal (December 2019), however, waste management has always been one of the priorities of European Commission which began this path in 2015 with the circular economy package. However, the conclusions from this study could be useful in future European Green Deal policies.

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