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How to detect illegal waste shipments? The case of the international trade in polyethylene waste

Rosanna Pittiglio
University of Campania "Luigi Vanvitelli"

Filippo Reganati
Rome - Sapienza University

Luca Toschi
Rome - Sapienza University

Abstract

The purpose of this research is to provide a methodological framework that is able to enhance our capability to detect illegal waste shipment with particular reference to waste plastics. Based on a very large cross-sectional dataset covering 187 countries over the period 2002-2012, our study aims to do this by using both the mirror statistics method and the network analysis. Specifically, by using mirror statistics, we identify the existence of a set of "suspicious" trade relations between pairs of countries. Then, we employ social network analysis in order to define the position of each country in this illegal trade structure, and to have a clear exposition of the connections between them. Our main findings reveal the central positions of the USA, Germany and the UK as sources and China and Malaysia as outlets of illegal shipments of waste plastics. Moreover, our methodology allows us to highlight the presence of other countries, which carry out an intermediary role within the global trade network, and to detect the changes in traditional illegal shipment routes. Therefore, this paper shows how social network analysis provides a useful instrument by means of which crime analysts and police detectives can develop effective strategies to interdict criminal activities.

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Contact: Rosanna Pittiglio - rosanna.pittiglio@unicampania.it, Filippo Reganati - filippo.reganati@uniroma1.it, Luca Toschi - luca.toschi@uniroma1.it.
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1. Introduction

International trade in waste products has been a steadily increasing phenomenon over the past decade. In the period 1999–2011, total exports from EU Member States increased by a factor of five for waste plastics and trebled for precious metals waste; they doubled for iron and steel, and for copper, aluminum and nickel. Such an increase in the international trade of waste has been driven, on the one hand, by the gap between volumes collected for recycling and the domestic recycling and reprocessing capacity in many industrialized countries: for example, only 25 per cent of global waste is recovered or recycled (UNEP 2015). On the other hand, the strong economic growth in many less developed countries has led to high demand for virgin raw materials[1]. Higher prices for virgin raw materials have in turn increased the demand and the relative price of secondary raw materials reclaimed through recycling. With a current annual estimated worth of $1 trillion, the global waste and sustainable resource market represents a significant financial opportunity.

However, together with the increasing value of the waste and sustainable resource market, there has been a similar growing interest by criminal organizations in illegal shipments of waste and recovered materials. Despite the difficulty in providing good estimates of both the volume and value of illegal waste trade, the European Environmental Agency (2009) suggests that annual illegal shipments vary between 6,000 and 47,000 tons with an average of about 22,000 tons (equivalent to 0.2 per cent of notified waste). According to the UN Environment Programme (2016), crime syndicates earn $10 to $12 billion a year from waste crime. Inspections of 18 European seaports in 2005 found as much as 47 per cent of waste destined for export was illegal.

In this paper, our attention is focused on waste plastics because their movement of pairings and scrap increased by a factor of five during the years 1999 to 2011 (Baird *et al.* 2014). The most significant type of waste plastics exported (4.3 million tons) is that of parings and scrap plastic from polymers of ethylene (code in the harmonized system 391510). Over ten years, the extra-EU trade in this product rose by over 1000 per cent.

Indeed, a comparison of the amounts of declared waste exported by reporter country and the amount of declared waste imported by its partner countries, shows that there is often a significant gap. For example, in 2012 exports of waste, parings and scrap, of plastics from polymers of ethylene declared by the United States to China amounted to around US 158.3 million dollars whereas China declared imports from the United States for about US 363.8 million dollars. Such a gap in the bilateral flows of legal trade could be a warning light signalling the suspicion of illegal shipments within them. In fact, overall growth in international trade has enhanced the opportunities for illegal trade. The European Union Network for the Implementation and Enforcement of Environmental Law suggests that waste plastics is one of the waste categories where violations have most frequently occurred: 100 out of 1,011 illegal shipments detected in European countries participating in the 2012-2013 study were illegal shipments of waste plastics (IMPEL 2014). According to the Italian Customs Authority, the highest share of illegal waste seized in the Italian ports is mainly composed of scrap metal (48.3 per cent in 2011), waste plastics (37.7 per cent in 2011), paper waste (37.0 per cent in 2010) and waste tires (58.7 per cent in 2012).

The academic literature on trade in plastic waste is rather scarce. There are few papers that have analyzed the determinants of "legal trade" (Michida, 2011; Kellenberg, 2012; Higashida and Managi, 2014), while the illegal shipment has mainly focused on other sectors such as natural resources, antiques, tobacco, weapons (see, among others, Vezina, 2015; Fishman and Wei,

[1] For example, many metals doubled or even trebled in price between 2000 and 2010 (EEA, 2012a).

2004). To the best of our knowledge this is the first study on illegal shipments in polyethylene waste using the network analysis.

Therefore, the purpose of this study is to attempt to provide a methodological framework that is able to enhance our understanding of illegal waste shipment of plastic with particular reference to waste plastics from polymers of ethylene (i.e. the most significant item in the international trade of waste plastic). It aims to do this in two steps. First, the existence of illegal trade is detected using the mirror statistics method, i.e., by identifying possible differences in the reporting of foreign trade between pairs of partner countries[2]. Second, in order to identify the global network of this illegal trade, we perform a social network analysis. This methodology, which defines and describes the topology of the trade network, allows us to illustrate not only the degree of connectivity among countries, but also the extent to which some countries play an increasingly central role in the network. To the best of our knowledge, this paper is the first study to provide a methodological framework that combines mirrors statistics technique and network analysis to detect illegal trade. The remainder of the paper proceeds as follows. In section 2 we attempt to detect the role of illegal shipments within the waste plastics market. Section 3 describes the global network of such illegal trade. Finally, Section 4 summarizes and concludes the paper.

2. The illegal trade in polyethylene waste

The illegal trafficking of waste has become one of the fastest growing areas of crime and one of the most lucrative industries among organized criminal activities with serious economic, as well as environmental and social damage. Illegal trafficking of waste arises when higher profits are expected compared to the legal options of recycling or disposal, combined with regulatory or enforcement failure. From an economic point of view, this environmental crime is mainly motivated by cost-saving decisions driven by the attempt: i) to reduce the relatively high costs of treatment and disposal of waste and ii) to take advantage of regional differences in environmental taxation (i.e., landfill and incineration taxes). However, another economic factor that can induce the illegal shipment of waste is the potential economic return of waste as an export. In fact, several waste streams are shipped to foreign countries as 'second-hand goods' or as recoverable materials in order to take advantage of the difference in price between used and new products.

Soaring crude oil prices have been pushing the price of virgin plastics up, and this has also affected waste plastic prices which almost doubled between 2002 and 2007 (from 252 €/ton to 365 €/ton between 2002 and 2007). After a sharp decline to 234 €/ton in 2010, the price recovered to 367 €/ton in 2013. Cheaper than virgin raw materials, imports of waste plastics are rising exponentially, with import volumes reaching 3,024 thousand tons in 2003 and 4,096 thousand tons in 2004.

However, with the transboundary movement of recyclable wastes, the problem arises of the irresponsible export and distribution of waste containing hazardous substances, and trash that is difficult to recycle. Broadly speaking, the flows of illegal transboundary shipments may take many forms such as: transporting any waste that is subject to the Basel Export Ban out of the EU or the OECD; transporting waste without notifying the authorities of source and destination when such a notification is necessary; falsifying any documentation regarding waste loads or not declaring waste on documentation; mixing certain types of waste; classifying hazardous waste as non-hazardous ('green-listed'); shipping waste whilst falsely claiming that it comprises second-hand goods and is therefore not subject to waste regulations.

[2] Mirror statistics are pairs of statistics which, for a given period, compare the quantity of a given product which country A declares that it exports directly to country B with the corresponding quantity which country B declares that it imports directly from country A.

In the literature, the principal technique for detecting illegal trade has been based on mirror trade statistics, i.e., by calculating the discrepancy between the value of exports recorded by the exporting country and the value of imports recorded by the importer. A possible criticism in the using of this technique for detecting illegal trade could be that the gap between exports declared by reported country and import declared by its partner country could be due also to differences in the registrations. To this regard, ITC (2003) identifies six possible differences: (i) the coverage and the time of recording; (ii) the application of: the trade system (general or special trade system); (iii) the commodity classification; (iv) the valuation (cif or fob, currency conversions); (v) the quantity measurement (gross or net, units); (vi) errors and estimations.
Nevertheless, starting from the seminal work of Bhagwati (1964), this methodology has been used in many research contexts to analyse the determinants of illicit trade (Carrère and Grigoriou 2014; Vezina 2015; Javorcik and Narciso 2008)–and of financial and tax crimes (McDonald 1985; Fisman and Wei 2004; De Boyrie *et al.* 2005; Mishra *et al.* 2008).
Therefore, keeping in the mind these drawbacks, we apply mirror statistics technique to detect the illegal trade in polyethylene waste using quantity instead of value data.
By doing so, it allows us to clear our data from possible valuation differences (i.e. cif and fob prices or currency conversions).
Starting from a sample of 187 reporter countries which account for 97 per cent of total trade, in the first step of our analysis we calculate the trade gap index ($TG_{kt}^{k'}$) in quantity as the log-ratio in percentage between the export from each country k to each country k' as reported by country k and the imports from country k as reported by each partner country k' at time t:

$$TG_{kt}^{k'} = \log\left(\frac{export_{kt}^{k'}}{import_{k't}^{k}}\right)\% \qquad (1)$$

It is worth noting that this index has been calculated using data recorded both (i) by country *A* as exports to country *B* that matches the data recorded by country *B* as imports from country A, and (ii) by country *B* as exports to country *A that* matches the data recorded by country *A* as imports from country B. Moreover, we consider worthy of attention all situations in which:

$$TG_{kt}^{k'} > \alpha \qquad (2)$$

where the parameter α is a dispersion factor which is somewhat arbitrarily fixed, although the values of 0.10 or 0.15 have been the most widely employed in the literature on international trade. Following Holzner and Gligorov (2004), who analyzed the illegal trade in South East Europe, in this paper we set $\alpha = 0.10$.[3] Finally, we considered as illegal all bilateral trade flows between countries where the TG index is higher than 10 per cent for consecutively all years considered.[4] This strategy allows us to partly overcome the restrictions of mirror analysis above highlighted.
Therefore, starting from 34,782 bilateral flows in polyethylene waste arising from 187 countries, we identify 100 illegal links that involve 53 countries of which 40 are origin countries and 32 are destination countries. Looking at the single country level, Table 1 shows that Germany, the Netherlands, the UK and the USA are the main origin countries while China, China Hong Kong SAR, Germany and Italy are the top destination countries of illegal flows.[5]

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[3] In order to evaluate the robustness of our conclusions, we conduct the same analysis setting α equal to 15 per cent finding similar results (available upon request).

[4] As in Holzner and Gligorov (2004), in doing this, we are assuming that all other reasons for discrepancies between partner-country trade data "*do not follow a certain pattern but occur randomly and therefore should balance over the period of observation*" [Holzner and Gligorov, 2004; page 5].

[5] We have also controlled for possible spatial correlation between the importers and exporters countries within the sample using the Global Moran's I Index. The results of this test calculated for each year exclude the existence of spatial autocorrelation. These results are available on request.

Table 1: Number of illegal links in polyethylene waste

Countries of origin							
	N. of links		N. of links		N. of links		N. of links
Germany	9	Australia	3	China	1	Philippines	1
Netherlands	7	Belgium	3	China Hong Kong SAR	1	Portugal	1
United Kingdom	7	Norway	3	Guatemala	1	Rep. of Korea	1
USA	7	Poland	3	Hungary	1	Romania	1
France	5	South Africa	3	India	1	Russian Federation	1
Italy	5	Czech Rep.	2	Indonesia	1	Saudi Arabia	1
Austria	4	Ireland	2	Iran	1	Singapore	1
Malaysia	4	Spain	2	Luxembourg	1	Slovenia	1
Sweden	4	Thailand	2	Mexico	1	Tunisia	1
Switzerland	4	Bulgaria	1	New Zealand	1	United Arab Emirates	1
Countries of destination							
	N. of links		N. of links		N. of links		N. of links
China Hong Kong SAR	17	Greece	4	Bahamas	1	India	1
China	11	Denmark	3	Botswana	1	Luxembourg	1
Germany	9	Netherlands	3	Croatia	1	Mexico	1
Italy	6	Singapore	3	Dominican Rep.	1	Namibia	1
Malaysia	5	USA	3	Ecuador	1	New Zealand	1
Spain	5	Slovenia	2	El Salvador	1	Nicaragua	1
Belgium	4	Sweden	2	Estonia	1	Russian Federation	1
France	4	Switzerland	2	Finland	1	Slovakia	1

Source: authors' elaborations on WITS database

It is worth noting that both the origin and destination countries in Table 1 appear in several studies on illegal shipments of waste. The 2014 data from IMPEL shows that 70 per cent of illegal shipments detected in Europe were going to other European countries. Illegal shipments to Asia accounted for 20 per cent of the violations. China, including China Hong Kong SAR, was the preferred destination for illegal shipments to non-OECD countries, accounting for almost 56 per cent of total violations detected for shipments to developing countries (UNEP 2015). Data from Legambiente (2013) on the investigations of Italian Customs Authority show that China, China Hong Kong SAR, Greece, Turkey, Tunisia, Albania and India were the major sources of waste being shipped internationally; Italy, Albania, North Africa, the Middle East, China, Bulgaria and Ghana are the countries considered to be the main destinations for illegal shipments of waste. The list of all suspicious trade relations for each country of origin is provided in Appendix 2.

However, the data on bilateral flows might not reveal the routes for illegal shipments of waste because criminal organizations very often use a complex system of triangular exchanges to disappear without a trace. As far as the Italian experience is concerned, Legambiente (2013) reveals that a classic route of transboundary illegal shipments is, for example, the following: Italy-Germany-Netherlands-China Hong Kong-China.

In the next paragraph, therefore we apply the network analysis to all illegal bilateral trade flows that we have detected. We believe that this technique is particularly helpful for illuminating the structural features of illegal markets (Bruinsma and Bernasco 2004; Kinsella 2006). The attempt to provide a methodological framework that combines mirrors statistics method and network analysis represents the main innovative contribution of our research.

3. The network of illegal trade in polyethylene waste

3.1 The methodology

Over the last few years, several scholars (Garlaschelli *et al.* 2007; Bhattacharya *et al.* 2008; Jackson 2007, 2010; Fagiolo *et al.* 2008, 2010; De Benedictis and Tajoli 2011; De Benedictis *et al.*, 2013) have applied network analysis to identify the intensity and types of connections among different countries in international trade. In line with this literature, the first step of our analysis consists of the construction for each year *t* of weight matrix $\widetilde{W}_{ij}^{t}$ that is a symmetric N x N matrix with only zeroes in its main diagonal. In this matrix, the rows represent exporting countries ("*i*"), whereas the columns report importing countries ("*j*"). Moreover, in the matrix, the generic element labelled as $\widetilde{\omega}_{ij}^{t}$ represents the export values from country i to j in year t (and zero if the corresponding trade flow is zero). Then, we define a new weight matrix W_t where each element is calculated as the arithmetic average of import and export flows as in:

$$\omega_{ij}^{t} = \frac{1}{2}\left[\widetilde{\omega}_{ij}^{t} + \widetilde{\omega}_{ji}^{t}\right] \quad (3)$$

Finally, in order to have weights $\omega_{ij}^{t} \in [0,1]$, for each i, j, t, we normalize all entries in W_t by their maximum value $\omega_{max}^{t} = max_{i,j=1}^{N}\{\omega_{ij}^{t}\}$. Consequently, all bilateral weights sum up to one. Therefore, the generic element of final matrix X_{ij} is obtained by multiplying all flows by weights.

Using the Graph Theory, a network is generally composed of a set of vertices $V = \{2, 3\ldots g\}$ – countries - and a set of links – trade flows - $L = \{0, 1\ldots m\}$. Vertices can be measured according to the structural position of power in the network, whereas the links can be measured according to the type and amount of resources exchanged between pairs of actors i and j. In this analysis, the links are *directed*, going from the exporting country i to the importing country j; they are also *weighted*, indicating the value of trade and not only the binary structure that detects the mere presence or absence of a link between a pair of countries.

In describing the international trade network, first of all we define the actor set of countries ($N = 53$) that are connected by a relational variable built on the value of trade in plastic materials. Therefore, the data matrix is a square matrix in which the rows and columns represent all the countries in the same order: rows and columns indicate, respectively, the exports and imports of each country $\{i, j\}$. In this analysis, in the year 2012 the graph associated with the international trade network of waste plastics $\mathcal{G} = (\mathcal{V}, \mathcal{L})$ in the year 2012 has a dimension of 53 vertices ($\mathcal{V} = 53$) and 566 trade links ($\mathcal{L} = 566$).

In order to describe the properties of the international trade network, we present some summary statistics generally used in social network analysis. The *density* provides general information on the degree of connectivity within the network. In a binary network, density is simply defined as the ratio between the number of ties that are actually in place and the number of maximum ties possible; consequently, it corresponds to the average value of the binary entries. In a weighted network, density is expressed as the sum of weights not equal to zero divided by the total number of possible ties, and is formally equal to:

$$D = \frac{1}{g(g-1)} \sum_{i=1;j=1}^{g} Xij \quad (4)$$

where D is the density, g the number of vertices and X_{ij} are the sociomatrix elements. An increase in the density index over time means that countries are becoming more integrated and more dependent on each other for trade.

Another important statistic in network analysis concerns the extent to which a given vertex is “central" in the graph. The two most commonly employed definitions of centrality refer to a local notion (a vertex is central if it has a large number of ties) or to a global notion (a vertex is central if it plays a strategic position in the overall structure of the network).

Local centrality can easily be measured by vertex *degree centrality* (c_i). In a binary network, vertex degree centrality measures the number of links that a given vertex has established, i.e., how many connections it holds. In a weighted network, vertex degree centrality is the sum of all values corresponding to the edges incident with it. In both cases, the mathematical expression is:

$$c_i = \sum_{j=1}^{g} Xij \qquad (5)$$

where g is the number of vertices and X_{ij} the sociomatrix elements.

Since vertex *degree centrality* depends on the number of existing links in the network, it is often useful to standardize the c_i by their maximum possible value[6]

$$c_i^{st} = \frac{c_i}{c_{max}} \qquad (6)$$

Since a vertex can be a sender and a receiver, the *in-degree* of a vertex *i* is the number of links received by i, whereas the *out-degree* is the number of links initiated by *i*. In a weighted network approach, degree centrality considers trade volumes instead of trade links. The normalized degree centrality is computed summing all the weights associated to the links held by any given node. By excluding reflexive links (the sociomatrix diagonal is always zero), the in-degree (C_i^{IN}) and out-degree (C_i^{OUT}) of vertex i may be written as:

$$C_i^{IN} = \frac{1}{g-1} \sum_{j=1}^{g} X_{ji} \qquad (7)$$

$$C_i^{OUT} = \frac{1}{g-1} \sum_{j=1}^{g} X_{ij} \qquad (8)$$

where g is the number of vertices and $\{X_{ji}, X_{ij}\}$ are the sociomatrix elements received and initiated by i.

As far as global centrality is concerned, the most used indicator is *betweenness centrality* (C_i^{BET}) defined as the proportion of all the shortest paths between any two nodes that pass through a given node. Based on the notion that a vertex *i* is central if it is essential in the indirect link between vertex j and vertex k, betweenness centrality measures the extent to which a given node acts as an intermediary in the network. In particular, the betweenness centrality for a given vertex *i*, is computed as the sum of the ratios of the number of geodesic paths between all possible pairs of vertices *j* and *k* involving vertex *i* to the number of all geodesic paths between *j* and *k*:

$$C_i^{BET} = \sum_{j=1;k=1}^{g} \frac{GPaths\ j \to i \to k}{GPaths\ j \to k} \qquad (9)$$

where *g* is the size of the network, *GPaths j→k* is the total number of geodesic paths from vertex *j* to vertex *k* and *GPaths j→i→k* is the total number of geodesic paths from vertex *j* to vertex *k* involving *i*[7]. Another measure of global centrality is the network centralization index [10] which describes the extent to which the cohesion of a network is organized around particular focal points; in particular, a high centralization index indicates a network where a few key actors are highly connected to all others, and less central actors tend to be connected only to those central actors.

Formally, the network centralization index (C) is equal to:

$$C = \frac{\sum_i (c^* - c_i)}{max \sum_j (c^* - c_i)} \qquad (10)$$

[6] This measure - calculated using the total number of possible neighbors excluding self, g-1, as normalized factor - ranges from 0 to 1; the closer degree centrality is to 1, the more directly connected a country is to the rest of the network.

[7] The normalized betweenness centrality is the betweenness divided by the maximum possible betweenness expressed as a percentage.

where $c^* = max\{c_1, c_2, \dots, c_n\}$. The network centralization index is $0 \leq C \leq 1$. In particular, C = 0 when all nodes have the same centrality; and C = 1 if one actor has maximal centrality and all others have minimal.

3.2. The network of illegal trade in polyethylene waste: some results

In Table 2, we compare some of the network characteristics of illegal flows in polyethylene waste over time. First, we note that the number of illegal trade links among countries (i.e., the number of arcs) has increased substantially, nearly doubling from 2002 to 2012. We also observe an increasing trend in the density of the network. This means that, on average, each country has a larger number of partners and that the network is becoming more intensely connected. Moreover, the increase in weighted density – its value tripled between 2002 (24.00) and 2012 (75.68) - means that on average countries tend to hold more intense trade relationships between one another.

However, the change in density was not as uniform within the network as the change in the centralization indices suggests. First, the network centralization index decreased over time from 19.92 per cent in 2002 to 13.07 per cent in 2012. Since this index provides a network-level measure of the range of centralities of an individual country in the network, with centrality representing how connected each country is to all the others, a reduction means that a growing number of countries have become increasingly central in the network, subtracting power from those that were initially dominant. As we will see later, this phenomenon could be better interpreted by comparing how the position of each country has changed in the ranking over time.

Table 2. Illegal trade network indices over time

	2002	2007	2012
N° of arcs	371	484	566
Out-degree (mean)	8457	25963	16115
In-degree (mean)	11823	45469	42262
Network Centralization Index	19.92%	17.11%	13.07%
Density (mean)	462	1374	1455
Density (Wtd mean)	24008	71423	75682

Source: authors' elaborations on WITS database

Looking at the trend of in-degree centrality over time, we see that trade intensity has become more concentrated around a core group of countries. On the other hand, considering outward flows (exports), we observe that until 2007 illegal trade was increasingly concentrated around a few main actors, while in 2012 centrality sharply declined. This might be a signal of the presence of new countries, which have increased their involvement in this market.

Table 3 provides an overview of countries' position within the trade network over time. Looking at the weighted in-degree index (column 1-Table 3), we see that China always occupies the top place, highlighting its central role in the trade network of polyethylene waste: the average flows of imports increased from 12061 tons in 2002 to 42920 tons in 2012. This is not surprising given that this country is the preferred destination for both legal and illegal shipments of plastic waste. Estimates suggest that the 87 per cent of all plastic collected in the EU goes to China (Velis 2014) and that 90 per cent of imported waste plastics have been imported without the required waste permit from the State Environmental Protection Administration (Kojima et al. 2011).

The Indian subcontinent also has an important role as a destination area for polyethylene waste. In particular, India moved from sixth place in 2002 to fourth in 2012, while Malaysia entered the top 10 positions in 2012.

Some countries deserve a special consideration for having top positions in terms of both their in-degree and out-degree indices. The case of China Hong Kong SAR is quite interesting since it occupied the second place in terms of in-degree index and the first in terms of out-degree index up to 2007. China Hong Kong SAR is a duty-free port known as an international through port for goods from Europe or the United States bound for China and the Asia region. Because of its geographical location and economic function as a gateway to the mainland, many shipments of waste, including plastic waste, pass through China Hong Kong SAR. However, its out-degree centrality is decreasing over time mainly due to enhanced control measures by local customs authorities; in fact, it moved from first position in 2002 and 2007 to fourth in 2012. Similarly, there are some European countries such as the Netherlands, Germany, and Belgium which always place in the top 10 positions in terms of both in-degree and out-degree indices; their centrality is due to the existence of large ports – such as Rotterdam in the Netherlands, Antwerp in Belgium, Bremen and Hamburg in Germany – which play an important role in transhipment operations. As both cause and effect, there is also the presumed existence of an underground infrastructure that makes it possible (even easy) to get waste to these countries and of course profitable. IMPEL-TFS (2005) reveals that Belgian and Dutch ports, which are identified as so-called hub ports for waste shipments within and outside of the EU, reported the most violations.

Finally, looking at the second column of Table 3, we observe how the US and the UK, occupy positions of prominence as the main country of origin over the considered period.

Quite often, the illegal shipment of waste is not a bilateral exchange between two countries, but involves a complex system of triangular exchanges among different countries that act as intermediaries. In such a case, the betweenness centrality index could be a good measure since it expresses the role of a country in mediating the interactions between nonadjacent nodes, and in acting as a hub within the network.

In the third column of Table 3, we see that in the top ten positions there are some countries identified as important source locales (the USA, Germany and the UK) and some of the countries identified as central destinations (China and Malaysia). However, it is also worth noting the presence of other countries which seem to have the specific role of intermediary (the Philippines and South Africa). The role of these countries in the illicit traffic of waste is also confirmed in Figures 1-3 in Appendix 1.

Table 3 Top ten countries' centrality in the illegal trade network

	IN-DEGREE			OUT-DEGREE			BETWEENNESS		
	Rank	Country	Index	Rank	Country	Index	Rank	Country	Index
Year 2002	1	China	12061.75	1	China Hong Kong SAR	8759.275	1	Germany	21.376
	2	China Hong Kong SAR	6088.216	2	Germany	3884.051	2	USA	20.383
	3	Netherlands	1233.602	3	USA	3657.146	3	China	6.892
	4	Italy	995.019	4	Belgium	2883.608	4	Netherlands	6.468
	5	Belgium	716.989	5	Netherlands	1275.495	5	Italy	5.78
	6	India	655.097	6	France	1160.04	6	China Hong Kong SAR	4.853
	7	Germany	566.512	7	United Kingdom	650.775	7	United Kingdom	4.524
	8	Spain	387.208	8	Switzerland	253.706	8	South Africa	3.698
	9	France	273.808	9	Denmark	245.186	9	Austria	2.648
	10	United Kingdom	231.84	10	Malaysia	227.979	10	Switzerland	2.469
Year 2007	1	China	45984.684	1	China Hong Kong SAR	26846.377	1	Germany	18.629
	2	China Hong Kong SAR	13177.079	2	Germany	14569.735	2	USA	13.269
	3	Netherlands	2643.563	3	USA	8249.809	3	China	11.27
	4	Belgium	1748.965	4	United Kingdom	5495.205	4	Italy	7.995
	5	India	1672.387	5	Netherlands	3296.252	5	United Kingdom	7.851
	6	Germany	1383.743	6	Belgium	3162.241	6	Belgium	7.186
	7	Italy	1049.947	7	France	2680.652	7	Malaysia	4.914
	8	Austria	824.738	8	Rep. of Korea	1399.955	8	South Africa	3.785
	9	France	717.533	9	Italy	668.707	9	Netherlands	3.453
	10	Spain	539.614	10	Sweden	635.967	10	China Hong Kong SAR	2.77
Year 2012	1	China	42920.004	1	Germany	17266.018	1	China	14.692
	2	China Hong Kong SAR	11535.78	2	USA	10970.224	2	USA	11.634
	3	Germany	4540.263	3	United Kingdom	10507.696	3	Germany	9.737
	4	India	3128.35	4	China Hong Kong SAR	9100.939	4	South Africa	7.098
	5	Netherlands	2602.625	5	France	5464.112	5	Malaysia	6.908
	6	Belgium	2333.814	6	Belgium	4031.018	6	Italy	5.58
	7	Austria	1174.438	7	Netherlands	3246.849	7	Philippines	5.205
	8	Malaysia	1063.048	8	Austria	1348.369	8	United Kingdom	4.87
	9	Italy	893.512	9	Italy	1297.091	9	China Hong Kong SAR	4.208
	10	USA	748.667	10	Mexico	1285.571	10	Belgium	3.466

Source: elaborations on WITS database using UCINET

In order to highlight the extent to which some countries play an increasingly central role in the network of illegal waste shipments, Table 4 shows how countries change their ranking in terms of the betweenness index over time. It is interesting to note how several countries jumped in their ranking between 2002 and 2012. In particular, the Philippines moved from 48th to 7th place, Thailand moved from 49th to 15th place, Poland moved from 38th to 17th place, the

Republic of Korea moved from 28th to 13th place, Singapore moved from 34th to 20th place, and Greece moved from 29th to 16th place.

Table 4. Countries' betweenness indices rankings

	Ranking			
	2002	**2007**	**2012**	
Germany	1	1	3	↓
USA	2	2	2	-
China	3	3	1	↑
Netherlands	4	9	11	↓
Italy	5	4	6	↓
China Hong Kong SAR	6	10	9	↓
United Kingdom	7	5	8	↓
South Africa	8	8	4	↑
Austria	9	47	21	↓
Switzerland	10	31	18	↓
Australia	11	13	25	↓
Malaysia	12	7	5	↑
Ireland	13	39	24	↓
Belgium	14	6	10	↑
Sweden	15	16	27	↓
France	16	12	12	↑
Hungary	17	20	37	↓
Slovenia	18	28	14	↑
Spain	19	29	22	↓
Norway	20	35	33	↓
Finland	21	23	34	↓
Denmark	22	22	23	↓
Mexico	23	19	31	↓
Russian Federation	24	42	40	↓
Indonesia	25	38	35	↓
Czech Rep.	26	14	28	↓
India	27	30	26	↑
Rep. of Korea	28	17	13	↑
Greece	29	36	16	↑
Luxembourg	30	53	53	↓
Bulgaria	31	26	38	↓
Romania	32	15	29	↑
Slovakia	33	27	30	↑
Singapore	34	18	20	↑
Portugal	35	32	36	↓
Croatia	36	37	39	↓
Estonia	37	25	32	↑
Poland	38	21	17	↑
Nicaragua	39	46	46	↓
Iran	40	44	43	↓
Dominican Rep.	41	51	42	↓

Table 4 (*continued*). Countries' betweenness indices rankings

	Ranking			
	2002	2007	2012	
Bahamas	42	48	48	↓
Namibia	43	49	49	↓
Botswana	44	45	44	-
New Zealand	45	41	45	-
Guatemala	46	11	19	↑
Saudi Arabia	47	40	47	-
Philippines	48	24	7	↑
Thailand	49	33	15	↑
Tunisia	50	50	50	-
United Arab Emirates	51	34	51	-
Ecuador	52	52	52	-
El Salvador	53	43	41	↑

Stringent enforcement in one country commonly leads to changes in traditional illegal shipment routes through neighboring countries. Strong enforcement practices, such as China's Green Fence campaign, have been changing the traditional routes for illegal waste shipments. For example, a report by the Associate Parliamentary Sustainable Resource Group (2014) in the UK reveals that evidence submitted to the inquiry indicated that Vietnam, Indonesia, Cambodia and Thailand might already have become the destinations of choice for poor quality material from UK plastic exports.

4. Conclusions

Over the past decade, international trade in waste products has been steadily increasing due to the gap between volumes collected for recycling and the domestic recycling and reprocessing capacity in many industrialized countries, as well as the higher demand for virgin raw materials in many less developed countries. However, together with the increasing value of the waste and sustainable resource market, there has been a similar growing interest by criminal organizations in the illegal shipment of waste and recovered materials. According to the UN Environment Programme (2016), crime syndicates earn $10 to $12 billion a year from waste crime. In this paper, we focus our attention on the illegal shipment of waste plastics with particular attention to waste in polymers of ethylene. The main purposes of this study it to provide a methodological framework able to enhance our understanding of illegal waste shipments. Quantities of waste traded illegally are by definition not recorded in official databases, we identify illegal trade flows by comparing for a given period, the quantity that country A declares that it exports directly to country B with the corresponding quantity that country B declares that it imports directly from country A. Once we have defined such a illegal trade structure, we perform network analysis in order to describe not only the degree of connectivity among countries but also the extent to which some countries play an increasingly central role in the network.

The results of this study, that is the first attempt of analyzing the illegal shipment of plastic waste using the network analysis, are in line with those of several reported investigations that have identified some countries as important source locales (the USA, Germany and the UK) and others as central destinations (China and Malaysia) of illegal shipments of waste plastics. Moreover, our methodology allows us to highlight the presence of other countries that play an intermediary role within the global trade network. Finally, looking at the evolution of the network over time, we can detect the changes in traditional illegal shipment routes.

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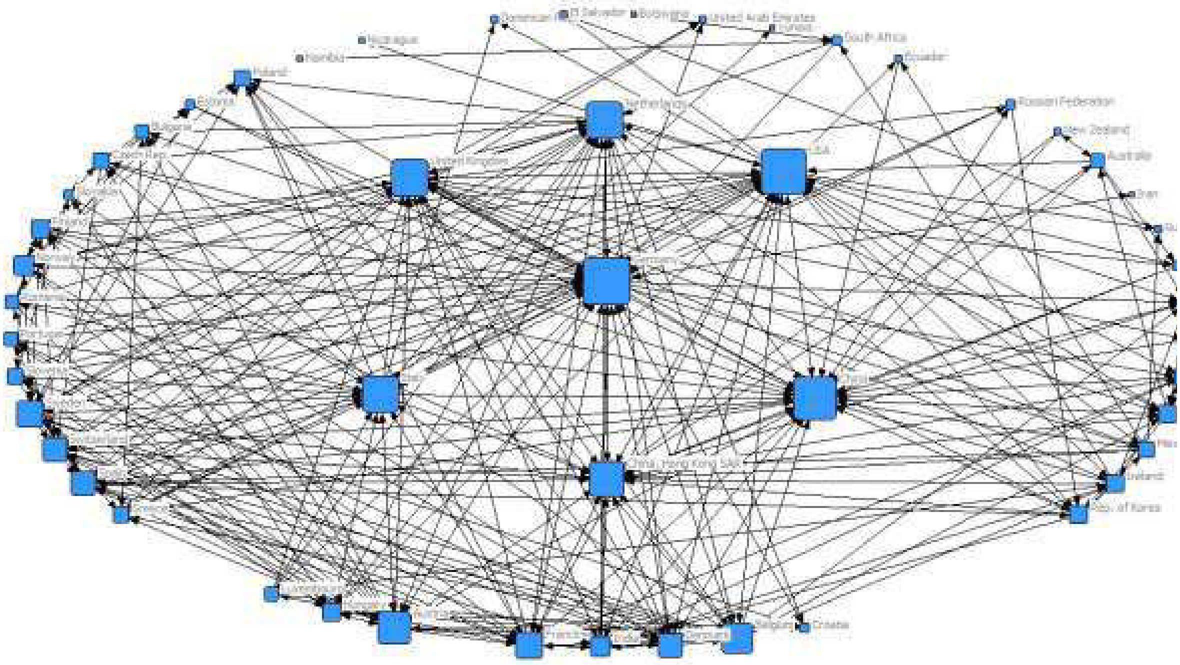
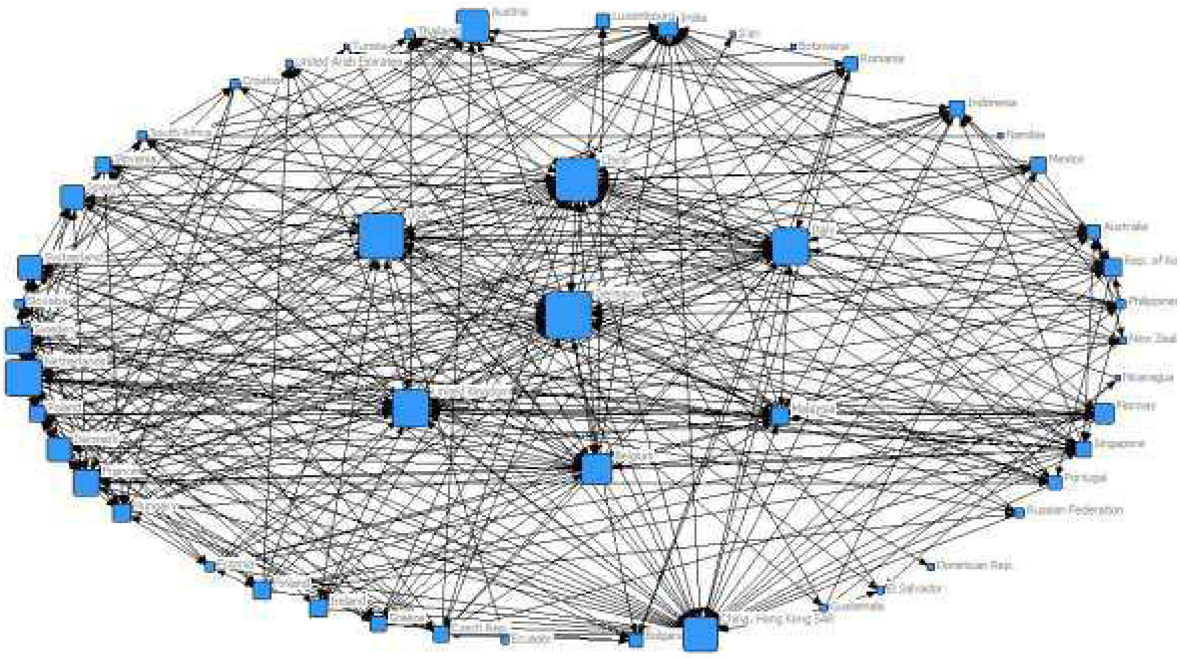
Appendix 1. Evolution of network of international trade of polyethylene waste

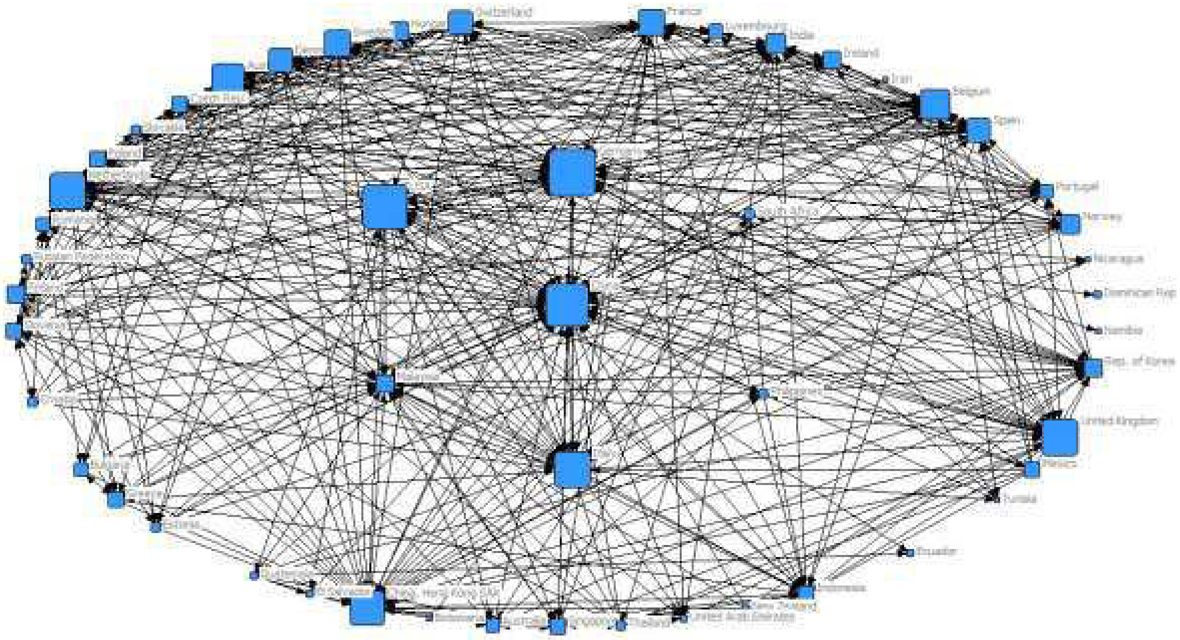
YEAR 2002



YEAR 2007



YEAR 2012


Switzerland
France
Luxembourg
India
Ireland
Iran
Belgium
Spain
Portugal
Norway
Nicaragua
Dominican Rep
Namibia
Rep. of Korea
United Kingdom
Mexico
Tunisia
Ecuador
Indonesia
New Zealand
United Arab Emirates
Thailand
Australia
China, Hong Kong SAR
El Salvador
Malaysia
Philippines
South Africa
Czech Rep.
Poland
Russian Federation

Appendix 2: Suspicious bilateral relationships

Countries	Suspicious bilateral relationships					
Australia	AUS_CHN	AUS_NZL	AUS_SGP			
Austria	AUT_BEL	AUT_DEU	AUT_ITA	AUT_SVN		
Belgium	BEL_CHN	BEL_GRC	BEL_ITA			
Bulgaria	BGR_GRC					
China	CHN_USA					
China Hong Kong SAR	HKG_CHN					
Czech Rep.	CZE_DEU	CZE_SVK				
France	FRA_BEL	FRA_CHE	FRA_CHN	FRA_HKG	FRA_MYS	
Germany	DEU_BEL	DEU_ESP	DEU_FRA	DEU_GRC	DEU_HRV	DEU_ITA
	DEU_LUX	DEU_RUS	DEU_SWE			
Guatemala	GTM_NIC					
Hungary	HUN_DEU					
India	IND_HKG					
Indonesia	IDN_CHN					
Iran	IRN_DEU					
Ireland	IRL_DEU	IRL_HKG				
Italy	ITA_FRA	ITA_GRC	ITA_HKG	ITA_SVN	ITA_USA	
Luxembourg	LUX_FRA					
Malaysia	MYS_CHN	MYS_HKG	MYS_SGP	MYS_USA		
Mexico	MEX_HKG					
Netherlands	NLD_BEL	NLD_CHN	NLD_DEU	NLD_DNK	NLD_ESP	NLD_HKG
	NLD_MYS					
New Zealand	NZL_HKG					
Norway	NOR_DEU	NOR_DNK	NOR_SWE			
Philippines	PHL_MYS					
Poland	POL_DEU	POL_HKG	POL_NLD			
Portugal	PRT_ESP					
Rep. of Korea	KOR_HKG					
Romania	ROU_ITA					
Russian Federation	RUS_CHN					
Saudi Arabia	SAU_HKG					
Singapore	SGP_HKG					
Slovenia	SVN_DEU					
South Africa	ZAF_BWA	ZAF_HKG	ZAF_NAM			
Spain	ESP_FRA	ESP_ITA				
Sweden	SWE_DNK	SWE_EST	SWE_FIN	SWE_HKG		
Switzerland	CHE_BEL	CHE_CHN	CHE_HKG	CHE_NLD		
Thailand	THA_HKG	THA_MYS				
Tunisia	TUN_CHN					
United Arab Emirates	ARE_IND					
United Kingdom	GBR_CHE	GBR_CHN	GBR_ESP	GBR_HKG	GBR_ITA	GBR_MYS
	GBR_NLD					
USA	USA_BHS	USA_DOM	USA_ECU	USA_ESP	USA_MEX	USA_SGP
	USA_SLV					