The role of local stakeholders in disseminating knowledge for supporting the Circular Economy: a network analysis approach

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1. Introduction

During the last years, the concept of the Circular Economy (CE) has received increasing attention from practitioners, policymakers and scholars alike (Antikainen et al., 2018; Korhonen et al. 2018); this is largely due to the rapid evolution of developed countries' industrial productive systems since the second half of the 19th century (Whicher et al., 2018). In advanced industrial systems, such as the ones of Europe, Japan, the US, and, in the last years, China, the dominant linear economic model 'take, make, and dispose' (Ghisellini et al., 2016) has increasingly been accompanied by new arguments focused on closed loop material systems (Stahel, 2010), cradle-to-cradle flows (Braungart et al., 2008), reuse of goods, recycling of materials and resource efficiency (Bocken et al., 2016), and decoupling prosperity from resource consumption (Sauvé et al., 2016). Therefore, CE emerged as a regenerative system that contributes positively to an efficient use of resources, by keeping materials and products at their highest utility and value through the adoption of closing-the-loop activities (Ellen MacArthur Foundation, 2013).

Worldwide, the concept of CE is thus gaining rapidly in importance, not only as an alternative cyclical flow model, but also as a biophysical and business model to boost competitiveness and the development of new forms of business (Bocken et al., 2014, 2016; De Jesus and Mendonça, 2018; Ghisellini et al., 2016; Lahti et al., 2018). Besides academia and business, the concept of CE has gained traction with governments and intergovernmental agencies (Geissdoerfer et al., 2017). Germany is considered a pioneer in this sense, with the enactment of the Closed Substance Cycle and Waste Management Act (Su et al., 2013), preceded by the implementation of the Dual System for waste collection in 1991 (Bertossi et al., 2002). Similarly, in 2002, the Japanese government introduced the Basic Law for Establishing a Recycling-Based Society (METI, 2004), while China was the first country to explicitly refer to CE in a normative act, with the 2009 Circular Economy Promotion Law (Su et al., 2013; Geissdoerfer et al., 2017). In 2015, the European Commission promoted the introduction of the European CE package (COM, 2015; Domenech and Bahn-Walkowiak, 2019), which supported the introduction of good practices of CE at different levels, in particular at local levels. Although the efforts made by the European Commission to make CE one of the leading concepts for its future industrial policy (COM, 2015), China and the United States are among the leaders in CE-related research programmes (Su et al., 2013; Stahel, 2016; McDowall et al., 2017) at the global level.

In spite of literature suggesting that the scientific research content of the CE 'remains largely unexplored' (Korhonen et al. 2018: 37), the cornerstones of the CE model have been clearly defined. It focuses on four main principles (restorative loops; resilience; energy from renewable resources; systemic approach), and it builds also upon the industrial ecology and industrial symbiosis literature (Abreu and Ceglia, 2018; Herczeg et al. 2018; Martin and Harris, 2018); it is primarily based on the notion of resource cycles, and it aims to keep products and materials at their highest value (Ellen MacArthur Foundation, 2013). In light of these four principles, the CE concept is related to network perspectives with their focus on coordination and knowledge exchange: Geissdoerfer et al. (2017: 762) highlight the 'relevance of coordination between multiple agents', while Ghisellini et al. (2016: 12) stress that 'sustainability patterns (such as CE) not only require innovative concepts but also innovative actors. In fact, due to the complexity of the sustainable development vision, most often its implementation needs to be supported by innovation designers and intermediaries who provide services and designs towards appropriate radical changes'. Similarly, from a supply chain management perspective, the stakeholders' involvement, as part of a more effective sustainability management approach, supports the transitioning toward a circular economy (Genovese et al., 2017). While the industrial ecology literature has also emphasized the multi-stakeholders' involvement in CE transitioning (Winans et al., 2017), the question remains what the particular role of individual and multiple stakeholders is in this transitioning process, in particular at local level. The review by Reed (2008) documented that stakeholder participation can enhance the quality of environmental decisions, while it has been recognized that multi-stakeholder processes are necessary to implement public policies in response to complex challenges related to environmental changes (Newig and Fritsch, 2009; Saint Ville et al., 2017). Recent work has thus analysed stakeholders' views for Extended Producer Responsibility (EPR) regulations, which require that producers organize and pay for treatment and recycling of waste arising from their products (Kunz et al., 2018). Other studies have investigated the contribution of single stakeholders, mainly private organizations, in changing product strategies to appeal to consumers (De los Rios and Charnley, 2017; Urbinati et al., 2017). Scholars have further identified the views of individual stakeholders, such as that of private organizations in

Europe (Leipold and Petit-Boix, 2018), the extent and role of local government (Wright et al., 2018), and the extent to which CE research aligns with local practices when considering city initiatives (Petit-Boix and Leipold, 2018).

The role of stakeholders' knowledge-sharing to support the transition toward CE has recently received attention in the literature, even if it is still an unexplored issue. The recent work by Marra et al. (2018) investigated the potential for knowledge sharing and research-based cooperation in policymaking process. Using Social Network Analysis (SNA) applied to secondary data, the authors investigate the potential for cooperation across research disciplines working on CE, to highlight that a shift to a CE system needs effective policy interventions. Sending to or receiving knowledge from experts has been viewed as the basis for the implementation of public policies (Reed et al., 2014), and policymaking has been characterized by the concurrent exchange of different forms of knowledge on different issues in a multi-stakeholder setting (Partidário and Sheate, 2013; Sheate and Partidário, 2010).

In spite of the above works, it appears that much of the CE-related studies concentrates on economic and environmental aspects, particularly on the redesign of manufacturing systems, the renewal of energy production and distribution systems, and the management of input flows (e.g. Murray et al., 2017), with a relatively more limited focus on knowledge exchange and the network dimension. Moreover, the social dimension appears to be neglected, both in terms of social impacts of CE and in terms of social relationships that can lead to the development of a CE system (Kirchherr et al., 2017; Moreau et al., 2017; Murray et al., 2017; Sauvé et al., 2016). It appears that there is a lack of empirical studies on the role of local stakeholders interacting for the development of a local CE system (Domenech and Bahn-Walkowiak, 2019). The introduction of a CE model requires the development of local processes aimed at introducing closing-the-loop activities (Ellen MacArthur Foundation, 2013). The assessment of these activities requires a micro- and local level evaluation framework (Christis et al., 2019). Specifically, a network-based analysis of local stakeholder interactions appears missing, and an investigation into the roles played by these stakeholders for developing a CE system.

In light of the above evidence, this paper seeks to answer the following research question: which roles are played by local stakeholders involved in the implementation of a local system of CE initiatives? The aim of this study is to provide two key contributions. First, we intend to contribute with the provision of a network perspective on CE, applied to primary data from stakeholders active in local CE-related initiatives. Second, we extend the evidence-basis on CE-based stakeholder involvement from European regions and cities. The case study from Bavaria by Messmann et al. (2019) focuses on the theoretical potential for the preparation for the reuse of specific waste material streams, whereas the case study from Sweden by Miliute-Plepiene et al. (2015) identifies factors for improving stakeholder behaviour with regard to food waste sorting. Since European cities comprise more than 70% of the total European population and mid- and low size cities (below 250,000 inhabitants) account for 28% of the total city residents in the European context (European Commission, 2016), our case analysis concentrates on the City of Ferrara (Italy), which is representative of the small or medium-sized European cities in terms of urban population; moreover, in the last years, this city has promoted a number of initiatives to promote CE with the aid of local stakeholders. In contrast to previous case analyses, ours is unique in that it maps interactions between stakeholders based on the knowledge exchange with respect to five of the most important activities gathered under the label of CE (COM, 2014): food waste reduction, organization of local supply chains, energy saving, waste management, and ecosystem services provision. The underlying data are used to conduct a SNA of stakeholders' activities within their knowledge networks. We map the multiple knowledge exchanges between stakeholders, and we analyse their brokerage roles pursuing shared objectives on specific CE activities. The paper is structured as follows. Section 2 provides a short introduction on the relevant CE literature, and, in particular, the importance of the stakeholder networks in CE implementation. In section 3, the data and methods are described. Section 4 presents and discusses the results, while section 5 concludes.

2. Literature

2.1. Circular Economy (CE)

The origins of CE can be traced to ecological economics, environmental economics and industrial ecology (Ellen MacArthur Foundation, 2013; Ghisellini et al., 2016; Geissdoerfer et al., 2017; Winans et al. 2017; Antikainen et al., 2018). As pointed out by Andersen (2007) and Geissdoerfer et al. (2017), the notion of CE is rooted in the works of Kenneth Boulding (1966), Nicholas

Georgescu-Roegen (1971), and Pearce and Turner (1990). Boulding (1966) was perhaps the first to highlight problems related with the standard open representation of the micro-economic system, which he labelled as 'cow-boy economy', to argue for a new conception that addressed recycling ('spaceship economy'). Georgescu-Roegen (1971) stressed the idea of the thermodynamic nature of the economic cycle and the unavoidable energy dissipation from raw materials to consumption. Starting from these contributions, Pearce and Turner (1990), by adopting an environmental economics perspective, first introduced the notion of CE, addressing the interlinkages between four economic functions: amenity values; a resource base for the economy; a sink for residual flows and a life support system.

Other theoretical foundations of CE are found in different disciplines (Ellen MacArthur Foundation, 2013): industrial metabolisms (Ayres, 1994); regenerative design (Lyle, 1994); biomimicry (Benyus, 2002); product life cycle and performance economy (Stahel, 2010); waste management, in particular the cradle-to-cradle approaches (Bakker et al., 2014; McDonough and Braungart, 2002). The notion of the CE is based on three key activities, namely reduction, reuse, and recycle (the so-called '3R's Principles') in the processes of production, consumption and circulation (Feng and Yan, 2007; Yong, 2007), which are applied to the design of products, directing consumer choice, lending or sharing of services, modernisation of waste policy, and resource efficiency (COM, 2014). The Ellen MacArthur Foundation (2013: 7) introduced CE as 'an industrial economy that is restorative or regenerative by intention and design'. Sauvé et al. (2016) add emphasis on the closed loops issue: CE is the production and consumption of goods through closed loop material flows, internalizing environmental externalities linked to virgin resource extraction and to the generation of waste and pollution. Geng and Doberstein (2008b) remark that the viability of the reintegration of post-consumption products into the manufacturing process claims for economic incentives. Bocken et al. (2016) refer to CE as a system of design and business model strategies able to slow down, close, and narrow resource loops: they claim that CE gets the cycling of resources through the design of long-life goods and product-life extension, the extension and intensification of the utilization period for products, the closure of the loop between post-use and production, and the saving of resources per product unit.

The application of the '3R's Principles' relates to the concepts of sustainability and sustainable development, in terms of their focus on environmental conservation and economic development (Pearce, 1988), since sustainable development is a collective long-term goal involving the exploitation and scarcity of resources, the direction of investments, and the orientation of technological development (Clark, 2007; von Weizsäcker and Wijkman, 2018).

Despite the linkages between the concepts of sustainable development and CE, a number of recent works have contributed to clarify their similarities and differences (Geissdoerfer et al., 2017; Korhonen et al. 2018; Pieroni et al., 2019). Scholars have increasingly supported the assumption that sustainability can be achieved through the CE as a new pattern of growth (Heshmati, 2016). As for the implementation of a sustainable system, CE requires the development of deep and harmonious relationships between economy, environment, and society, in order to achieve mutually supporting progress and competitiveness (Domenech and Bahn-Walkowiak, 2019). Nonetheless, sustainable development is a society objective defined at the macro-level and includes broad notions of ecological, economic, and social sustainability (Bartelmus, 2013); in contrast, the CE concept is also defined at the micro- and local level (Christis et al., 2019), yet is an evolving concept (Merli et al., 2018). In this sense, the idea of CE prioritises the economic systems with primary benefits for the environment, and only implicit gains for social aspects.

CE emerged as an umbrella concept in the 2010's (Blomsma and Brennan, 2017), envisioning the achievement of a more resource effective and efficient economic system through the implementation of business model strategies based on narrowing resource loops (Bocken et al., 2016). This concept is seen as a means to achieving sustainability, with a narrower focus on the economic and environmental dimensions, rather than the social dimension. The concept of CE has progressively influenced policymakers at local, national, and international levels (Geissdoerfer et al., 2017a): CE initiatives started to be promoted at institutional levels, sometimes by means of soft legislation, e.g. in Japan (UNEP, 2013) and in the EU as part of CE initiatives (COM, 2015), and sometimes with a top-down approach through command-and-control policies, e.g. in China (Geng et al., 2012; Su et al., 2013). As for the EU, only limited progress has been accomplished in regard to implementing the CE concept (Kirchherr et al., 2018). In many cases, legislation and policy initiatives have followed five key activities gathered together under the label of CE (COM, 2014), namely food waste reduction, the organization of local supply chains, energy saving, waste

management, and ecosystem services provision. Food waste and waste management in general are worldwide problems, which are both increasingly addressed by governments and international organizations (Xu et al., 2016; Canali et al., 2017) and explored by researchers interested in the transition towards a circular food system (Ek and Miliute-Plepiene, 2018; Jurgilevich et al., 2016). Considering the organization of local supply chains, it is viewed neither as a strictly social nor an environmental problem or an objective to achieve, but it can be a strategy to reduce wastage and increase logistic efficiency throughout socially and environmentally responsible value chains (Gallaud and Laperche, 2016). With regard to energy saving, it is viewed as an objective of a functional circular model, which provides for the reduction of energy demand and the increase in using renewable energy sources (Cooper et al., 2017). The provision of ecosystem services is strictly related to the concept of circular flows of resources, even if it is 'far less well understood' (Ellen MacArthur Foundation, 2013: 17).

In light of the above conceptual underpinnings, we anticipate that the implementation of a CE system requires the involvement of multiple stakeholders at different institutional and regional levels, since it needs the development of deep and harmonious relations in order to achieve mutually supporting progress and competitiveness (Domenech and Bahn-Walkowiak, 2019). The adoption of local policies for the implementation of a CE system can result from stakeholder interactions occurring at a macro-institutional (Geng and Doberstein, 2008a) or micro levels (Kirchherr et al., 2018). This focus on inter-organizational relationships points to the potential importance of networks among stakeholders, and the potential role that policymakers have in developing strategies built on CE.

2.2. **Local stakeholder involvement and network perspective for promoting CE**

The geographical scale at which the notion of CE is analysed and implemented is critical for its success, yet the issue of spatial and system boundaries remains contested in the CE debate (Bahers et al., 2017). The policies for the implementation of CE perspectives are mostly designed at the national, if not supranational level (e.g. EU), frequently paying less attention to local levels (McDowall et al., 2017). This is also evident with respect to the definition of the indicator system for CE, which is well-developed at the national-level, but still incomplete at the urban-level (Geng et al., 2012). The idea of CE at the local (urban) scale embraces the notion of proximity and the role of local actors (Bahers et al., 2017). It focuses on the capability at which local-level basic needs can be satisfied, such as with regard to food or waste recovering (Emelianoff, 2007). Therefore, a local-level focus for developing CE becomes potentially of fundamental importance, because, as illustrated by Graymore et al. (2008: 369), at this scale 'the community is more easily mobilised for collective action'. However, it is important to distinguish between stakeholders' involvement in the CE and stakeholders' involvement in sustainability activities. CE-related activities are specifically based on the idea of keeping materials and products circulating in a closed loop; as illustrated by Pieroni et al. (2019), CE is intended as a means to achieve sustainability, but not all systems adopting CE principles are intrinsically sustainable. Universities and research centres, whose social mission is to support knowledge dissemination, stimulate circular regeneration by cooperating in symbiosis with local communities, supporting the introduction of knowledge-based systems and mobilising human and economic resources in order to promote a culture of reduction, reuse, and recycle (De Medici et al., 2018; Kalmykova et al., 2018). Private organizations concentrate on innovating their productive processes by creating 'products that are easy to disassemble, and maintain an internal responsibility for reutilizing material through successive life cycles' (Buch et al., 2018: 709); moreover, they are encouraged to create 'holistically sustainable supply chains', to increase 'competitive advantage, reputation, and legitimacy' (Buch et al., 2018: 710).

Local stakeholder involvement has been investigated in a number of researches. German and Scottish case studies have shown that public awareness and understanding about CE is still poor between local stakeholders (Leipold and Petit-Boix, 2018, and Wicher et al., 2018, respectively). This is likely an outstanding problem, since stakeholder participation and collaboration are crucial for the development of CE systems (Ghisellini et al. 2016; Govindan and Hasanagic, 2018; IES, 2015; Leipold and Petit-Boix, 2018; Wicher et al., 2018). The existence of barriers to the implementation of CE claims is critical for educational and awareness actions by institutions (Su et al., 2013), as well as for deeper communication and information among local stakeholders (Brown and Bajada, 2018). When these barriers are overcome, local stakeholders can communicate effectively, for instance for directing and coordinating local inhabitants' activities and for measuring related performance (Brown and Bajada, 2018). The potential role of stakeholders is

further addressed by Messmann et al. (2019), who identify via a case study from Bavaria a theoretical potential for the preparation for reuse of specific waste material streams, highlighting the importance of the role of mode of collection. Miliute-Plepiene and Plepys (2015) provide further case study evidence from Sweden, identifying factors for improved stakeholder behaviour with regard to food waste sorting.

Stakeholder and network perspectives are also captured in the literature on Industrial Symbiosis (IS), which highlights the importance of possessing different capabilities to promote CE, i.e. involving different stakeholders in networks of relations. Abreu and Ceglia (2018: 100) point out that 'CE requires actors to work together to solve a collective problem, their ability to do so being shaped by institutional capacity (IC)'. The specific knowledge owned by local stakeholders can be targeted to solve problems, such as local environmental management issues; therefore, integrating different spheres of knowledge, by creating relational networks, while supporting the capacity to absorb new knowledge from others, is fundamental to find common solutions (Jiao and Boons, 2017).

Beyond stakeholder involvement at multiple levels, the question remains as to the specific network characteristics relevant for promoting the CE implementation. Ashton (2008) found that strong inter-organizational relationships focused on IS practices are common within groups of actors operating at the core of the network; central actors play a special role in local networks, by encouraging, or reducing, the spread of knowledge flows. The network theory suggests that local stakeholders can take this knowledge dissemination role more effectively when they assume a central position in the network (Scott and Carrington, 2011). Specifically, local stakeholders can enhance network performance, supporting knowledge dissemination by acting as brokers, facilitating the acquisition of knowledge for the members of their own group (i.e., being internally-oriented) or supporting the diffusion of knowledge to other groups (i.e., being externally-oriented) (Gould and Fernandez, 1989).

A broker can bridge a gap in a social structure by offering goods, information, or knowledge across gaps (Burt, 1992; Gould and Fernandez, 1989). Interacting with members of different groups can provide greater opportunities and power, through sharing knowledge and resources with specific selected actors, thereby benefiting from structural holes that can create new synergies (Burt, 1992; Shipilov and Li, 2008). However, a broker position of power can also lead to disadvantages (a form of 'isolation' due to the particular position towards other actors), and therefore requires a balancing in social relationships (Burt, 1992). Furthermore, the CE literature has also investigated the degree to which networks are characterized by path dependencies and lock-in (Korhonen et al., 2018), in particular in the context of CE-type innovations and the related economics literature on path dependency.

The above insights suggest the investigation of two key hypotheses, and in developing these specifically in the context of local CE stakeholders, we need to distinguish between two specific network brokerage types. The network theory literature distinguishes between '*tertius gaudens*' and '*tertius iungens*' broker (Burt, 1992; Garriga, 2009; Quintane and Carnabuci, 2016). The former refers to an agent who consciously creates and maintains structural gaps, selecting information for his personal benefit and procuring to become essential in the network; the latter refers to an agent who makes the coordination effort, bridging together the different nodes, reducing isolation to a minimum. The language and the behaviour of the '*tertius gaudens*' local stakeholders are made of competition, control, and manipulation, in contrast to the language of coordination and common benefit belonging to '*tertius iungens*' strategy (Garriga, 2009).

Through the exchange of knowledge, we conjecture that local stakeholders can benefit by acquiring new knowledge on different issues related to CE, or by spreading their own knowledge on a topic in which they are specialized. From the above, this knowledge exchange could be understood in terms of inward- versus outward-orientation. Adopting a specific strategy is anticipated to have a direct impact on the 'orientation' of the stakeholders, which leads to two different solutions: reducing the number of relationships and adopting a '*tertius gaudens*' strategy, becoming 'the only passage through which information flows across the hole' (Quintane and Carnabuci, 2016: 1343); or being involved in a dense network of relationships to facilitate knowledge exchange amongst all groups of stakeholders, adopting a '*tertius iungens*' strategy. The above considerations lead us to propose the following two central hypotheses:

H1: Stakeholders who act as '*tertius gaudens*' are characterized by inward-orientation of their brokerage activity for supporting knowledge diffusion on CE initiatives.

H2: Stakeholders who act as '*tertius iungens*' are characterized by outward-orientation of their brokerage activity for supporting knowledge diffusion on CE initiatives.

3. Data and methods

3.1. Empirical context: The City of Ferrara

Our empirical context is embedded into European CE policy initiatives that have received little scrutiny. The EU has been judged as 'taking baby steps' (Stahel, 2016: 436) in developing research programmes to foster CE, also through multi-stakeholder involvement for achieving resource efficiency and promoting CE since 2014 (COM, 2014). Nevertheless, these steps have been judged to have resulted in the strengthening of multiple interactions between stakeholders at different CE levels (Geissdoerfer et al., 2017), whose tangible effects are visible by consulting the European Circular Economy Stakeholder Platform, which displays initiatives on CE promoted by single or multiple stakeholders (European Circular Economy Stakeholder Platform, 2018). The importance of local CE-related practices and policies is evident at the micro- and local level, especially for European cities (Christis et al., 2019), which comprise more than 70% of the total European population (source: European Commission 2016). Our study focus is on the City of Ferrara for several reasons. This city, which is located in the Emilia-Romagna region, the first Italian region that adopted a regional law dedicated to the CE (Regione Emilia-Romagna, 2015), could be viewed as a representative mid-size European city (approximately 130,000 inhabitants in 2018, i.e. the median population of EU cities according to Eurostat[4]), the kind of settlement that hosts almost one third of the total urban residents (European Commission, 2016). Ferrara has been noted for its exemplary implementation of CE-related practices over the past years (Joss, 2011; Balducci and Ferrara, 2018; Bonato and Orsini, 2018). In particular, Ferrara has introduced a mixed top-down/bottom-up approach to develop CE at the local level, involving local stakeholders in sharing ideas on strategies and the implementation of CE-related initiatives: e.g. the implementation of the Green Public Procurement since 1994; municipal campaigns that offer waste recycling laboratories; the support of food waste reduction initiatives; the establishment of a multi-stakeholder advisory board, openness to citizenship and the fostering of innovative activities in collaboration with the local multi-utility company (Municipality of Ferrara, 2014a; Municipality of Ferrara, 2014b). In addition to being particularly attentive to environmental issues (Municipality of Ferrara, 2014a; Municipality of Ferrara, 2014b), to which Ferrara and other European municipalities are subscribing through the Aalborg Charter, Ferrara has fostered the creation of a multi-stakeholder network aimed to develop CE in the community.

3.2. Data collection

Primary data were collected in autumn 2017, as part of a European Interreg project on environmental and resource efficiency. The objective of this project was to address the issue of environment and resource efficiency, by fostering collaboration and the exploitation of good practices amongst local stakeholders. The City of Ferrara was in charge of managing the project and establishing contacts with all relevant stakeholders.

In collaboration with public managers from the Centre for Sustainability Education (CEAS) of the City of Ferrara, we created an initial list of key local stakeholders that were involved in CE projects during 2017 or in the past, or whose mission presented a connection with the topics concerning the CE issue. Afterwards, a Snowball Sampling Approach (Scott and Carrington, 2011) was used to identify other stakeholders that should be interviewed on the issues surrounding CE. The identification and mapping process of the local stakeholders considered the importance of organizational characteristics and local representativeness of the different groups (Friedman and Miles, 2006). In total, 42 local stakeholders involved in CE-related activities within the City of Ferrara were mapped out.

The CEAS organized two round tables in November and December 2017, where project researchers acquired contact information from the participants. To collect data, we used an online questionnaire that was sent to stakeholders by e-mail, using the above contact information. The questionnaire was structured into five sections, primarily using Likert-scale question and open response formats: involvement of the organization on CE activities; level of experience of the organization; collaborations; availability to establish new collaboration and general information about the organization. Every respondent was responsible for answering on behalf of their

[4] Our own elaboration based on data available at: https://ec.europa.eu/eurostat/web/cities/data/database.

organization, taking into consideration the attributes and the relations pertaining to their organization.

[Figure 1]

We divided local stakeholders into six categories, according to their primary organizational activities: business associations, foundations, local and regional administrations and agencies, private organizations, research institutes, and social organizations (citizens' associations, NGOs with a primary social mission, NGOs involved in CE and environmental issues). More than half of the total of the local stakeholders (22 on 42 stakeholders, hence 52.4%) answered the online questionnaire. Respondents are mainly local and regional administrations and agencies (Figure 1). In our analysis, we also include those organizations that did not complete the survey, since we rely on the information provided by the group of respondents. Therefore, the results illustrated in Section (4) concern the full list of 42 stakeholders.

3.3 Social Network Analysis (SNA)

To define the roles assumed by each local stakeholder, we used tools derived from SNA, (Borgatti et al., 2009; Scott and Carrington, 2011). In particular, SNA is used to map the relationships between stakeholders and analyse their roles. To do so, we asked interviewees about the extent to which their organization received (provided) knowledge on food waste reduction, energy saving, ecosystem services provision, waste management, and/or the organization of local supply chains during the 2012-2017 period, from (to) other organization(s), and which one provided (received) knowledge. Interviewees had the opportunity to select multiple sources of knowledge, and to indicate additional organizations not provided in the roster. We considered the 2012-2017 period as the European Commission started to promote the knowledge of CE since 2012 (Ellen MacArthur Foundation, 2013; COM, 2014). Based on the response data, we created five one-mode knowledge networks that consist of nodes (stakeholders) connected by edges representing a knowledge transfer between pairs of stakeholders on each of the five topics of interest for CE. From these networks, we calculated three measures for determining the stakeholders' role within each network: degree centrality, betweenness centrality (Freeman, 1979), and brokerage (Gould and Fernandez, 1989). The analysis was undertaken using the software UCINET VI (Borgatti et al., 2002). The degree centrality is the number of connections detected for each stakeholder, and it measures the 'popularity' in the network. For directed networks, i.e. those networks where the ties between actors have a direction (Scott and Carrington, 2011), in-degree is the number of incoming ties of a node, while out-degree is the number of outgoing ties. Betweenness centrality is a measure of centrality that is useful to assess the strategic importance of a node in a network, and it is measured as the fraction of shortest paths between node pairs that pass through the node of interest (Scott and Carrington, 2011).

[Figure 2]

Brokerage is defined as the possibility to interact with a specific actor on behalf of a third actor. Group affiliation is important in brokerage processes (Burt, 1992). According to the direction of the tie and the group affiliation (using the six stakeholders' categories illustrated in Paragraph 3.2), in a situation where *a* sends a tie to *b*, *b* sends a tie to *c*, and there are no ties between *a* and *c*, the five possible brokerage roles of *b* are (Figure 2): a.) Coordinator (when both actors belong to the same group); b.) Consultant (when *a* and *c* belong to the same group, while *b* belongs to a different group); c.) Gatekeeper (when *a* and *b* belong to the same group, while *c* belongs to a different group); d.) Representative (when *b* and *c* belong to the same group, while *a* belongs to a different group); e.) Liaison (when each actor belongs to a different group). The first two roles have an inward orientation, while the last three roles have an outward orientation; the former put emphasis on knowledge accumulation within their own group, i.e. they transfer knowledge mainly to their fellows, while the latter are modes dedicated to 'knowledge dispersion' towards different actor and their groups.

4. Results

Through the network data, we could identify five knowledge networks, one for each of the five key activities of CE. The sum of these five networks depicts the total knowledge network. These networks enable a quantitative analysis that identifies the roles played by stakeholders in the implementation of a local CE system. It is important to consider the total knowledge network for the analysis, since it provides information on the total exchange of knowledge without differentiating the type of knowledge exchanged. Given that this network information on the

presence (or the absence) of a relationship is relevant, and not the information on the frequency of knowledge exchanges between the same stakeholder dyads, we therefore created an adjacency matrix *A* where for each pair of stakeholders *i* and *j* the component a_{ij} assumes the following values:

- 1, if there is an edge from *i* to *j* due to the presence of one or more knowledge exchanges (i.e. the exchange of knowledge on one or more CE-related activities);
- 0, otherwise.

As we see from Figure 3, three social organizations (ID1, ID5, and ID31) are particularly central in the network. In contrast, business associations are peripheral, since they mainly receive knowledge from other stakeholders, without actively taking part to the local exchange. Private organizations have a strategic position: they are closely located to the most central stakeholders, but they seem to form a 'cluster of fellows', being very close to each other. A similar situation can be observed for the group of local and regional administrations and agencies made by ID9, ID10, ID18, ID19, and ID37, which occupy a semi-peripheral area in the network.

[Figure 3]

In light of this qualitative description, we turn to the issues of centrality and brokerage across stakeholder types. We calculate in-degree, out-degree, and betweenness centrality for each actor in the network, and we identify which stakeholders fulfil particular brokerage roles, using the statistical procedure developed by Gould and Fernandez (1989), highlighting the stakeholders who broker more, or fewer, relationships in exchanging CE-related activities (total) knowledge.

[Table 1a]

[Table 1b]

[Table 2a]

[Table 2b]

Table 1a illustrates the centrality scores for each stakeholder. On average (Table 1b), business associations and social organizations receive more knowledge (7.2 and 9.8 inflows, respectively) than what they spread over the network (7.0 and 8.8 outflows, respectively). This is also the case for foundations, even if we observe only a single stakeholder. Private organizations are amongst the more active stakeholders in terms of both inflows (11.2) and outflows (12.0) of knowledge. In terms of betweenness, social organizations and private organizations show the higher average scores; however, for social organizations this is due to the outlier scores registered for ID1 and ID5, while the role of private organizations and local and regional administrations and agencies is distinct, as they both placed three stakeholders amongst the first ten organizations.

Table 2a illustrates which stakeholders broker knowledge exchange relationships in developing a CE system; the brokerage scores are relativized, i.e. the raw scores are divided by the number of pairs. Local and regional administrations and agencies play a relevant role as coordinators, while business associations are leaders for gatekeeping activities (Table 2b). On the other hand, looking at the externally-oriented roles (representative, consultant, and liaison), local and regional administrations and agencies are still at the top as representatives, but the foundation (ID29) and the two research institutions (ID40 and ID41) have the highest scores as consultants and liaisons. However, this is also a function of their reduced number, i.e. they likely interact out of necessity with other types of stakeholders.

Local and regional administrations and agencies are also characterized by significant liaison brokerage. They mediate a number of knowledge exchanges because of their institutional role, which is focused on interacting and getting in touch with different local actors. However, they are not strong as gatekeepers, i.e. they do not appear to aim to spread externally-acquired knowledge towards other public bodies.

Social organizations are mainly internally-oriented. Since they typically work under resource constraints (Austin and Wei-Skillern, 2006), they aim to adopt strategies aimed at acquiring the largest amount of knowledge in order to operate in the local network.

In conclusion, with regard to the total knowledge network, our first hypothesis is confirmed, while our second hypothesis is not. Business associations and social organizations act as '*tertius gaudens*', since they show a high betweenness centrality and receive more knowledge than those

they spread in the network, and they are more internally-oriented. Hence, the first hypothesis is confirmed. On the other hand, private organizations and local and regional administrations and agencies act as '*tertius iungens*', since they spread more knowledge than those they receive, but their brokerage strategy is mixed internally- and externally-oriented, thus we cannot confirm our second hypothesis.

Apart from the stakeholder roles in the total knowledge network, our purpose was also to investigate the single networks regarding knowledge exchange on food waste reduction, energy saving, ecosystem services provision, waste management, and/or the organization of local supply chains, to see if our hypotheses hold for any single CE-related activity. Hence, we checked for centrality and brokerage activities of stakeholders within each knowledge network, exploring the existing interrelations between different behaviours in different knowledge networks.

We first employed a Quadratic Assignment Procedure (QAP) to test for correlation amongst the five knowledge networks (Figures 4-8). QAP is used instead of the 'classic' correlation analysis when dealing with network data, because in this case observations are non-independent (Scott and Carrington, 2011). The QAP correlation is useful to depict knowledge networks' similarity, so that we can assess the extent to which knowledge exchanges for some activities follow the same path, and stakeholders assume the same roles.

[Figure 4]

[Figure 5]

[Figure 6]

[Figure 7]

[Figure 8]

Table 3 shows the results of the QAP test. All the results are statistically significant, but there are no strong positive correlations, except for the relations between the organization of local supply chains, energy saving, and waste management. The ecosystem services knowledge network is less correlated with the other networks, i.e. the actors exchanging knowledge regarding ecosystem services have created a system of relationships that has no overlap with the knowledge networks related to other activities.

[Table 3]

We then estimated centrality measures and brokerage scores for each stakeholder.

[Table 4a]

[Table 4b]

[Table 5a]

[Table 5b]

[Table 6a]

[Table 6b]

[Table 7a]

[Table 7b]

[Table 8a]

[Table 8b]

[Table 9a]

[Table 9b]

[Table 10a]

[Table 10b]

[Table 11a]

[Table 11b]

[Table 12a]

[Table 12b]

[Table 13a]

[Table 14b]

Regarding the food waste knowledge network, private and social organizations are amongst the most central stakeholders, even if business associations play a relevant role as 'bridges', since they have high scores of betweenness centrality. The first hypothesis is, therefore, confirmed, while our second hypothesis is not. Private organizations and social organizations act as '*tertius gaudens*' and their brokerage strategy is internally-oriented. Business associations and local and regional administrations and agencies act as '*tertius iungens*', but they also show an internally-oriented strategy, thus we reject our second hypothesis.

With regard to the local supply chain knowledge network, local and regional administrations and social organizations are the only important stakeholder types. In particular, the latter operate by connecting the parts of the network (as highlighted by the high betweenness score), transferring knowledge from their group to other groups of stakeholders (as they show a high brokerage score as representatives). In this case, neither hypothesis 1 nor hypothesis 2 are confirmed, as both '*tertius gaudens*' and '*tertius iungens*' show mixed brokerage strategies.

The energy saving knowledge network is dominated by the local and regional administrations and agencies. They are the most central stakeholders, as well as the nodes in the network through which most of the knowledge regarding this activity is exchanged. However, they tend to be internally-oriented, while private organizations, research institutions, and social organizations are more externally-oriented. The first hypothesis is rejected, while the second hypothesis is confirmed. Private organizations and local and regional administrations and agencies, which act as '*tertius gaudens*', have a mixed brokerage strategy. Research institutions and social organizations can be identified as '*tertius iungens*', and they show a clear externally-oriented strategy.

Regarding the waste management knowledge network, an important role is played by research institutions and private organizations, which are central in the network. However, the most relevant stakeholder type when discussing this activity is a business organization (ID35), which has the highest centrality scores. Private organizations are more internally-oriented, as they show high values of gatekeeping, as well as local and regional administrations and agencies, which are instead strong 'coordinator brokers'. For this knowledge network, we reject both hypothesis 1 and hypothesis 2, since the groups of stakeholders present a mixed brokerage strategy.

Finally, in the ecosystem services knowledge network, public bodies and private organizations act as main stakeholders, even if the latter are relevant because of the high scores, as shown by a single stakeholder (ID25), which operates as an independent actor with its own network. Not many stakeholders exchange knowledge concerning this activity, therefore this network is rather different from the others, which is also visible by considering the QAP correlations (Table 3). Since this is a very small knowledge network, it does not provide sufficient statistical basis for testing our hypothesis.

5. Conclusions

With increasing global awareness of the need to address environmental issues, the interest in sustainability has intensified the search of policymakers and researchers for new instruments for promoting sustainable development. In particular, the notion of the Circular Economy (CE) has come into the focus of policymakers in many OECD and developing countries, which have started to introduce legislative proposals for implementing the CE model (COM, 2015; UNEP, 2013). However, despite the growing interest in CE, we observe limited implementation of CE policy initiatives in practice, as well as a lack of consensus on theoretical frameworks that satisfy the interdisciplinary concept underpinning the CE (Ghisellini et al., 2016; Lahti et al., 2018; Moreau et al., 2017). Furthermore, while the existing network-focused CE literature concentrates on secondary data to analyse knowledge sharing and scientific cooperation (e.g. Marra et al., 2018), we observe an absence of works that identify how CE stakeholders interact through knowledge exchange to define the boundaries of a local CE system.

This paper focuses on stakeholder networks implementing a CE system in the City of Ferrara (Italy). It uses Social Network Analysis (SNA) to map the knowledge exchanges aimed at pursuing shared objectives on specific activities, distinguishing between the total network

spanning multiple knowledge network types and specific networks regarding individual knowledge network types (food waste reduction; organization of local supply chains; energy saving; waste management; ecosystem services provision). Private organizations, as well as local and regional administrations and agencies, are found to be amongst the most central stakeholders in the complete knowledge network, while social organizations and business associations are central in the food waste knowledge network. The analysis of brokerage roles highlights several features that suggest the presence of an unbalanced system of relationships, since more than half of a given stakeholder type plays a brokerage role within the network. This evidence suggests that the network does not correspond to an institutional system that could be expected to operate in such a multi-stakeholder CE environment. Moreover, our analysis suggests that a key brokerage stakeholder still has to arise in the CE network under investigation, and therefore policymakers could help facilitate the emergence of a '*tertium iugens*' rather than a '*tertium gaudens*' figure (Garriga, 2009), opening the network to the widest participation and effective knowledge exchange. An externally-oriented strategy from '*tertium iugens*' is missing, and stakeholders with the ability to connect different groups of the network prefer to adopt a brokerage strategy that strengthens their importance in the network, enhancing their own knowledge on specific topics. To develop a more effective CE system, local (and national) institutions need targeted policy interventions that support networking between stakeholders, to exchange knowledge on different CE-related activities. These interventions could benefit from taking into account the specificities of the stakeholders; however, the focal point could be on their strategic behaviour, rather than their organizational typology, since it has been demonstrated that different stakeholders act differently according to the various knowledge networks in which they are embedded. The growing popularity of the CE concept is encouraging stakeholders to intensify their activities related to this topic; however, they could be addressed to facilitate the knowledge flows across the local (or national) network of stakeholders, in order to maximize the diffusion of knowledge for the whole community, rather than acquiring useful knowledge for themselves or their own group.

Our study bears three main limitations. First, the lack of information on the strength of the relationships between stakeholders as a function of the intensity and quality of knowledge exchange. In particular, the analysis focuses on the presence or absence of ties and thus, knowledge exchange between stakeholders. Second, considering the cross-sectional nature of the underlying surveys and interviews, the impossibility to investigate the persistence of network relationships over time poses a limitation, since it does not enable us to evaluate possible changes in local network interactions. Third, although Ferrara is a representative small to medium size European city, particularly active from the point of view of sustainability policies and CE-related practices (Balducci and Ferrara, 2018; Bonato and Orsini, 2018), our focal city is likely to differ somewhat from large European cities and metropolitan areas with respect to logistic, waste management, and energy-related issues, among others (Nijkamp and Kourtit, 2013). Future research could therefore focus further on larger European cities and metropolitan areas, in order to deliver a more comprehensive assessment of the European urban framework in the context of the CE debate. Despite the above limitations, our results suggest new policy avenues to potentially reach a more effective transition to a CE. Future works could build upon our evidence that the elicited networks denote a weak involvement of research institutions, such as universities and R&D centres, which also complements previous evidence from Marra et al. (2018) on weak potentials for cooperation. In particular, future studies could advance our understanding of more effective paths to transitioning to a CE, by investigating why the interaction between practitioners and researchers in the CE is apparently still lacking, and how public administrations and agencies could be more effectively engaged in the CE policy design and implementation.

References

Abreu, M.C.S.D., Ceglia, D., 2018. On the implementation of a circular economy: The role of institutional capacity-building through industrial symbiosis. Resources, Conservation and Recycling 138, 99-109. doi: 10.1016/j.resconrec.2018.07.001.

Andersen, M.S., 2007. An introductory note on the environmental economics of the circular economy. Sustainability Science 2(1), 133-140. doi: 10.1007/s11625-006-0013-6.

Antikainen, R., Lazarevic, D., Seppälä, J., 2018. Circular Economy: Origins and Future Orientations. In: Lehmann, H. (Ed.), Factor X: Challenges, Implementation Strategies and Examples for a Sustainable Use of Natural Resources (pp. 115-129). Springer. doi: 10.1007/978-3-319-50079-9_7.

Ashton, W., 2008. Understanding the organization of industrial ecosystems: A social network approach. Journal of Industrial Ecology 12(1), 34-51. doi: 10.1111/j.1530-9290.2008.00002.x.

Austin, J.S.H., Wei-Skillern, J., 2006. Social and commercial entrepreneurship: same, different, or both? Entrepreneurship Theory and Practice 30(1), 1-22. doi: 10.1111/j.1540-6520.2006.00107.x.

Ayres, R.U., 1994. Industrial metabolism; theory and policy. In Allenby, B.R. and Richards, D.J. (Eds.), The Greening of Industrial Ecosystems (pp. 23-37). Washington, DC: National Academy Press.

Bakker, C., Den Hollander, M., van Hinte, E., Zijlstra, Y., 2014. Product that Last. Product Design for Circular Business Models, Delft: TU Delft Library.

Bahers, J.B., Durand, M., Beraud, H., 2017. Quelle territorialité pour l'économie circulaire? Interprétation des typologies de proximité dans la gestion des déchets. Flux 109-110, 129-141. doi: 10.3917/flux1.109.0129.

Balducci, F., Ferrara, A., 2018. Using urban environmental policy data to understand the domains of smartness: An analysis of spatial autocorrelation for all the Italian chief towns. Ecological Indicators 89, 386-396. doi: 10.1016/j.ecolind.2017.12.064.

Bartelmus, P., 2013. The future we want: Green growth or sustainable development? Environmental Development 7, 165-170. doi: 10.1016/j.envdev.2013.04.001.

Benyus, J.M., 2002. Biomimicry. New York: Harper Perennial.

Bertossi P., Buclet N., Fischer L., Kaulard A., Massarutto A., 2002. The dynamic effects of interactions between national regimes: towards harmonisation. In: Buclet, N. (Ed.), Municipal Waste Management in Europe. Environment & Management, vol 11 (pp. 55-79). Springer. doi: 10.1007/978-94-015-9910-8_4.

Blomsma, F., Brennan, G., 2017. The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. Journal of Industrial Ecology 21(3), 603-614. doi: 10.1111/jiec.12603.

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. Journal of Cleaner Production 65, 42-56. doi: 10.1016/j.jclepro.2013.11.039.

Bocken, N.M.P., Bakker, C., de Pauw, I., 2016. Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering 33(5), 308-320. doi: 10.1080/21681015.2016.1172124.

Bonato, D., Orsini, R., 2018. Urban Circular Economy: The New Frontier for European Cities' Sustainable Development. In W. W. Clark (Ed.), Sustainable Cities and Communities Design Handbook: Green Engineering, Architecture, and Technology, 2nd Edition (pp. 235-245). Elsevier, Butterworth-Heinemann. doi: 10.1016/C2017-0-00936-9.

Borgatti, S.P., Everett, M.G., Freeman, L.C., 2002. Ucinet for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.

Borgatti, S.P., Mehra, A., Brass, D.J., Labianca, G., 2009. Network Analysis in the Social Sciences. Science 323(5916), 892-895. doi: 10.1126/science.1165821.

Boulding, K., 1966. The Economics of the Coming Spaceship Earth. In H. Jarrett (Ed.), Environmental Quality in a Growing Economy (pp. 3-14). Baltimore: Johns Hopkins University Press.

Braungart, M., Bondesen, P., Kälin, A., Gabler, B., 2008. Specific Public Goods for Economic Development: With a Focus on Environment. In British Standards Institution (Ed.), Public Goods for Economic Development. Compendium of Background papers (pp. 139-175). Vienna: United Nations Industrial Development Organisation.

Brown, P.J., Bajada, C., 2018. An economic model of circular supply network dynamics: Toward an understanding of performance measurement in the context of multiple stakeholders. Business Strategy and the Environment 27(5), 643-655. doi: 10.1002/bse.2069.

Buch, R., O'Neill, D., Lubenow, C., DeFilippis, M., Dalrymple, M., 2018. Collaboration for regional sustainable circular economy innovation. In: Dhiman, S., Marques, J. (Eds.), Handbook of Engaged Sustainability (pp. 703-728). Springer. doi: 10.1007/978-3-319-71312-0_24.
Burt, R.S., 1992. Structural holes: The structure of competition. Cambridge, MA: Harvard University Press.
Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., Silvennoinen, K., Waldron, K., Vittuari, M., 2017. Food waste drivers in Europe, from identification to possible interventions. Sustainability 9(1), 37. doi: 10.3390/su9010037.
Christis, M., Athanassiadis, A., Vercalsteren, A., 2019. Implementation at a city level of circular economy strategies and climate change mitigation – the case of Brussels. Journal of Cleaner Production 218, 511-520. doi: 10.1016/j.jclepro.2019.01.180.Clark, W.C., 2007. Sustainability science: a room of its own. Proceedings of the National Academy of Sciences 104(6), 1737. doi: 10.1073/pnas.0611291104.
COM - European Commission, 2014. Towards a circular economy: a zero waste programme for Europe. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52014DC0398. Accessed 23 January 2018.
COM - European Commission, 2015. Closing the Loop - An EU action plan for the Circular Economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614. Accessed 23 January 2018.
Cooper, S.J.G., Giesekam, J., Hammond, G.P., Norman, J.B., Owen, A., Rogers, J.G., Scott, K., 2017. Thermodynamic insights and assessment of the 'circular economy'. Journal of Cleaner Production 162, 1356-1367. doi: 10.1016/j.jclepro.2017.06.169.
De Jesus, A., Mendonça, S. (2018). Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. Ecological Economics 145, 75-89. doi: 10.1016/j.ecolecon.2017.08.001.
De los Rios, I.C., Charnley, F.J.S., 2017. Skills and capabilities for a sustainable and circular economy: The changing role of design. Journal of Cleaner Production 160, 109-122. doi: 10.1016/j.jclepro.2016.10.130.
De Medici, S., Riganti, P., Viola, S., 2018. Circular economy and the role of universities in urban regeneration: The case of Ortigia, Syracuse. Sustainability 10(11), 4305. doi: 10.3390/su10114305.
Domenech, T., Bahn-Walkowiak, B., 2019. Transition Towards a Resource Efficient Circular Economy in Europe: Policy Lessons From the EU and the Member States. Ecological Economics 155, 7-19. doi: 10.1016/j.ecolecon.2017.11.001.
Ek, C., Miliute-Plepiene, J., 2018. Behavioral spillovers from food-waste collection in Swedish municipalities. Journal of Environmental Economics and Management 89, 168-186. doi: 10.1016/j.jeem.2018.01.004.
Ellen MacArthur Foundation, 2013. Towards the Circular Economy: Volume 1. Economic and business rationale for an accelerated transition. London: Ellen MacArthur Foundation.
Emelianoff, C., 2007. La ville durable: l'hypothèse d'un tournant urbanistique en Europe. L'Information géographique 71, 48-65. doi: 10.3917/lig.713.0048.
European Circular Economy Stakeholder Platform, 2018. European Circular Economy Stakeholder Platform : A joint initiative by the European Commission and the European Economic and Social Committee. Available at: https://circulareconomy.europa.eu/platform/en. Accessed 15 September 2018.
European Commission, 2016. The State of European Cities 2016: Cities leading the way to a better future. Brussels, Belgium. Available at: https://ec.europa.eu/regional_policy/sources/policy/themes/cities-report/state_eu_cities2016_en.pdf.
Feng, Z., Yan, N., 2007. Putting a circular economy into practice in China. Sustainable Science 2(1), 95-101. doi: 10.1007/s11625-006-0018-1.
Freeman, L.C., 1979. Centrality in Social Networks: Conceptual Clarification. Social Networks 1(3), 215-239. doi: 10.1016/0378-8733(78)90021-7.
Friedman, A.L., Miles, S., 2006. Stakeholders: Theory and Practice. Oxford: Oxford University Press.

Gallaud, D., Laperche, B., 2016. Circular economy, industrial ecology and short supply chain. London, UK: ISTE.
Garriga, E., 2009. Cooperation in Stakeholder Networks: Firms' 'Tertius Iungens' Role. Journal of Business Ethics 90, 623-637. doi: 10.1007/s10551-010-0596-9.
Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production 143, 757-768. doi: 10.1016/j.jclepro.2016.12.048.
Geng, Y., Doberstein, B., 2008a. Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'. International Journal of Sustainable Development & World Ecology 15(3), 231-239. doi: 10.3843/SusDev.15.3:6.
Geng, Y., Doberstein, B., 2008b. Greening government procurement in developing countries: Building capacity in China. Journal of Environmental Management 88(4), 932-938. doi: 10.1016/j.jenvman.2007.04.016.
Geng, Y., Fu, J., Sarkis J., Xue, B. (2012). Towards a circular economy indicator system in China: an evaluation and critical analysis. Journal of Cleaner Production 23, 216-224. doi: 10.1016/j.jclepro.2011.07.005.
Genovese, A., Acquaye, A.A., Figueroa, A., Koh, S.L., 2017. Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. Omega 66(Part B), 344-357. doi: 10.1016/j.omega.2015.05.015.
Georgescu-Roegen, N., 1971. The entropy law and the economic process. Cambridge, MA: Harvard University Press.
Ghisellini, P., Cialini, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production 114, 11-32. doi: 10.1016/j.jclepro.2015.09.007.
Gould, R.V., Fernandez, R.M., 1989. Structures of Mediation: A Formal Approach to Brokerage in Transaction Networks. Sociological Methodology 19, 89-126. doi: 10.2307/270949.
Govindan, K., & Hasanagic, M., 2018. A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. International Journal of Production Research 56(1-2), 278-311. doi: 10.1080/00207543.2017.1402141.
Graymore, M.L.M., Sipe, N.G., Rickson, R.E., 2008. Regional sustainability: How useful are current tools of sustainability assessment at the regional scale? Ecological Economics 67(3), 362-372. doi: 10.1016/j.ecolecon.2008.06.002.
Herczeg, G., Akkerman, R., Hauschild, M.Z., 2018. Supply chain collaboration in industrial symbiosis networks. Journal of Cleaner Production 171, 1058-1067. doi: 10.1016/j.jclepro.2017.10.046.
Heshmati, A., 2016. A Review of the Circular Economy and its Implementation. The Royal Institute of Technology – CESIS (Centre of Excellence for Science and Innovation Studies), WP 431.
IES - The Institution of Environmental Sciences (2015). The Circular Economy in Japan. Available at: https://www.the-ies.org/analysis/circular-economy-japan. Accessed 19 November 2018.
Jiao, W., Boons, F., 2017. Policy durability of Circular Economy in China: A process analysis of policy translation. Resources, Conservation and Recycling 117, 12-24. doi: 10.1016/j.resconrec.2015.10.010.
Joss, S., 2011. Eco-cities: The mainstreaming of urban sustainability–key characteristics and driving factors. International Journal of Sustainable Development and Planning 6(3), 268-285. doi: 10.2495/SDP-V6-N3-268-285.
Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., Schösler, H., 2016. Transition towards Circular Economy in the Food System. Sustainability 8(1), 69. doi: 10.3390/su8010069.
Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy - From review of theories and practices to development of implementation tools. Resources, Conservation and Recycling 135, 190-201. doi: 10.1016/j.resconrec.2017.10.034.
Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation & Recycling 127, 221-232. doi: 10.1016/j.resconrec.2017.09.005.
Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M., 2018. Barriers to the Circular Economy: Evidence From the European Union (EU). Ecological Economics 150, 264-272. doi: 10.1016/j.ecolecon.2018.04.028.

Korhonen, J., Honkasalo, A., Seppälä, J., 2018. Circular Economy: The Concept and its Limitations. Ecological Economics 143, 37-46. doi: 10.1016/j.ecolecon.2017.06.041.
Kunz, N., Mayers, K., Van Wassenhove, L.N., 2018. Stakeholder Views on Extended Producer Responsibility and the Circular Economy. California Management Review 60(3), 45-70. doi: 10.1177/0008125617752694.
Lahti, T., Wincent, J., Parida, V., 2018. A Definition and Theoretical Review of the Circular Economy, Value Creation, and Sustainable Business Models: Where Are We Now and Where Should Research Move in the Future? Sustainability 10(8), 2799. doi: 10.3390/su10082799.
Leipold, S., Petit-Boix, A., 2018. The circular economy and the bio-based sector - Perspectives of European and German stakeholders. Journal of Cleaner Production 201, 1125-1137. doi: 10.1016/j.jclepro.2018.08.019.
Lyle, J.T., 1994. Regenerative Design for Sustainable Development. New York: John Wiley & Sons.
Marra, A., Mazzocchitti, M., Sarra, A., 2018. Knowledge sharing and scientific cooperation in the design of research-based policies: The case of the circular economy. Journal of Cleaner Production 194, 800-812. doi: 10.1016/j.jclepro.2018.05.164.
Martin, M., Harris, S., 2018. Prospecting the sustainability implications of an emerging industrial symbiosis network. Resources, Conservation and Recycling 138, 246-256. doi: 10.1016/j.resconrec.2018.07.026.
McDonough, W., Braungart, M., 2002. Cradle to Cradle: Remaking the Way We Make Things. New York: North Point Press.
McDowall, W., Geng, Y., Huang, B., Barteková, E., Bleischwitz, R., Türkeli, S., Kemp, R., Doménech, T., 2017. Circular Economy Policies in China and Europe. Journal of Industrial Ecology 21(3), 651-661. doi: 10.1111/jiec.12597.
Merli, R., Preziosi, M., Acampora, A., 2018. How do scholars approach the circular economy? A systematic literature review. Journal of Cleaner Production 178, 703-722. doi: 10.1016/j.jclepro.2017.12.112.
Messmann, L., Boldoczki, S., Thorenz, A., Tuma, A., 2019. Potentials of preparation for reuse: A case study at collection points in the German state of Bavaria. Journal of Cleaner Production 211, 1534-1546. doi: 10.1016/j.jclepro.2018.11.264.
METI - Japanese Ministry of Economy, Trade and Industry, 2004. Handbook on Resource Recycling Legislation and 3R Initiatives. Tokyo.
Miliute-Plepiene, J., Plepys, A., 2015. Does food sorting prevents and improves sorting of household waste? A case in Sweden. Journal of Cleaner production 101, 182-192. doi: 10.1016/j.jclepro.2015.04.013.
Moreau, V., Sahakian, M., van Griethuysen, P., Vuille, F., 2017. Coming full circle: why social and institutional dimensions matter for the circular economy. Journal of Industrial Ecology 21(3), 497-506. doi: 10.1111/jiec.12598.
Municipality of Ferrara, 2014a. La storia di A21 a Ferrara. Available at: http://servizi.comune.fe.it/4136/la-storia-di-a21-a-ferrara. Accessed 20 January 2018.
Municipality of Ferrara, 2014b. Forum A21. Available at: http://servizi.comune.fe.it/4144/forum-a21. Accessed 20 January 2018
Murray, A., Skene, K., Haynes, K., 2017. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. Journal of Business Ethics 140(3), 369-380. doi: 10.1007/s10551-015-2693-2.
Newig, J., Fritsch, O., 2009. Environmental governance: participatory, multi-level – and effective? Environmental Policy and Governance 19(3), 197-214. doi: 10.1002/eet.509.
Nijkamp, P., Kourtit, K. (2013). The "new urban Europe": global challenges and local responses in the urban century. European Planning Studies 21(3), 291-315.
Partidário, M.R., Sheate, W.R., 2013. Knowledge brokerage - potential for increased capacities and shared power in impact assessment. Environmental Impact Assessment Review 39, 26-36. doi: 10.1016/j.eiar.2012.02.002.
Pearce, D., 1988. Economics, equity and sustainable development. Futures 20(6), 598-605. doi: 10.1016/0016-3287(88)90002-X.
Pearce, D.W., Turner, R.K., 1990. Economics of Natural Resources and the Environment. New York: Harvester Wheatsheaf.
Petit-Boix, A., Leipold, S., 2018. Circular economy in cities: Reviewing how environmental research aligns with local practices. Journal of Cleaner Production 195, 1270-1281. doi: 10.1016/j.jclepro.2018.05.281.

Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2019. Business model innovation for circular economy and sustainability: A review of approaches. Journal of Cleaner Production 215, 198-216. doi: 10.1016/j.jclepro.2019.01.036.
Quintane, E., Carnabuci, G., 2016. How do brokers broker? Tertius gaudens, tertius iungens, and the temporality of structural holes. Organization Science 27(6), 1343-1360. doi: 10.1287/orsc.2016.1091.
Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation 141(10), 2417-2431. doi: 10.1016/j.biocon.2008.07.014.
Reed, M.S., Stringer, L.C., Fazey, I., Evely, A.C., Kruijsen, J.H.J., 2014. Five principles for the practice of knowledge exchange in environmental management. Journal of Environmental Management 146, 337-345. doi: 10.1016/j.jenvman.2014.07.021.
Regione Emilia-Romagna, 2015. Disposizioni a sostegno dell'economia circolare, della riduzione della produzione di rifiuti urbani, del riuso dei beni a fine vita, della raccolta differenziata e modifiche alla Legge Regionale 19 Agosto 1996 n. 31 (Disciplina del tributo speciale per il deposito in discarica dei rifiuti solidi). Regional Law n. 16/2015.
Saint Ville, A.S., Hickey, G.H., Phillip, L.E., 2017. How do stakeholder interactions influence national food security policy in the Caribbean? The case of Saint Lucia. Food Policy 68, 53-64. doi: 10.1016/j.foodpol.2017.01.002.
Sauvé, S., Bernard, S., Sloan, P., 2016. Environmental sciences: sustainable development and circular economy: alternative concepts for trans-disciplinary research. Environmental Development 17, 48-56. doi: 10.1016/j.envdev.2015.09.002.
Scott, J., Carrington, P.C., 2011. Handbook of social network analysis. London: Sage.
Sheate, W.R., Partidário, M.R., 2010. Strategic approaches and assessment techniques – Potential for knowledge brokerage towards sustainability. Environmental Impact Assessment Review 30(4), 278-288. doi: 10.1016/j.eiar.2009.10.003.
Shipilov, A.V., Li, S.X., 2008. Can you have your cake and eat it too? Structural holes' influence on status accumulation and market performance in collaborative networks. Administrative Science Quarterly 53(1), 73-108.
Stahel, W.R., 2010. The Performance Economy. Second Edition. Hampshire, UK: Palgrave Macmillan.
Stahel, W.R., 2016. The circular economy. Nature 531(7595), 435-438. doi: 10.1038/531435a.
Su, B., Heshmati, A., Geng, Y., Yu, X., 2013. A review of the circular economy in China: moving from rhetoric to implementation. Journal of Cleaner Production 42, 215-227. doi: 10.1016/j.jclepro.2012.11.020.
Urbinati, A., Chiaroni, D., Chiesa, V., 2017. Towards a new taxonomy of circular economy business models. Journal of Cleaner Production 168, 487-498. doi: 10.1016/j.jclepro.2017.09.047.
UNEP - United Nations Environmental Program, 2013. The Japanese Industrial Waste Experience: Lessons for rapidly industrializing countries. Available at: http://www.unep.org/ietc/Portals/136/Publications/Waste%20Management/UNEP%20DTIE_Japanese%20waste_english_web.pdf. Accessed 5 October 2017.
von Weizsäcker, E.U., Wijkman, A. (2018). Come On! Capitalism, Short-termism, Population and the Destruction of the Planet. New York: Springer. doi: 10.1007/978-1-4939-7419-1.
Whicher, A., Harris, C., Beverley, K., Swiatek, P., 2018. Design for circular economy: Developing an action plan for Scotland. Journal of Cleaner Production 172, 3237-3248. doi: 10.1016/j.jclepro.2017.11.009.
Winans, K., Kendall, A., Deng, H., 2017. The history and current applications of the circular economy concept. Renewable and Sustainable Energy Reviews 68, 825-833. doi: 10.1016/j.rser.2016.09.123.
Wright, S., Sharpe, S., Giurco, D., 2018. Greening regional cities: the role of government in sustainability transitions. In: Leal Filho, W., Rogers, J., Iyer-Raniga, U. (Eds.), Sustainable Development Research in the Asia-Pacific Region: Education, Cities, Infrastructure and Buildings (pp. 327-343). Springer. doi: 10.1007/978-3-319-73293-0_19.
Xu, W., Zhou, C., Cao, A., Luo M., 2016. Understanding the mechanism of food waste management by using stakeholder analysis and social network model: An industrial ecology perspective. Ecological Modelling 337, 63-72. doi: 10.1016/j.ecolmodel.2016.06.006.
Yong, R., 2007. The circular economy in China. Journal of Material Cycles Waste Management 9(2), 121-129. doi: 10.1007/s10163-007-0183-z.

Figure 1 Number of interviews (by stakeholders)

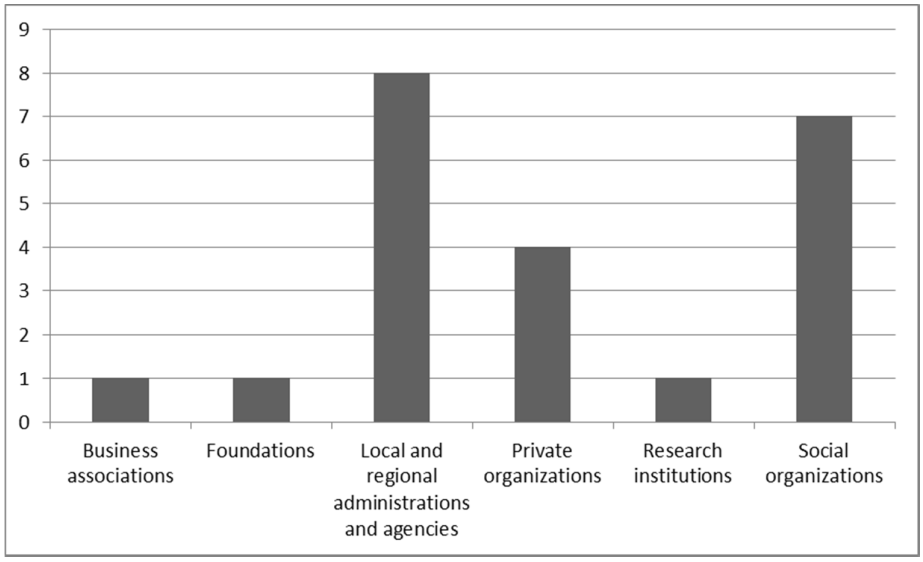
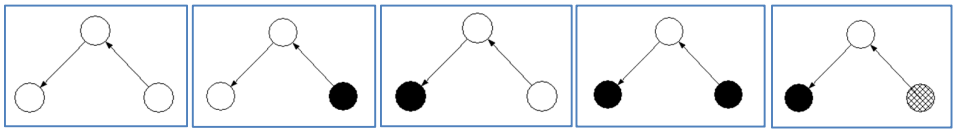


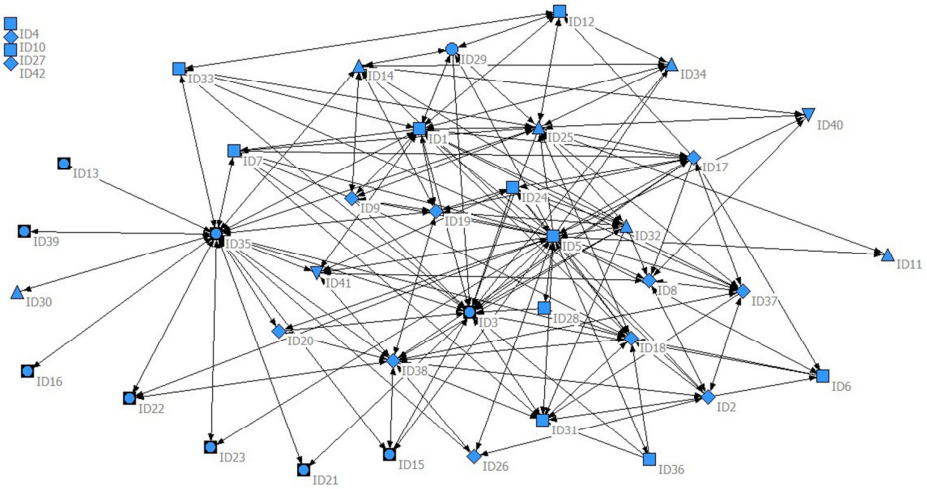
Figure 2 Brokerage roles



Coordinator Gatekeeper Representative Consultant Liaison

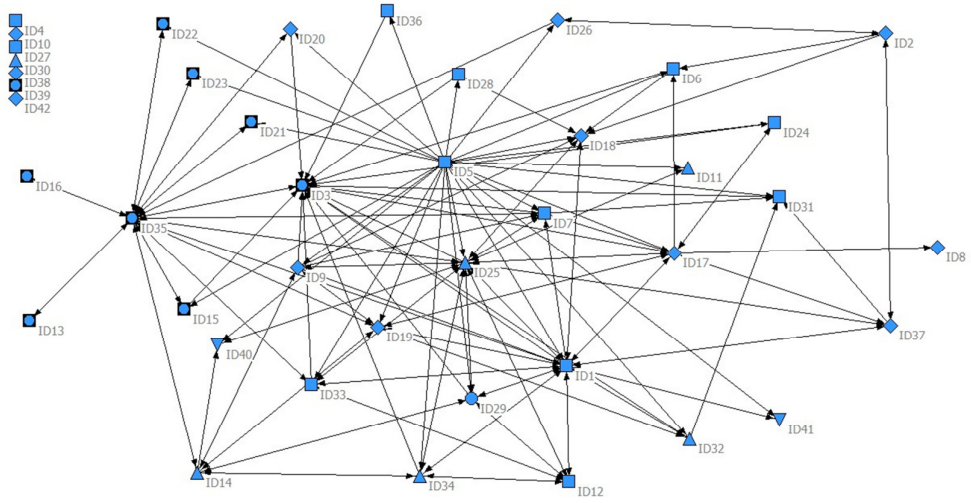
Source: Gould and Fernandez (1989)

Figure 3 The total knowledge network



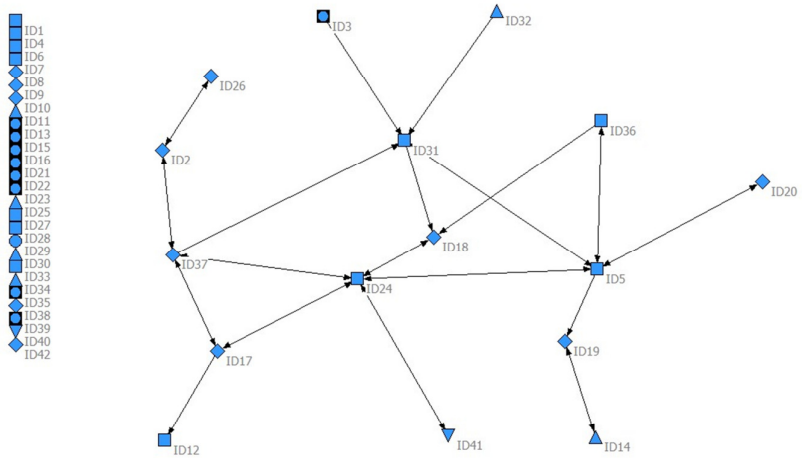
Legend: circles-in-boxes are business associations, diamonds are local and regional administrations and agencies, up triangles are private organizations, and squares are social organizations.

Figure 4 The food waste knowledge network



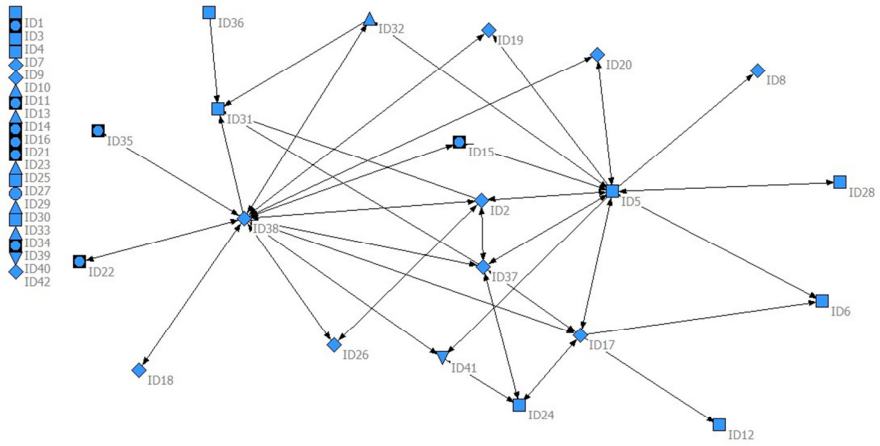
Legend: circles-in-boxes are business associations, circles are foundations, diamonds are local and regional administrations and agencies, up triangles are private organizations, down triangles are research institutions, and squares are social organizations.

Figure 5 The local supply chain knowledge network



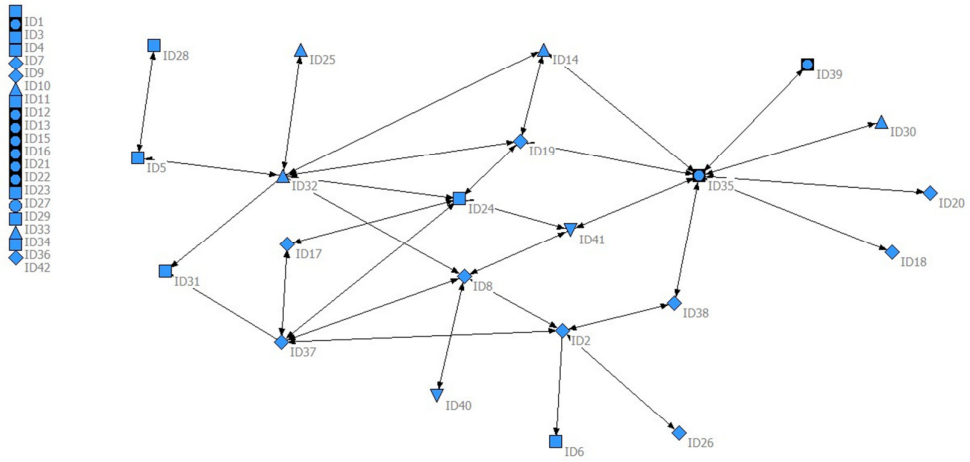
Legend: circles-in-boxes are business associations, diamonds are local and regional administrations and agencies, up triangles are private organizations, down triangles are research institutions, and squares are social organizations.

Figure 6 The energy saving knowledge network



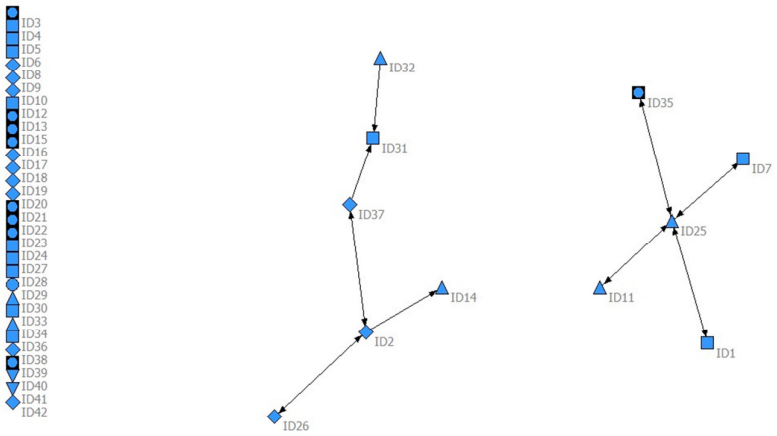
Legend: circles-in-boxes are business associations, diamonds are local and regional administrations and agencies, up triangles are private organizations, down triangles are research institutions, and squares are social organizations.

Figure 7 The waste management knowledge network



Legend: circles-in-boxes are business associations, diamonds are local and regional administrations and agencies, up triangles are private organizations, down triangles are research institutions, and squares are social organizations.

Figure 8 The ecosystem services knowledge network



Legend: circles-in-boxes are business associations, diamonds are local and regional administrations and agencies, up triangles are private organizations, and squares are social organizations.

Table 1a Total knowledge network: Centrality measures

ID	Group	In-degree	Out-degree	Betweenness
3	Business association	3	6	1.25
13	Business association	2	3	0
15	Business association	4	6	0.485
16	Business association	8	8	5.349
21	Business association	5	4	1.558
22	Business association	8	4	0.905
23	Business association	5	4	0.277
35	Business association	25	24	202.062
39	Business association	5	4	0.17
29	Foundation	6	5	3.788
2	Local and regional administration and agency	8	15	19.986
8	Local and regional administration and agency	8	8	8.406
9	Local and regional administration and agency	10	20	44.197
10	Local and regional administration and agency	5	4	1.337
17	Local and regional administration and agency	11	12	20.147
18	Local and regional administration and agency	17	8	24.744
19	Local and regional administration and agency	12	12	6.024
20	Local and regional administration and agency	5	4	0.079
26	Local and regional administration and agency	3	6	0.758
37	Local and regional administration and agency	11	13	18.65
38	Local and regional administration and agency	22	21	111.524

42	Local and regional administration and agency	5	4	0.97
11	Private organization	2	2	0
14	Private organization	14	11	30.566
25	Private organization	25	22	217.504
30	Private organization	11	10	20.334
32	Private organization	9	21	39.083
34	Private organization	6	6	5.416
40	Research institution	4	3	0.667
41	Research institution	12	12	25.754
1	Social organization	39	21	337.572
4	Social organization	0	1	0
5	Social organization	20	33	284.181
6	Social organization	5	4	1.08
7	Social organization	6	7	1.983
12	Social organization	6	5	2.15
24	Social organization	13	15	23.018
27	Social organization	1	3	0.139
28	Social organization	2	4	0.079
31	Social organization	19	4	9.748
33	Social organization	5	5	3.059
36	Social organization	1	4	0

Table 1b Total knowledge network: Average centrality measures (by group)

Group	In-degree	Out-degree	Betweenness
Business associations	7.222	7.000	23.562
Foundations	6.000	5.000	3.788
Local and regional administrations and agencies	9.750	10.583	21.402
Private organizations	11.167	12.000	52.151
Research institutions	8.000	7.500	13.211
Social organizations	9.750	8.833	55.251

Table 2a Total knowledge network: Relative brokerage scores (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

ID	Group	Coor	Gate	Repr	Cons	Liai
3	Business association	0	2.004	0	2.004	0.735
13	Business association	0	0	0	0	0
15	Business association	0	3.006	1.503	0	0.551
16	Business association	0	0.633	0.316	0.949	1.508
21	Business association	0	1.718	0.859	0.859	0.945
22	Business association	0	2.405	0	1.203	0.882
23	Business association	0	4.008	0	0	0.735
35	Business association	2.686	1.452	1.593	0.531	0.613
39	Business association	0	3.006	0	0	1.102
29	Foundation	0	0	0	2.672	1.225
2	Local and regional administration and agency	9.475	0.982	1.595	0.368	0.135
8	Local and regional administration and agency	0.959	1.366	1.913	0.547	0.701
9	Local and regional administration and agency	1.826	0.694	2.544	0.231	0.742
10	Local and regional administration and agency	4.221	0	1.203	1.203	0.882
17	Local and regional administration and agency	1.195	1.475	1.248	0.908	0.749

18	Local and regional administration and agency	0.659	1.597	0.752	0.658	1.033
19	Local and regional administration and agency	3.724	1.592	1.768	0.531	0.389
20	Local and regional administration and agency	0	0	0	0	2.204
26	Local and regional administration and agency	0	0	3.006	0	1.102
37	Local and regional administration and agency	3.638	1.451	1.659	0.518	0.494
38	Local and regional administration and agency	3.667	1.514	1.663	0.533	0.461
42	Local and regional administration and agency	0	1.203	1.203	1.203	0.882
11	Private organization	0	0	0	0	0
14	Private organization	0.459	1.242	0.85	0.85	1.078
25	Private organization	0.488	0.819	0.912	0.896	1.19
30	Private organization	0	0.654	0	1.83	1.294
32	Private organization	0.474	0.405	1.689	1.013	1.015
34	Private organization	3.247	0.925	1.85	1.85	0.17
40	Research institution	0	0	0	3.006	1.102
41	Research institution	0	0	0	1.46	1.669
1	Social organization	0.918	0.965	1.337	0.855	0.951
4	Social organization	0	0	0	0	0
5	Social organization	1.968	0.835	2.191	0.496	0.708
6	Social organization	0	1.503	0	3.006	0.551
7	Social organization	3.517	2.004	1.002	0.501	0.551
12	Social organization	0	2.004	1.336	0	0.98
24	Social organization	0.227	1.422	0.647	1.034	1.043
27	Social organization	0	6.013	0	0	0
28	Social organization	0	0	6.013	0	0
31	Social organization	2.221	2.215	0.633	0.949	0.58
33	Social organization	8.441	1.203	2.405	0	0
36	Social organization	0	0	0	0	0

Table 2b Total knowledge network: Average relative brokerage scores (by group) (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

Group	Coor	Gate	Repr	Cons	Liai
Business associations	0.298	2.026	0.475	0.616	0.786
Foundations	0.000	0.000	0.000	2.672	1.225
Local and regional administrations and agencies	2.447	0.990	1.546	0.558	0.815
Private organizations	0.778	0.674	0.884	1.073	0.791
Research institutions	0.000	0.000	0.000	2.233	1.386
Social organizations	1.441	1.514	1.297	0.570	0.447

Table 3 QAP correlations on CE knowledge networks

	Food waste	Local supply chain	Energy saving	Waste management	Ecosystem services
Food waste	1.000				
Local supply chain	0.276***	1.000			
Energy saving	0.210***	0.396***	1.000		
Waste management	0.220***	0.362***	0.344***	1.000	
Ecosystem services	0.274***	0.269***	0.183**	0.190***	1.000

*p ≤ .05. **p ≤ .01. ***p ≤ .001

Table 4a Food waste knowledge network: Centrality measures

ID	Group	In-degree	Out-degree	Betweenness
3	Business association	0	0	0
13	Business association	1	1	0
15	Business association	2	2	1.494
16	Business association	1	1	0
21	Business association	1	2	1.494
22	Business association	1	2	1.494
23	Business association	1	2	1.494
35	Business association	15	15	301.648
39	Business association	0	0	0
29	Foundation	5	5	9.881
2	Local and regional administration and agency	4	2	5.5
8	Local and regional administration and agency	0	1	0
9	Local and regional administration and agency	7	5	10.14
10	Local and regional administration and agency	0	0	0
17	Local and regional administration and agency	8	7	57.23
18	Local and regional administration and agency	2	7	9.195
19	Local and regional administration and agency	7	8	22.122
20	Local and regional administration and agency	2	2	1.494
26	Local and regional administration and agency	2	2	20.461
37	Local and regional administration and agency	5	4	29.819
38	Local and regional administration and agency	0	0	0
42	Local and regional administration and agency	0	0	0
11	Private organization	1	2	0
14	Private organization	6	5	14.9
25	Private organization	14	14	162.026
30	Private organization	0	0	0
32	Private organization	4	3	2.797
34	Private organization	5	5	9.881
40	Research institution	1	3	0.469
41	Research institution	1	2	0
1	Social organization	15	14	145.391
4	Social organization	0	0	0
5	Social organization	25	17	429.249
6	Social organization	2	3	8.717
7	Social organization	5	5	11.332
12	Social organization	5	5	1.4
24	Social organization	2	2	0
27	Social organization	0	0	0
28	Social organization	2	1	0
31	Social organization	1	4	1.583
33	Social organization	5	5	8.792
36	Social organization	1	1	0

Table 4b Food waste knowledge network: Average centrality measures (by group)

Group	In-degree	Out-degree	Betweenness
Business associations	2.444	2.778	34.180
Foundations	5.000	5.000	9.881
Local and regional administrations and agencies	3.083	3.167	12.997
Private organizations	5.000	4.833	31.601
Research institutions	1.000	2.500	0.235
Social organizations	5.250	4.750	50.539

Table 5a Local supply chain knowledge network: Centrality measures

ID	Group	In-degree	Out-degree	Betweenness
3	Business association	1	0	0
13	Business association	0	0	0
15	Business association	0	0	0
16	Business association	0	0	0
21	Business association	0	0	0
22	Business association	0	0	0
23	Business association	0	0	0
35	Business association	0	0	0
39	Business association	0	0	0
29	Foundation	0	0	0
2	Local and regional administration and agency	2	2	23
8	Local and regional administration and agency	0	0	0
9	Local and regional administration and agency	0	0	0
10	Local and regional administration and agency	0	0	0
17	Local and regional administration and agency	3	2	12
18	Local and regional administration and agency	1	3	14
19	Local and regional administration and agency	2	3	13
20	Local and regional administration and agency	1	1	0
26	Local and regional administration and agency	1	1	0
37	Local and regional administration and agency	4	3	44.5
38	Local and regional administration and agency	0	0	0
42	Local and regional administration and agency	0	0	0
11	Private organization	0	0	0
14	Private organization	1	1	0
25	Private organization	0	0	0
30	Private organization	0	0	0
32	Private organization	1	0	0
34	Private organization	0	0	0
40	Research institution	0	0	0
41	Research institution	1	1	0
1	Social organization	0	0	0
4	Social organization	0	0	0
5	Social organization	5	4	71.5
6	Social organization	0	0	0
7	Social organization	0	0	0

12	Social organization	0	1	0
24	Social organization	5	5	79.667
27	Social organization	0	0	0
28	Social organization	0	0	0
31	Social organization	3	5	35.667
33	Social organization	0	0	0
36	Social organization	2	1	0.667

Table 5b Local supply chain knowledge network: Average centrality measures (by group)

Group	In-degree	Out-degree	Betweenness
Business associations	0.111	0.000	0.000
Foundations	0.000	0.000	0.000
Local and regional administrations and agencies	1.167	1.250	8.875
Private organizations	0.333	0.167	0.000
Research institutions	0.500	0.500	0.000
Social organizations	1.250	1.333	15.625

Table 6a Energy saving knowledge network: Centrality measures

ID	Group	In-degree	Out-degree	Betweenness
3	Business association	0	0	0
13	Business association	0	0	0
15	Business association	2	2	4.375
16	Business association	0	0	0
21	Business association	0	0	0
22	Business association	1	1	0
23	Business association	0	0	0
35	Business association	1	1	0
39	Business association	0	0	0
29	Foundation	0	0	0
2	Local and regional administration and agency	5	4	13.875
8	Local and regional administration and agency	0	1	0
9	Local and regional administration and agency	0	0	0
10	Local and regional administration and agency	0	0	0
17	Local and regional administration and agency	6	4	37.35
18	Local and regional administration and agency	1	1	0
19	Local and regional administration and agency	1	2	1.5
20	Local and regional administration and agency	2	2	4.375
26	Local and regional administration and agency	2	2	0
37	Local and regional administration and agency	6	5	19.35
38	Local and regional administration and agency	13	12	160.317
42	Local and regional administration and agency	0	0	0
11	Private organization	0	0	0
14	Private organization	0	0	0
25	Private organization	0	0	0
30	Private organization	0	0	0

32	Private organization	3	2	5.375
34	Private organization	0	0	0
40	Research institution	0	0	0
41	Research institution	2	3	7.8
1	Social organization	0	0	0
4	Social organization	0	0	0
5	Social organization	11	8	92.267
6	Social organization	1	2	0
7	Social organization	0	0	0
12	Social organization	0	1	0
24	Social organization	3	3	3.417
27	Social organization	0	0	0
28	Social organization	1	1	0
31	Social organization	0	5	0
33	Social organization	0	0	0
36	Social organization	1	0	0

Table 6b Energy saving knowledge network: Average centrality measures (by group)

Group	In-degree	Out-degree	Betweenness
Business associations	0.444	0.444	0.486
Foundations	0.000	0.000	0.000
Local and regional administrations and agencies	3.000	2.750	19.731
Private organizations	0.500	0.333	0.896
Research institutions	1.000	1.500	3.900
Social organizations	1.417	1.667	7.974

Table 7a Waste management knowledge network: Centrality measures

ID	Group	In-degree	Out-degree	Betweenness
3	Business association	0	0	0
13	Business association	0	0	0
15	Business association	0	0	0
16	Business association	0	0	0
21	Business association	0	0	0
22	Business association	0	0	0
23	Business association	0	0	0
35	Business association	8	8	165.167
39	Business association	1	1	0
29	Foundation	0	0	0
2	Local and regional administration and agency	5	4	69.5
8	Local and regional administration and agency	4	5	67
9	Local and regional administration and agency	0	0	0
10	Local and regional administration and agency	0	0	0
17	Local and regional administration and agency	2	2	0
18	Local and regional administration and agency	1	1	0
19	Local and regional administration and agency	5	5	41.833
20	Local and regional administration and agency	1	1	0
26	Local and regional administration and agency	1	1	0
37	Local and regional	5	4	40.167

	administration and agency			
38	Local and regional administration and agency	2	2	33
42	Local and regional administration and agency	0	0	0
11	Private organization	0	0	0
14	Private organization	3	3	25.833
25	Private organization	1	1	0
30	Private organization	1	1	0
32	Private organization	7	5	124.167
34	Private organization	0	0	0
40	Research institution	1	1	0
41	Research institution	3	3	44.667
1	Social organization	0	0	0
4	Social organization	0	0	0
5	Social organization	2	2	38
6	Social organization	0	1	0
7	Social organization	0	0	0
12	Social organization	0	0	0
24	Social organization	5	5	66.667
27	Social organization	0	0	0
28	Social organization	1	1	0
31	Social organization	0	2	0
33	Social organization	0	0	0
36	Social organization	0	0	0

Table 7b Waste management knowledge network: Average centrality measures (by group)

Group	In-degree	Out-degree	Betweenness
Business associations	1.000	1.000	18.352
Foundations	0.000	0.000	0.000
Local and regional administrations and agencies	2.167	2.083	20.958
Private organizations	2.000	1.667	25.000
Research institutions	2.000	2.000	22.334
Social organizations	0.667	0.917	8.722

Table 8a Ecosystem services knowledge network: Centrality measures

ID	Group	In-degree	Out-degree	Betweenness
3	Business association	0	0	0
13	Business association	0	0	0
15	Business association	0	0	0
16	Business association	0	0	0
21	Business association	0	0	0
22	Business association	0	0	0
23	Business association	0	0	0
35	Business association	1	1	0
39	Business association	0	0	0
29	Foundation	0	0	0
2	Local and regional administration and agency	3	2	5
8	Local and regional administration and agency	0	0	0
9	Local and regional administration and agency	0	0	0
10	Local and regional administration and agency	0	0	0
17	Local and regional administration and agency	0	0	0

18	Local and regional administration and agency	0	0	0
19	Local and regional administration and agency	0	0	0
20	Local and regional administration and agency	0	0	0
26	Local and regional administration and agency	1	1	0
37	Local and regional administration and agency	2	1	2
38	Local and regional administration and agency	0	0	0
42	Local and regional administration and agency	0	0	0
11	Private organization	1	1	0
14	Private organization	0	1	0
25	Private organization	4	4	12
30	Private organization	0	0	0
32	Private organization	1	0	0
34	Private organization	0	0	0
40	Research institution	0	0	0
41	Research institution	0	0	0
1	Social organization	1	1	0
4	Social organization	0	0	0
5	Social organization	0	0	0
6	Social organization	0	0	0
7	Social organization	1	1	0
12	Social organization	0	0	0
24	Social organization	0	0	0
27	Social organization	0	0	0
28	Social organization	0	0	0
31	Social organization	0	2	0
33	Social organization	0	0	0
36	Social organization	0	0	0

Table 8b Ecosystem services knowledge network: Average centrality measures (by group)

Group	In-degree	Out-degree	Betweenness
Business associations	0.111	0.111	0.000
Foundations	0.000	0.000	0.000
Local and regional administrations and agencies	0.500	0.333	0.583
Private organizations	1.000	1.000	2.000
Research institutions	0.000	0.000	0.000
Social organizations	0.167	0.333	0.000

Table 9a Food waste knowledge network: Relative brokerage scores (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

ID	Group	Coor	Gate	Repr	Cons	Liai
3	Business association	0	0	0	0	0
13	Business association	0	0	0	0	0
15	Business association	0	6.257	0	0	0
16	Business association	0	0	0	0	0
21	Business association	0	6.257	0	0	0
22	Business association	0	6.257	0	0	0
23	Business association	0	6.257	0	0	0
35	Business association	4.396	1.831	1.793	0.343	0.382
39	Business association	0	0	0	0	0

29	Foundation	0	0	0	2.503	1.253
2	Local and regional administration and agency	16.021	0	2.086	0	0
8	Local and regional administration and agency	0	0	0	0	0
9	Local and regional administration and agency	1.849	0.963	1.444	0.963	0.803
10	Local and regional administration and agency	0	0	0	0	0
17	Local and regional administration and agency	3.004	2.151	1.369	1.369	0.196
18	Local and regional administration and agency	0	0	2.086	2.086	0.696
19	Local and regional administration and agency	2.403	1.564	1.564	0.626	0.626
20	Local and regional administration and agency	0	0	0	0	2.088
26	Local and regional administration and agency	0	2.086	2.086	0	0.696
37	Local and regional administration and agency	4.806	1.251	2.503	0.626	0.209
38	Local and regional administration and agency	0	0	0	0	0
42	Local and regional administration and agency	0	0	0	0	0
11	Private organization	0	0	0	0	0
14	Private organization	0	1.192	1.49	0	1.193
25	Private organization	0.37	0.963	1.011	0.77	1.14
30	Private organization	0	0	0	0	0
32	Private organization	0	0	0	2.086	1.392
34	Private organization	4.806	1.877	1.877	1.251	0
40	Research institution	0	0	0	6.257	0
41	Research institution	0	0	0	0	0
1	Social organization	0.702	1.325	0.868	0.776	1.036
4	Social organization	0	0	0	0	0
5	Social organization	3.54	1.01	2.145	0.372	0.603
6	Social organization	0	3.129	0	3.129	0
7	Social organization	3.004	2.346	0.782	0.782	0.522
12	Social organization	0	2.086	2.086	0	0.696
24	Social organization	0	0	0	0	0
27	Social organization	0	0	0	0	0
28	Social organization	0	0	0	0	0
31	Social organization	0	6.257	0	0	0
33	Social organization	9.613	1.251	2.503	0	0
36	Social organization	0	0	0	0	0

Table 9b Food waste knowledge network: Average relative brokerage scores (by group) (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

Group	Coor	Gate	Repr	Cons	Liai
Business associations	0.488	2.984	0.199	0.038	0.042
Foundations	0.000	0.000	0.000	2.503	1.253
Local and regional administrations and agencies	2.340	0.668	1.095	0.473	0.443
Private organizations	0.863	0.672	0.730	0.685	0.621
Research institutions	0.000	0.000	0.000	3.129	0.000
Social organizations	1.405	1.450	0.699	0.422	0.238

Table 10a Local supply chain knowledge network: Relative brokerage scores (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

ID	Group	Coor	Gate	Repr	Cons	Liai
3	Business association	0	0	0	0	0
13	Business association	0	0	0	0	0
15	Business association	0	0	0	0	0
16	Business association	0	0	0	0	0
21	Business association	0	0	0	0	0
22	Business association	0	0	0	0	0
23	Business association	0	0	0	0	0
35	Business association	0	0	0	0	0
39	Business association	0	0	0	0	0
29	Foundation	0	0	0	0	0
2	Local and regional administration and agency	12.444	0	0	0	0
8	Local and regional administration and agency	0	0	0	0	0
9	Local and regional administration and agency	0	0	0	0	0
10	Local and regional administration and agency	0	0	0	0	0
17	Local and regional administration and agency	0	0	2.684	2.684	0
18	Local and regional administration and agency	0	0	0	5.367	0
19	Local and regional administration and agency	0	0	0	0	2.772
20	Local and regional administration and agency	0	0	0	0	0
26	Local and regional administration and agency	0	0	0	0	0
37	Local and regional administration and agency	3.556	0.767	2.3	0.767	0
38	Local and regional administration and agency	0	0	0	0	0
42	Local and regional administration and agency	0	0	0	0	0
11	Private organization	0	0	0	0	0
14	Private organization	0	0	0	0	0
25	Private organization	0	0	0	0	0
30	Private organization	0	0	0	0	0
32	Private organization	0	0	0	0	0
34	Private organization	0	0	0	0	0
40	Research institution	0	0	0	0	0
41	Research institution	0	0	0	0	0
1	Social organization	0	0	0	0	0
4	Social organization	0	0	0	0	0
5	Social organization	4.667	1.006	2.013	0.335	0
6	Social organization	0	0	0	0	0
7	Social organization	0	0	0	0	0
12	Social organization	0	0	0	0	0
24	Social organization	0	1.193	1.193	1.193	0.924
27	Social organization	0	0	0	0	0
28	Social organization	0	0	0	0	0
31	Social organization	0	2.3	0.767	0.767	0.792
33	Social organization	0	0	0	0	0
36	Social organization	0	0	5.367	0	0

Table 10b Local supply chain knowledge network: Average relative brokerage scores (by group) (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

Group	Coor	Gate	Repr	Cons	Liai
Business associations	0.000	0.000	0.000	0.000	0.000
Foundations	0.000	0.000	0.000	0.000	0.000
Local and regional administrations and agencies	1.333	0.064	0.415	0.735	0.231
Private organizations	0.000	0.000	0.000	0.000	0.000
Research institutions	0.000	0.000	0.000	0.000	0.000
Social organizations	0.389	0.375	0.778	0.191	0.143

Table 11a Energy saving knowledge network: Relative brokerage scores (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

ID	Group	Coor	Gate	Repr	Cons	Liai
3	Business association	0	0	0	0	0
13	Business association	0	0	0	0	0
15	Business association	0	0	0	0	3.093
16	Business association	0	0	0	0	0
21	Business association	0	0	0	0	0
22	Business association	0	0	0	0	0
23	Business association	0	0	0	0	0
35	Business association	0	0	0	0	0
39	Business association	0	0	0	0	0
29	Foundation	0	0	0	0	0
2	Local and regional administration and agency	2.771	1.279	1.918	0.639	0
8	Local and regional administration and agency	0	0	0	0	0
9	Local and regional administration and agency	0	0	0	0	0
10	Local and regional administration and agency	0	0	0	0	0
17	Local and regional administration and agency	0	0.787	2.361	1.967	0
18	Local and regional administration and agency	0	0	0	0	0
19	Local and regional administration and agency	0	5.115	0	0	0
20	Local and regional administration and agency	0	2.558	2.558	0	0
26	Local and regional administration and agency	0	0	0	0	0
37	Local and regional administration and agency	1.705	1.18	1.574	1.574	0
38	Local and regional administration and agency	2.956	1.326	1.516	0.227	0.412
42	Local and regional administration and agency	0	0	0	0	0
11	Private organization	0	0	0	0	0
14	Private organization	0	0	0	0	0
25	Private organization	0	0	0	0	0
30	Private organization	0	0	0	0	0
32	Private organization	0	0	0	1.705	2.062
34	Private organization	0	0	0	0	0
40	Research institution	0	0	0	0	0
41	Research institution	0	0	0	1.279	2.32
1	Social organization	0	0	0	0	0
4	Social organization	0	0	0	0	0

5	Social organization	0.296	0.75	1.228	1.091	1.155
6	Social organization	0	0	0	0	0
7	Social organization	0	0	0	0	0
12	Social organization	0	0	0	0	0
24	Social organization	0	0	0	0	3.093
27	Social organization	0	0	0	0	0
28	Social organization	0	0	0	0	0
31	Social organization	0	0	0	0	0
33	Social organization	0	0	0	0	0
36	Social organization	0	0	0	0	0

Table 11b Energy saving knowledge network: Average relative brokerage scores (by group) (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

Group	Coor	Gate	Repr	Cons	Liai
Business associations	0.000	0.000	0.000	0.000	0.344
Foundations	0.000	0.000	0.000	0.000	0.000
Local and regional administrations and agencies	0.619	1.020	0.827	0.367	0.034
Private organizations	0.000	0.000	0.000	0.284	0.344
Research institutions	0.000	0.000	0.000	0.640	1.160
Social organizations	0.025	0.063	0.102	0.091	0.354

Table 12a Waste management knowledge network: Relative brokerage scores (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

ID	Group	Coor	Gate	Repr	Cons	Liai
3	Business association	0	0	0	0	0
13	Business association	0	0	0	0	0
15	Business association	0	0	0	0	0
16	Business association	0	0	0	0	0
21	Business association	0	0	0	0	0
22	Business association	0	0	0	0	0
23	Business association	0	0	0	0	0
35	Business association	0	0.762	0.762	1.524	1.13
39	Business association	0	0	0	0	0
29	Foundation	0	0	0	0	0
2	Local and regional administration and agency	11.224	0	1.679	0	0
8	Local and regional administration and agency	0	2.519	1.679	0.84	0.335
9	Local and regional administration and agency	0	0	0	0	0
10	Local and regional administration and agency	0	0	0	0	0
17	Local and regional administration and agency	0	0	0	0	0
18	Local and regional administration and agency	0	0	0	0	0
19	Local and regional administration and agency	0	0	0	0	2.348
20	Local and regional administration and agency	0	0	0	0	0
26	Local and regional administration and agency	0	0	0	0	0
37	Local and regional administration and agency	5.238	0.98	2.449	0.49	0
38	Local and regional administration and agency	0	2.939	2.939	0	0

42	Local and regional administration and agency	0	0	0	0	0
11	Private organization	0	0	0	0	0
14	Private organization	0	2.939	2.939	0	0
25	Private organization	0	0	0	0	0
30	Private organization	0	0	0	0	0
32	Private organization	1.209	1.13	2.035	1.13	0.451
34	Private organization	0	0	0	0	0
40	Research institution	0	0	0	0	0
41	Research institution	0	0	0	0	2.348
1	Social organization	0	0	0	0	0
4	Social organization	0	0	0	0	0
5	Social organization	0	2.939	2.939	0	0
6	Social organization	0	0	0	0	0
7	Social organization	0	0	0	0	0
12	Social organization	0	0	0	0	0
24	Social organization	0	0	0	1.469	1.761
27	Social organization	0	0	0	0	0
28	Social organization	0	0	0	0	0
31	Social organization	0	0	0	0	0
33	Social organization	0	0	0	0	0
36	Social organization	0	0	0	0	0

Table 12b Waste management knowledge network: Average relative brokerage scores (by group) (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

Group	Coor	Gate	Repr	Cons	Liai
Business associations	0.000	0.085	0.085	0.169	0.126
Foundations	0.000	0.000	0.000	0.000	0.000
Local and regional administrations and agencies	1.372	0.537	0.729	0.111	0.224
Private organizations	0.202	0.678	0.829	0.188	0.075
Research institutions	0.000	0.000	0.000	0.000	1.174
Social organizations	0.000	0.245	0.245	0.122	0.147

Table 13a Ecosystem services knowledge network: Relative brokerage scores (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

ID	Group	Coor	Gate	Repr	Cons	Liai
3	Business association	0	0	0	0	0
13	Business association	0	0	0	0	0
15	Business association	0	0	0	0	0
16	Business association	0	0	0	0	0
21	Business association	0	0	0	0	0
22	Business association	0	0	0	0	0
23	Business association	0	0	0	0	0
35	Business association	0	0	0	0	0
39	Business association	0	0	0	0	0
29	Foundation	0	0	0	0	0
2	Local and regional administration and agency	13.75	0	2.75	0	0
8	Local and regional administration and agency	0	0	0	0	0
9	Local and regional administration and agency	0	0	0	0	0
10	Local and regional administration and agency	0	0	0	0	0
17	Local and regional administration and agency	0	0	0	0	0

18	Local and regional administration and agency	0	0	0	0	0
19	Local and regional administration and agency	0	0	0	0	0
20	Local and regional administration and agency	0	0	0	0	0
26	Local and regional administration and agency	0	0	0	0	0
37	Local and regional administration and agency	0	0	5.5	0	0
38	Local and regional administration and agency	0	0	0	0	0
42	Local and regional administration and agency	0	0	0	0	0
11	Private organization	0	0	0	0	0
14	Private organization	0	0	0	0	0
25	Private organization	0	1.375	1.375	0.917	0.797
30	Private organization	0	0	0	0	0
32	Private organization	0	0	0	0	0
34	Private organization	0	0	0	0	0
40	Research institution	0	0	0	0	0
41	Research institution	0	0	0	0	0
1	Social organization	0	0	0	0	0
4	Social organization	0	0	0	0	0
5	Social organization	0	0	0	0	0
6	Social organization	0	0	0	0	0
7	Social organization	0	0	0	0	0
12	Social organization	0	0	0	0	0
24	Social organization	0	0	0	0	0
27	Social organization	0	0	0	0	0
28	Social organization	0	0	0	0	0
31	Social organization	0	0	0	0	0
33	Social organization	0	0	0	0	0
36	Social organization	0	0	0	0	0

Table 13b Ecosystem services knowledge network: Average relative brokerage scores (by group) (Coor=coordinator; Gate=gatekeeper; Repr=representative; Cons=consultant; Liai=liaison)

Group	Coor	Gate	Repr	Cons	Liai
Business associations	0.000	0.000	0.000	0.000	0.000
Foundations	0.000	0.000	0.000	0.000	0.000
Local and regional administrations and agencies	1.146	0.000	0.688	0.000	0.000
Private organizations	0.000	0.229	0.229	0.153	0.133
Research institutions	0.000	0.000	0.000	0.000	0.000
Social organizations	0.000	0.000	0.000	0.000	0.000