<https://helda.helsinki.fi>

Toward the creation of novel food waste management systems : A network approach

Ghini, Stefano

2020-02-10

Ghini, S, Silvestri, F & Steiner, PhD, P B 2020, 'Toward the creation of novel food waste management systems : A network approach', Journal of Cleaner Production, vol. 246, 118987. <https://doi.org/10.1016/j.jclepro.2019.118987>

<http://hdl.handle.net/10138/311895>

<https://doi.org/10.1016/j.jclepro.2019.118987>

submittedVersion

Downloaded from Helda, University of Helsinki institutional repository.

This is an electronic reprint of the original article.

This reprint may differ from the original in pagination and typographic detail.

Please cite the original version.

Toward the creation of novel food waste management systems: a network approach

Stefano Ghinoi^{a,b}, Francesco Silvestri^{c,d}, Bodo Steiner^{a,b}

^a University of Helsinki, Department of Economics and Management, Latokartanonkaari 5, P.O. Box 27, 00014 Helsinki, Finland

^b HELSUS, Helsinki Institute of Sustainability Science, Finland

^c University of Modena and Reggio Emilia, Department of Communication and Economics, Viale Allegri 9, 42121 Reggio Emilia, Italy

^d eco&eco Srl., Via Guglielmo Oberdan 11, 40126 Bologna, Italy

Abstract

In light of the global significance of food waste, a greater focus on improving food waste management strategies is called for. Implementing such management strategies requires a better understanding of stakeholder relations. This paper analyses the structure of multiplex relations among stakeholders involved in the creation of a novel food waste management system, investigating the drivers of network formation when multiple collaborations are observed between pairs of stakeholders. We apply Social Network Analysis to study food waste reduction strategies in the City of Ferrara (Italy). Our results provide support for the practical relevance of multiple interactions across dyadic relationships in stakeholder networks. They also suggest that ‘third parties’ are not necessary for an effective networking strategy, and that relationships between stakeholders of similar levels of expertise are not required for establishing multiple relationships,

23 suggesting that functionally diverse coalitions are of greater practical relevance for food waste
24 management strategies.

25

26 *Keywords:* food waste management; stakeholders; multiplexity; Social Network Analysis.

27

28 **1. Introduction**

29 Food waste is a global issue that is relevant for developed and developing countries alike, linking
30 food safety, food security, and other key aspects of sustainability (FAO, 2019; Walia and Sanders,
31 2019). Urbanization and changing consumption habits have contributed to the rising food waste
32 issue (Priefer et al., 2016). The third target of the United Nations Sustainable Development Goal 12
33 (‘Ensure sustainable consumption and production patterns’) commits countries to halve per-capita
34 food waste at retail and consumption level, and to reduce food waste along the entire food chain by
35 2030. Recent estimates of food loss and waste generation range between 194-389 kg per person per
36 year at the global scale, and between 158-298 kg per person per year at European level (Corrado
37 and Sala, 2018), which translates into 88 million tons of food annually wasted, or equivalent losses
38 of around 143 billion Euro (FUSIONS, 2016). Since the European Union (EU) is globally the
39 second most significant contributor in terms of per capita food losses and waste at consumption and
40 pre-consumption stages (FAO, 2019), it is unsurprising that debates on food waste management are
41 thus becoming increasingly vocal amongst European stakeholders at national and local level
42 (Gustavsson et al., 2011; Priefer et al., 2016; Grainger et al., 2018a).

43 The stakeholders interested in reducing food waste operate across the entire food supply chain,
44 involving producers, food processors, retailers, consumers, social organizations, and public
45 authorities (Lipinski et al. 2013; Halloran et al., 2014; Mourad, 2016; Aschemann-Witzel et al.,

2017). There seems to be a consensus that reducing food waste requires a co-operative intervention among these stakeholders, to effectively introduce changes in technologies, practices, and policies that a single actor cannot afford (Papargyropoulou et al., 2014). Yet, we have limited insight into the nature of such co-operative intervention. Garcia-Garcia et al. (2017) suggest that handling complex food waste management systems requires a flexible relational analytical perspective. Previous work that has taken such a relational perspective in a food supply chain context suggests that stakeholders can achieve their objectives best through repeated interaction, and by relying on multiple relations, given the stakeholders' different interests, resources, and capabilities (Steiner et al., 2017). In the context of food waste management, previous work suggests that multi-stakeholder initiatives can foster the establishment of multiple overlapping relations, i.e. the exchange of information, the sharing of resources, and the development of cooperative projects (Kaipia et al., 2013; Lipinski et al. 2013; Mourad, 2016; Saint Ville et al., 2017). However, we observe a striking absence of studies that take into account multiplex networks in the context of food waste management systems. More specifically, it appears that no studies have thus far investigated the drivers of relationships in these networks, which are fundamental to understanding stakeholders' behaviour toward the implementation of novel food waste management systems. Empirical work as part of network studies has shown how specific endogenous network characteristics and exogenous organizational attributes drive the networking behaviour of stakeholders (Lazega et al., 2012; Lusher et al., 2013), but, to the best of our knowledge, this issue has not been explored in applied studies dedicated to food waste management.

Therefore, our study aims to fill this gap by exploring the drivers of stakeholder interactions in the creation of a novel food waste management system, contributing to the literature on food waste management in several ways. First, it demonstrates that a network perspective of multiplex relations is useful to understand how stakeholders define their structure of relationships. Second, our study highlights the role of relationship quality, by identifying three different formal and informal

71 networking relationships in food waste management. Finally, we of augment the evidence base on
72 food waste management case studies from different countries (Xu et al., 2016; Bustos and Moors,
73 2018), by adding the perspective of a representative European city particularly active on
74 environmental issues. Our focus on the City of Ferrara (Italy) as a case study is motivated by its
75 characteristics of being a representative mid-size European city that has taken national leadership
76 by promoting a number of key initiatives aimed to support the circular economy perspective and to
77 foster food waste reduction involving local stakeholders.

78 This paper is organized as follows. Section 2 describes relevant background to food waste
79 management strategies in Europe, followed by a review of the relevant literature. Section 3 presents
80 our hypotheses. Section 4 develops methods and data, while sections 5 and 6 present and discuss
81 the results, respectively. Section 7 concludes, also providing policy implications and suggesting
82 further research avenues.

83 **2. Theoretical background**

84 **2.1 Food waste: definition and policymaking**

85 The FAO Global Initiative on Food Loss and Waste Reduction defines food loss as a decrease in
86 quantity or quality of food, intended as any substance suitable for human consumption (FAO, 2014:
87 4). The FAO (2011: 2) defines food waste as *‘the food losses occurring at the end of the food*
88 *chain’*; therefore, food waste can be seen as a subset of food loss consisting of edible food that has
89 not been consumed by humans.

90 In order to minimize the amount of food waste, the European Commission invited EU Members to
91 define a roadmap for reducing food waste, thus contributing to improve *‘resource efficiency and*
92 *food security at a global level’* (European Commission, 2011: 17).. In 2015, the Commission also
93 adopted an Action Plan for the Circular Economy, including actions for stimulating food waste
94 reduction (European Commission, 2015). However, national food waste policies in European

95 countries are not homogeneous in their implementation. In Belgium, the Public Flemish Waste
96 Management Company uses a food waste management hierarchy scheme that starts from prevention
97 strategy, passes through the use as raw material in industry, and arrives at storage in landfills (De
98 Clercq et al., 2017). The Spanish government has developed a waste strategy as part of the research
99 project ‘More Food, Less Waste’, to collect data on food waste in households, industries, and farms,
100 in order to implement a national strategy for reshaping the food chain (Blas et al., 2018). Germany
101 devises strategies for supporting the circular economy, and a pivotal role is played by retailers,
102 which are active in redistributing non-marketable food items to charitable organizations (Hermsdorf
103 et al., 2017). Charitable organizations are particularly relevant also in Italy (Garrone et al., 2016),
104 whose National Government implemented a national law in 2016 to regulate the distribution of
105 edible food to reduce wastage¹.

106 **2.2 Stakeholders and multiplex networks involved in food waste management**

107 The food chain is a complex system characterized by a variety of relational risks (Priefer et al.,
108 2016; Steiner et al., 2017), where the very nature of food (perishability) leads to potential food
109 waste with corresponding environmental costs and dietary quality consequences (Conrad et al.,
110 2018). As a result, knowledge transfer and cooperation between stakeholders can be an effective
111 means to reduce negative externalities and transaction costs associated with relational risks (Buzby
112 and Hyman, 2012; Lipinski et al., 2013).. Such collaborative initiatives are reflected in stakeholder
113 relationships in terms of entrepreneurial ecosystems (Spigel, 2017); Figure 1 aims to visualize the
114 key stakeholders that are involved in the food chain and in the planning of food waste management
115 strategies (Figure 1).

116 [Figure 1]

¹ National Law n. 166, 19 August 2016: Provision regarding donation and distribution of food and pharmaceutical products for social solidarity and wastage reduction (16G00179) (*‘Disposizioni concernenti la donazione e la distribuzione di prodotti alimentari e farmaceutici a fini di solidarietà sociale e per la limitazione degli sprechi (16G00179)’*).

117 Stakeholders' cooperation and the strengthening of inter-organizational relationships can lead to
118 positive performance outcomes (Mena et al., 2011; Bliemel et al., 2016), though this depends on the
119 types of stakeholder relationships (Uzzi, 1997; Rank et al., 2010). It is generally acknowledged that
120 organizations are *'bound by manifold interdependencies within and across the layers of the network*
121 *within which they are embedded'* (Simpson, 2015: 45). In the context of inter-organizational
122 networks, network theory offers a perspective to simultaneously consider different interdependent
123 layers (networks), therefore analysing the multiplex social structures underlying a relational context
124 (Lomi and Pattison, 2006; Scott and Carrington, 2011). Multiplexity has increasingly become a key
125 topic in organization and management studies because taking into account only single relations,
126 rather than the whole set, can lead to biases in the analysis of network structures (Lomi and
127 Pattison, 2006; Bliemel et al., 2016).

128 In the context of food waste management, the literature has further discussed the role of different
129 relational forms in stakeholder networks. These forms can be identified as exchange of information,
130 sharing of resources, and development of cooperative projects. Information exchange is considered
131 an important source of organizational learning (Lazega et al., 2012); the more a stakeholder
132 exchanges information with others, the more it will be stimulated to develop new ideas (Reed et al.,
133 2014). The lack of information sharing between stakeholders is one of the main causes of food
134 waste in the retail stores (Kaipia et al., 2013). Sharing resources (physical spaces and workforce) is
135 also an important element in promoting the integration of a number of stakeholders in innovation
136 activities (Fountain, 1998), especially in the food context (León-Bravo et al., 2017). In particular,
137 the implementation of a novel food waste management system can be supported by the sharing of
138 material resources, since the development of technologies and practices requires tools and people
139 enabling this process (Lipinski et al. 2013). Finally, there is widespread evidence that formal
140 cooperative projects are important for more effective sustainability-oriented organizations (Lozano,
141 2008; Govindan et al., 2016). Aschemann-Witzel et al. (2017) suggest that collaboration among

142 stakeholders appears especially useful due to the complexity of the food waste issue. Garrone et al.
143 (2016) provide evidence from ten Italian food manufacturers which highlight that the inclusion of
144 non-governmental organizations (NGOs) in the decision-making process is not only supportive but
145 necessary to reduce food waste effectively. Similarly, De Steur et al. (2016) and Mourad (2016)
146 emphasize the importance of formal multi-stakeholder collaborations in the process of reducing
147 food waste.

148 Furthermore, stakeholders may not limit their relations solely to the exchange of information in
149 order to acquire knowledge which is not freely available: they can also decide to structure formal
150 projects aimed at realizing innovative solutions (Mourad, 2016; Ribeiro et al. 2019). The conceptual
151 perspective of multiplexity enables the analyst to consider the simultaneous existence of various
152 forms of relationships, reflecting on the complexity and effectiveness of the underlying decision
153 system among the stakeholders.

154 **3. Hypotheses**

155 Networks are characterized by the presence of two types of structures, which are the smallest
156 elements of possible relational systems: dyads and triads. A dyad consists of a pair of actors and a
157 link (tie) between them, which can be directed (e.g. an information sent from actor *i* to actor *j*) or
158 undirected (e.g. a family relation between two individuals). Triads are made by three actors sharing
159 a set of relationships; as for dyads, also triadic structures can present directed or undirected links. In
160 multiplex networks, dyads and triads present multiple links at the same time that can be, as in the
161 case of single networks, directed or undirected (Scott and Carrington, 2011).

162 At the dyadic level, the social embeddedness perspective suggests that when two actors form a link
163 in a specific context, this behaviour is frequently related to the presence of other links (Shipilov and
164 Li, 2012). The overall assumption is that those combinations of observed links are a reflection of
165 stakeholders' perceived assets embedded in the food waste governance fabric (Reed et al., 2009;

166 Bodin and Prell, 2011). This mixed pattern of relationships between dyads can exist between the
167 information exchange and the resource sharing relation, the information exchange and the projects-
168 related relation, and the resource sharing and the projects-related relation: instrumental relationships
169 based in the exchange of information are often observed in conjunction with more stable
170 collaborations (sharing resources and collaborative projects), while sharing resources is
171 fundamental to the success of a formal cooperative project, especially in the food chain (Galanakis,
172 2016). Considering the above observations, we propose the following competing hypotheses:

173 H1a) Considering dyads in food waste management networks, information exchange is
174 observed in combination with resources sharing efforts of stakeholders;

175 H1b) Considering dyads in food waste management networks, information exchange exists
176 in combination with relationships that are project-focused;

177 H1c) Considering dyads in food waste management networks, resource sharing exists in
178 combination with project-focused relationships.

179 The presence of multiplex dyadic structures reflects the importance of establishing multiple
180 collaborations between pairs of stakeholders. Besides, network scholars have also highlighted the
181 importance of three-actor configurations, since dyadic relationships are not independent from their
182 neighbourhood of relationships. Gulati and Gargiulo (1999) and Lomi and Pattison (2006) have
183 pointed out that partners of the same actor are likely to become partners themselves as well, since
184 shared partners are a source of trust and reliability. In closed network structures, trust can be a
185 means for governance and can reduce the risk of opportunism (Williamson, 1993). The resulting
186 closer and stronger relationships with lower costs of sanctioning are likely more effective as part of
187 a bonding (social capital) relationship (Putnam, 2000). We assert that these benefits also carry over
188 to triadic relationships among stakeholders involved in developing a new food waste management
189 system, i.e. the benefits of triadic structures carry over to the exchange of information, the sharing

190 of resources, and the development of cooperative projects. Simpson (2015: 44) suggests that
191 *‘tendencies for alliance to be embedded in triangles formed with co-occurring ties suggests that*
192 *signalling, by means of structural position, helps to govern alliance formation in multilayered*
193 *systems’*; moreover, as illustrated by Lee and Monge (2011), common third party ties between
194 stakeholders in one network lead to the formation of a tie in another. Third parties are crucial in the
195 food supply chain, because practices of food waste reduction are activated only when *‘all parts of*
196 *the food supply chain cooperate in mutual agreement’* (Priefer et al., 2016: 159). The above
197 rationale leads us to propose the following hypotheses:

198 H2a) Considering triads in food waste management networks, the exchange of information
199 between two stakeholders is observed in combination with resource sharing with third
200 parties;

201 H2b) Considering triads in food waste management networks, the exchange of information
202 between two stakeholders is observed in combination with projects-related links with third
203 parties;

204 H2c) Considering triads in food waste management networks, the sharing of resources
205 between two stakeholders is observed in combination with projects-related links with third
206 parties.

207 In addition to the configuration of dyadic and triadic structures, organizational attributes also
208 influence networking (Scott and Carrington, 2011). In particular, developing bridging network ties
209 likely confer to the stakeholders in the food chain the benefits of open network structures (Blay-
210 Palmer et al., 2016). Lavie (2006) has demonstrated that, from a Resource-Based View perspective,
211 internal resources of the organization can be seen as generators of rents and quasi-rents. Yet, they
212 can be drivers of inter-organizational alliances (Lomi and Pattison, 2006), as partners could search
213 for interactions with different organizational structures in order to obtain inter-disciplinary skills

214 and trans-organizational competencies (Boström et al., 2015; Thyberg and Tonjes, 2015). On the
215 other hand, organizations recognize the benefits of endorsing relationships with partners possessing
216 similar levels of expertise. In network theory, the concept of homophily defines a situation where
217 two actors have a relation because of their similar characteristics, i.e. similar actors with respect to
218 organizational attributes are more likely to establish relations with each other (Lazega et al., 2012).
219 In the governance of a novel food waste management system, having similar levels of expertise
220 facilitates interactions based on trust: because of the specificity of the topic, and the technical
221 expertise that is required to manage such a sensitive issue, stakeholders prefer to rely on those who
222 already show a deep knowledge of the food waste-related problems (Risvik and Finne, 2018).
223 Hence, multiple relationships can more easily be developed on the basis of expertise similarities
224 between stakeholders. Taking the above rationale into account, we propose the following
225 hypothesis:

226 H3a) Considering food waste management networks, homophily between dyads (in terms of
227 organization similarity) is negatively associated with the presence of multiplex ties across
228 organizations;

229 H3b) Considering food waste management networks, homophily between dyads (in terms of
230 expertise on food waste management) is positively associated with the presence of multiplex
231 ties across organizations.

232 **4. Data and methods**

233 **4.1. Empirical context: The City of Ferrara (Italy)**

234 New strategies have been implemented in recent years in Europe (Vaqué, 2015), resulting in the
235 development of multiple initiatives that have strengthened the cooperation between stakeholders at
236 national, regional, and local level (Priefer et al., 2016). In Italy, the National Law n. 166/2016 led
237 local and national stakeholders to develop new initiatives aimed to reduce food waste. Compared to

238 other EU countries, Italy's food waste production per capita (179 Kg) is aligned with the EU
239 average (173 Kg) (European Parliament, 2017). However, some Italian regions present high levels
240 of food waste production (Piras et al., 2018); in particular, the Emilia-Romagna region shows one of
241 the highest levels of household food waste, while this region has been a pioneer in food waste
242 reduction initiatives by promoting, in 2015, a regional law for supporting circular economy and
243 food waste reduction (Regione Emilia-Romagna, 2015). Therefore, this region provides a relevant
244 and interesting case to investigate. Notably, we focus on the City of Ferrara, one of the nine main
245 cities in Emilia-Romagna. Ferrara could be considered a representative mid-size European city
246 (approximately 130,000 inhabitants in 2018), which has implemented a number of circular
247 economy-related practices and initiatives during the past years (Bonato and Orsini, 2018;
248 Municipality of Ferrara, 2014). Moreover, it has been among the first Italian cities to support the
249 creation of a multi-stakeholder network aimed to promote circular economy and food waste
250 reduction in the community (Municipality of Ferrara, 2014).

251 Primary data for this paper were collected using a questionnaire applied to the stakeholders mapped
252 for the EU Interreg Project 'ECOWASTE4FOOD' (2017-2020), dedicated to the improvement of
253 policy tools for promoting circular economy and food waste reduction. In collaboration with the
254 Centre for Sustainability Education (CEAS) of the City of Ferrara, we created an initial list of key
255 local stakeholders (organizations) that were involved in circular economy or food waste reduction
256 initiatives, or whose mission presented a connection with these topics. Afterwards, a Snowball
257 Sampling Approach (Scott and Carrington, 2011) was used to identify other stakeholders,
258 considering the importance of organizational characteristics and local representativeness of the
259 different groups (Friedman and Miles, 2006). In total, 42 local stakeholders were mapped out:
260 farmers, retailers, public authorities, research centres, consumer associations, and NGOs. During
261 the first phase of this project, the representatives of these stakeholders were invited to participate in
262 four round tables and one international workshop between November 2017 and April 2018, for

discussing about strengths and weaknesses of the food chain, since public participation is considered a key element in food waste management (Refsgaard and Magnussen, 2009; Priefer et al., 2016). Those representatives, which were in charge of providing information about their organizations, were mainly managers, project coordinators, high-level researchers and professors, and presidents of the organizations; thus, individuals with relevant expertise and awareness of the activities and the strategies of their organizations. We submitted the questionnaire during these events; we also created an online version for those who were not available during the round tables but still interested in completing the survey. The final version of the questionnaire is presented in Appendix 1: since the original version is in Italian, the text has been translated into English. Network data were collected using a roster recall method (Scott and Carrington, 2011): a complete list (roster) of all the 42 stakeholders has been included in the questionnaire, including the possibility to indicate a maximum of five additional stakeholders not listed in the roster, and respondents could specify the existence of a given type of relationship their organization activated in the last five years. With regard to the stakeholder attributes, we asked for general information on the organization (e.g., type of organization) and the level of expertise (of the organization, not the individual respondent) in food waste management activities, using a five-point Likert scale ranging from 'Not at all' to 'Excellent'.

4.2. Method: bivariate Exponential Random Graph Models (ERGMs)

Since we aim to detect drivers of inter-organizational networking, we adopt a quantitative method approach based on Social Network Analysis (SNA). SNA is used to visualize and analyse network data: the relational structures are depicted through graphs, where actors (individuals, organizations, or other entities) are represented as nodes and relations as lines (Scott and Carrington, 2011). The actors operating in a specific network can be characterized by a variety of relationships, and their behaviour can be driven by endogenous network forces and actor-level attributes. In this study, we

use bivariate Exponential Random Graph Models (ERGMs) for investigating network structures, which are probability models for complete networks that allow to estimate the effect of network structures (dyads and triads) and actors' attributes on network formation, when two networks are observed simultaneously (Snijders et al., 2006; Robins et al., 2007; Simpson, 2015). These models make it possible to consider the interdependence of multiplex network structures made by two networks when making inference on how relationships are created.

Univariate ERGMs, i.e. models that consider one network at a time, take the following form (Robins et al. 2007):

$$Pr(Y = y) = \left(\frac{1}{k}\right) \exp\{\sum_A \eta_A Z_A(y)\} \quad (1)$$

The probability that the observed network y is identical to the randomly generated network Y is given by an exponential model, where η_A is the parameter corresponding to network configuration A and $Z_A(y)$ is the network statistic corresponding to configuration A . Assuming that all counted network formation instances are equiprobable, Markov dependence allows to identify the associated parameters for each configuration. For the bivariate ERGMs, $Z_A(y)$ is a bi-graph defined by the relationships across the two networks under examination².

In this study, three different bivariate ERGMS are estimated: information exchange and resource sharing; information exchange and cooperative projects; resource sharing and cooperative projects. Since the relationships in these networks are undirected, only specific parameters for undirected networks have been included in the models (Table 1). We named the information exchange network as network A, the resource sharing network as network B, and the cooperative projects network as network C. *Edge* parameters (*EdgeA*, *EdgeB*, and *EdgeC*) control for the number of edges in the network. *EdgeAB*, *EdgeAC*, and *EdgeBC* are used to test for the co-occurrence, at dyadic level, of

² For a detailed description of univariate and bivariate ERGMs estimation and simulation, see Koskinen and Snijders (2013) and Wang (2013).

two types of relationships in bivariate networks, i.e. testing hypotheses 1a-1c. Triadic configurations *TriangleAAB*, *TriangleAAC*, *TriangleBBC*, *TriangleABB*, *TriangleACC*, *TriangleBCC*, *AT-ABA*, *AT-ACA*, *AT-BCB*, *AT-CAC*, *AT-CBC*, and *AT-BAB* are used to test hypotheses 2a-2c. The *Triangle* configurations represent collaborations between pairs of organizations having a common contact with whom they have established another type of relation; the alternating triangles (*AT*) configurations control for the ‘social circuit effect’ (Lusher et al., 2013), i.e. the presence of cohesive subsets of triangles in denser parts of the network, where edges combine different forms of collaborations. Hypothesis 3a is tested using *MatchAB_cat*, *MatchAC_cat*, and *MatchBC_cat*, while *MatchAB_exp*, *MatchAC_exp*, and *MatchBC_exp* test for the presence of homophily, in terms of expertise level, as a driver of networking between stakeholders (hypothesis 3b). Stakeholders’ expertise has been coded as a dummy equal to one when respondents identify their organization having ‘good’ or ‘excellent’ competences (points four and five of the Likert scale, respectively) on food waste management, zero otherwise. Organization similarity is detected when two organizations belong to the same stakeholder category (consumer association, NGO, private enterprise, public authority, research centre).

In the estimation process, the convergence t-ratio (estimate divided by standard error) for each parameter should be less than or close to 0.1 in absolute value. Estimates that are more than twice their standard errors are considered statistically significant (Robins et al., 2007), and a positive and significant estimate indicates that there is a structural effect which can not be explained by a random set of ties in the network.

[Table 1]

Once the estimates are obtained, goodness-of-fit (GOF) tests are conducted following the procedures suggested by Hunter et al. (2008). A sample of 1,000 simulated networks is compared with the observed network, with respect to the differences between their characteristics. As well as

for the estimation process, in GOF tests the t-ratio for each network statistic must be less than 0.1 in absolute value. XPnet software (Wang et al., 2009) is used for the analysis. Results of the GOF are illustrated in Appendix 2.

5. Results

We received 22 questionnaires out of 42 sent, obtaining a 51% response rate: ten public authorities (of which one research centre), seven NGOs, and five private enterprises (of which two of the major regional retailers and one of the main Italian food producers). The 22 stakeholders show 58 dyadic relations with respect to the exchange of information, 39 dyadic relations based on the sharing of resources, and 62 dyadic relations illustrative of cooperative projects (Figures 2-4; square nodes are public authorities, circle nodes are NGOs, and triangle nodes are private enterprises).

[Figure 2]

[Figure 3]

[Figure 4]

Table 2 reports the results for the three bivariate ERGMs. The *EdgeAB*, *EdgeAC*, and *EdgeBC* parameters are positive and significant in all three networks, i.e. the co-occurrence of multiple collaborations between pairs of stakeholders is consistent with hypotheses H1a-H1c. As a matter of fact, the establishment of a type of collaboration between two stakeholders increases the probability that the same actors establish another type of collaboration. This result suggests that attitudes of two stakeholders, who are both involved in the food waste management system, are such that they prefer to develop relationships of different kinds, while strengthening their mutual reliance. On the other hand, triadic multiplex configurations are almost never statistically significant. In particular, for the first ('Information exchange (A) & Resource sharing (B)') and the third ('Resource sharing (B) & Cooperative projects (C)') bivariate networks, none of the triadic configurations is statistically

significant. This indicates that sharing resources between stakeholders does not favour the formation of triadic relationships supporting other types of collaboration; the assumption that sharing a food waste related network relationship with the same third party (for instance, stakeholders i and j exchanging information with the same stakeholder z) would encourage the creation of a new relationship in another network (e.g. a cooperative project) is not confirmed. We also observe that having a connection with the same stakeholder in a network is not considered enough by network members to engage in a new food waste management-oriented relationship; in this sense, it seems that trust and confidence are not transitive toward new relationships. Only for the second bivariate network ('Information exchange (A) & Cooperative projects (C)') the *AT-ACA* configuration is positive and statistically significant. This suggests that stakeholders who have a dense exchange of information with the same third parties have a high propensity to interact with their partner for developing formal collaborations, providing limited support for the presence of bridging social capital (Putnam, 2000). Given this mixed evidence, we reject Hypotheses 2a-2c.

[Table 2]

Hypotheses 3a-3b, which examine homophily in multiplex relations with respect to stakeholders' organizational structure and expertise in food waste management, cannot be supported by the bivariate ERGMs results. On one hand, belonging to the same organizational category (*MatchAB_cat*, *MatchAC_cat*, and *MatchBC_cat*) decreases the probability to establish multiple networks: the parameter coefficients are all negative, and in one case (*MatchAB_cat*, for the multiplex network 'Information exchange (A) & Resource sharing (B)') we observe a statistically significant result. However, this is not sufficient to confirm hypothesis 3a. On the other hand, *MatchAB_exp*, *MatchAC_exp*, and *MatchBC_exp* present a positive sign, suggesting that stakeholders with a similar level of expertise are likely to establish multiple relationships, mostly to

379 support information exchange and collaborative projects; however, none of the above parameters is
380 statistically significant, and hence we cannot confirm hypothesis 3b.

381 **6. Discussion**

382 One way to address food waste reduction is through effective waste management strategies. In the
383 context of food waste management systems that connect relevant stakeholders, the relational drivers
384 influencing stakeholders' networking are the basis for understanding stakeholders' behaviour
385 toward the implementation of novel systems for waste reduction. Ferrara is characterized by the
386 presence of informal (information exchange) and formal (resource sharing and cooperative projects)
387 relationships between a set of actors with different organizational forms and expertise. The results
388 of our study suggest that there is a positive chance for two organizations (dyadic level) to establish
389 multiple relationships aimed to develop a new food waste management system. According to the
390 social embeddedness perspective (Shipilov and Li, 2012), those actors who have already established
391 relationships in specific contexts are more likely to trust in their partners and develop multiple
392 relationships among each other. However, multiplexity is not detected in triadic structures: relying
393 on 'third parties' to expand the network of multiplex relationships does not play a role in supporting
394 the networking process between stakeholders acting in the food waste management system under
395 investigation. This result indicates that stakeholders who are looking at new networking
396 opportunities are less likely to trust in actors other than their current partners. They seem to
397 perceive that the benefits in terms of multiple sources of information or resources obtained by
398 relating to more than a single partner do not outweigh the costs in terms of the dark side of trust due
399 to over-embeddedness in existing relationships (Uzzi, 1997; Hagedoorn and Frankort, 2008). In this
400 sense, our results suggest that social embeddedness could also lead to lock-in problems (Dosi and
401 Malerba, 1996). In other words, the innovative process of creating a novel food waste management
402 system seems to be grounded on basic (dyadic) networking relationships, where the lack of shared

trust, which prevents stakeholders from the development of triadic network structures, is not compensated by perceived benefits of one-to-one agreements based on information exchange, resource sharing, and the creation of formal projects. A positive, but not statistically significant, effect on the establishment of multiple collaborations between stakeholders is produced by the presence of homophily in terms of similar levels of expertise on food waste management. Hence, the level of expertise does not seem to be a strong driver of multiplex networking. This result could be due to the dimension of the system under investigation: local stakeholders know their strengths and weaknesses, and relying exclusively on the level of expertise to establish a relation is sometimes detrimental for trust between actors (Newman and Dale, 2007). On the other hand, belonging to the same organizational category is negatively associated with the presence of multiplexity when considering the ‘Information exchange’ and the ‘Resources sharing’ networks, advocating that local stakeholders in Ferrara do not have a strong interest in multiple collaborations with stakeholder organizations of a similar nature, at least for the above types of relationships. This result suggests that existing relationships have already achieved the level of partnership-internal resource requirements (Harrison et al., 2001; Lin et al., 2009) that motivated the establishment of the partnership in the first place and that the imperfect tradability of resources that motivates the formation of alliances and collaborations (Das and Teng, 2000; Steiner et al., 2017), as put forward by the Resource-Based View (Barney, 2001; Lavie, 2006), is not motivating stakeholders to go beyond their existing relationships. The perceived low costs of over-embeddedness (Hagedoorn and Frankort, 2008) associated with existing relationships and the potentially high transaction costs of establishing further relationships (Williamson 1993) seem to outweigh the perceived benefits from establishing novel relationships, and it is perhaps due to this combination of factors that there is no interest for establishing other types of relationships with similar stakeholders.

7. Conclusions

427 Food waste is a global issue that could be tackled through co-operative efforts amongst food chain
428 stakeholders. Since European countries are among the most significant contributors in terms of per
429 capita food waste in the world (FAO, 2019), different mixed top-down/bottom up approaches are
430 being adopted in these countries to address this problem. In order to be effective, previous evidence
431 suggests that food waste policies should be developed according to evidence-based data (Grainger
432 et al., 2018b). Our paper employs evidence from an archetypal Italian and thus European
433 municipality, investigating the relative effectiveness of drivers of network formation through the
434 analysis of organizational attributes of its food waste management system. Our results suggest that a
435 more integrated network of multiplex relationships between stakeholders involved in food waste
436 management strategies is needed for establishing an effective stakeholder network tasked with
437 reducing food waste. Our analysis explores three sets of hypotheses involving, on one hand, the
438 dyadic and the triadic relationships among stakeholders, and on the other hand, the degree of
439 homophily that is identified as desirable and effective by the stakeholders when putting into practice
440 food waste management stakeholder networks.

441 To the best of our knowledge, this paper is the first attempt investigating the multiplex networks
442 intervening in the implementation of a novel food waste management system. Focusing on the
443 drivers of networking between stakeholders, we find that an existing relationship between two
444 stakeholders is positively and robustly related to the propensity to establish novel relationships of
445 different types. Hence, members of the food waste eco-system in Ferrara are found to be more
446 willing to collaborate with well-known organizations, rather than with novel partners in different
447 networks. However, when considering more complex structures as drivers of networking (i.e. triadic
448 relational structures), there is no evidence of their influence on stakeholders' networking behaviour.
449 Furthermore, the analysis suggests that homophily in food waste stakeholder networks is not a
450 driver of multiplex relations that could support an effective reduction of food waste: stakeholders
451 with a different organizational form than their own tend to avoid multiple relationships with others,

452 while there is not statistical evidence of a more pro-active behaviour by those stakeholders with a
453 similar level of expertise on food waste issues. Our empirical evidence thus contrasts with previous
454 work suggesting that for stakeholder relationships to effectively handle food waste management
455 issues, organizations are required to differ in terms of knowledge gained through access to different
456 stakeholders (with regard to personal history, mission and objectives), thereby benefiting from
457 bridging social capital (Putnam, 2000; Burt, 2005).

458 Therefore, our findings are particularly significant to the extent that they suggest that the food waste
459 networking system under investigation promotes bonding (i.e. the strengthening of relationships
460 between close members), rather than bridging (i.e. the linking of new partners) social capital.
461 Additionally, one could conjecture that the dark side of trust, in terms of costs of over-
462 embeddedness (Hagedoorn and Frankort, 2008) in the network under investigation, is not perceived
463 as sufficiently relevant by the stakeholders in question, to motivate them toward bridging beyond
464 their existing relationship partners.

465 Our results suggest a number of policy implications, which relate to the likelihood of food waste
466 network stakeholders toward strengthening their relationships through the participation in different
467 networks. First, our results corroborate with Niesten et al. (2017), suggesting that more policy
468 (institutional) support is needed for more collaboration of boundary-spanning organizational
469 networks. In particular, local authorities could provide institutional and financial incentives for
470 strengthening knowledge transfer and spurring cooperative projects to more effectively deal with
471 food waste issues. Practical policy tools could also include the encouragement of stakeholder
472 participation in mixed working groups aimed at developing functionally diverse food waste
473 management coalitions for more effective food waste management strategies. At the same time, it is
474 necessary to support these coalitions towards common planning, for example by enabling them to
475 influence the institutional framework for local food waste management, or by supporting them with

476 seed-funding and resources to acquire external funding at national and European level. These
477 resources could thus be used for a more extensive stakeholder-weaving (Vance-Borland and Holley,
478 2011) and the support of further bridging networking activities, for example by targeting central
479 communication stakeholders to identify effective leverage points for more boundary-spanning food
480 waste management efforts.

481 The main limitation of our analysis lies in the cross-sectional nature of our case study. Areas for
482 future research involve a comparison of multiple regions, and the collection of longitudinal network
483 data. This could help to identify the impact of institutional differences on the effectiveness of
484 relational characteristics among stakeholders in dealing with food waste management issues.

485

486 **References**

- 487 Aschemann-Witzel, J., De Hooge, I.E., Rohm, H., Normann, A., Bossle, M.B., Grønhøj, A.,
488 Oostindjer, M., 2017. Key characteristics and success factors of supply chain initiatives tackling
489 consumer-related food waste – A multiple case study. *Journal of Cleaner Production* 155(Part 2),
490 33-45.
- 491 Barney, J.B., 2001. Resource-based theories of competitive advantage: A ten-year retrospective on
492 the resource-based view. *Journal of management* 27(6), 643-650.
- 493 Blas, A., Garrido, A., Willaarts, B., 2018. Food consumption and waste in Spanish households:
494 Water implications within and beyond national borders. *Ecological Indicators* 89, 290-300.
- 495 Blay-Palmer, A., Sonnino, R., Custot, J., 2016. A food politics of the possible? Growing sustainable
496 food systems through networks of knowledge. *Agriculture and Human Values* 33(1), 27-43.
- 497 Bliemel, M.J., McCarthy, I.P., Maine, E.M., 2016. Levels of multiplexity in entrepreneur's
498 networks: implications for dynamism and value creation. *Entrepreneurship Research Journal* 6(3),
499 247-272.
- 500 Bodin, Ö., Prell, C., 2011. *Social Networks and Natural Resource Management: Uncovering the*
501 *Social Fabric of Environmental Governance*. Cambridge: Cambridge University Press.
- 502 Bonato, D., Orsini, R., 2018. Urban Circular Economy: The New Frontier for European Cities'
503 Sustainable Development. In W. W. Clark (Ed.), *Sustainable Cities and Communities Design*
504 *Handbook: Green Engineering, Architecture, and Technology*, 2nd Edition (pp. 235-245). Elsevier,
505 Butterworth-Heinemann.
- 506 Boström, M., Jönsson, A.M., Lockie, S., Mol, A.P.J., Oosterveer, P., 2015. Sustainable and
507 responsible supply chain governance: Challenges and opportunities. *Journal of Cleaner Production*
508 107, 1-7.

509 Burt, R., 2005. Brokerage and Closure: An Introduction to Social Capital. New York: Oxford
 510 University Press.

511 Bustos, C.A., Moors, E.H., 2018. Reducing post-harvest food losses through innovative
 512 collaboration: Insights from the Colombian and Mexican avocado supply chains. *Journal of Cleaner*
 513 *Production* 199, 1020-1034.

514 Buzby, J.C., Hyman, J., 2012. Total and per capita value of food loss in the United States. *Food*
 515 *Policy* 37(5), 561-570.

516 Conrad, Z., Niles, M.T., Neher, D.A., Roy, E.D., Tichenor, N.E., Jahns, L., 2018. Relationship
 517 between food waste, diet quality, and environmental sustainability. *PloS ONE* 13(4), e0195405.

518 Corrado, S., Sala, S., 2018. Food waste accounting along global and European food supply chains:
 519 State of the art and outlook. *Waste Management* 79, 120-131.

520 Das, T., Teng, B., 2000. A resource-based theory of strategic alliances. *Journal of Management*
 521 26(1), 31-61.

522 De Clercq, D., Wen, Z., Gottfried, O., Schmidt, F., Fei, F. (2017). A review of global strategies
 523 promoting the conversion of food waste to bioenergy via anaerobic digestion. *Renewable and*
 524 *Sustainable Energy Reviews* 79, 204-221.

525 De Steur, H., Wesana, J., Dora, M.K., Pearce, D., Gellynck, X., 2016. Applying value stream
 526 mapping to reduce food losses and wastes in supply chains: A systematic review. *Waste*
 527 *Management* 58, 359-368.

528 Dosi G., Malerba F., 1996. Organizational Learning and Institutional Embeddedness. In: G. Dosi, F.
 529 Malerba (Eds.), *Organization and Strategy in the Evolution of the Enterprise*. London: Palgrave
 530 Macmillan.

531 European Commission (2011). Roadmap to a Resource Efficient Europe - COM(2011) 571 Final.
 532 Bruxelles: European Commission.

533 European Commission (2015). Closing the Loop - An EU Action Plan for the Circular Economy -
 534 COM(2015) 614 Final. Bruxelles: European Commission.

535 European Parliament (2017). Food waste: the problem in the EU in numbers [infographic].
 536 Available at: [http://www.europarl.europa.eu/news/en/headlines/society/20170505STO73528/food-](http://www.europarl.europa.eu/news/en/headlines/society/20170505STO73528/food-waste-the-problem-in-the-eu-in-numbers-infographic)
 537 [waste-the-problem-in-the-eu-in-numbers-infographic](http://www.europarl.europa.eu/news/en/headlines/society/20170505STO73528/food-waste-the-problem-in-the-eu-in-numbers-infographic).

538 Food and Agriculture Organization of the United Nations – FAO (2011). Global food losses and
 539 food waste: Extent, causes and prevention. Rome: Food and Agriculture Organisation of the United
 540 Nations.

541 Food and Agriculture Organization of the United Nations - FAO (2014). Definitional framework of
 542 food loss. Global Initiative on Food Loss and Waste Reduction. Rome: FAO Working papers.

543 Food and Agriculture Organization of the United Nations - FAO (2019). SAVE FOOD: Global
 544 Initiative on Food Loss and Waste Reduction. Available at: <http://www.fao.org/save-food/it/>
 545 (accessed February 16, 2019).

546 Fountain, J.E., 1998. Social Capital: Its Relationship to Innovation in Science and Technology.
 547 Science and Public Policy 25(2), 103:115.

548 Friedman, A.L., Miles, S., 2006. Stakeholders: Theory and Practice. Oxford: Oxford University
 549 Press.

550 FUSIONS, 2016. Estimates of European food waste levels. Bruxelles: European Commission.

551 Galanakis, C.M., 2016. Innovation Strategies in the Food Industry. Academic Press.

552 Garcia-Garcia, G., Woolley, E., Rahimifard, S., Colwill, J., White, R., Needham, L., 2017. A
 553 methodology for sustainable management of food waste. Waste and Biomass Valorization 8(6),
 554 2209-2227.

555 Garrone, P., Melacini, M., Perego, A., Sert, S. (2016). Reducing food waste in food manufacturing
556 companies. *Journal of Cleaner Production* 137, 1076-1085.

557 Govindan, K., Seuring, S., Zhu, Q., Azevedo, S.G., 2016. Accelerating the transition towards
558 sustainability dynamics into supply chain relationship management and governance structures.
559 *Journal of Cleaner Production* 112, 1813-1823.

560 Grainger, M.J., Aramyan, L., Logatcheva, K., Piras, S., Righi, S., Setti, M., Vittuari, M., Stewart, G.
561 B., 2018a. The use of systems models to identify food waste drivers. *Global Food Security* 16, 1-8.

562 Grainger, M.J., Aramyan, L., Piras, S., Quested, T.E., Righi, S., Setti, M., Vittuari, M., Stewart,
563 G.B., 2018b. Model selection and averaging in the assessment of the drivers of household food
564 waste to reduce the probability of false positives. *PLoS ONE* 13(2): e0192075.

565 Gulati, R., Gargiulo, M., 1999. Where Do Interorganizational Networks Come From? *American*
566 *Journal of Sociology* 104(5), 1439-1493.

567 Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A., 2011. *Global Food*
568 *Losses and Food Waste: Extent, Causes and Prevention*. Rome: Food and Agriculture Organisation
569 of the United Nations.

570 Hagedoorn, J., Frankort, H.T., 2008. The gloomy side of embeddedness: The effects of
571 overembeddedness on inter-firm partnership formation. *Advances in Strategic Management* 25,
572 503-530.

573 Halloran, A., Clement, J., Kornum, N., Bucatariu, C., Magid, J., 2014. Addressing food waste
574 reduction in Denmark. *Food Policy* 49(P1), 294-301.

575 Harrison, J.S., Hitt, M.A., Hoskisson, R.E., Ireland, R.D., 2001. Resource complementarity in
576 business combinations: Extending the logic to organizational alliances. *Journal of Management*
577 27(6), 679-690.

578 Hermsdorf, D., Rombach, M., Bitsch, V., 2017. Food waste reduction practices in German food
579 retail. *British Food Journal* 119(12), 2532-2546.

580 Hunter, D.R., Goodreau, S.M., Handcock, M.S., 2008. Goodness of Fit of Social Network Models.
581 *Journal of the American Statistical Association* 103(481), 248-258.

582 Kaipia, R., Dukovska-Popovska, I., Loikkanen, L., 2013. Creating sustainable fresh food supply
583 chains through waste reduction. *International Journal of Physical Distribution & Logistics*
584 *Management* 43(3), 262-276.

585 Koskinen, J., Snijders, T., 2013. Simulation, estimation and goodness of fit. In: D. Lusher, J.
586 Koskinen, G.L. Robins (Eds.), *Exponential Random Graph Models for Social Networks: Theory,*
587 *Methods and Applications*, pp. 141-166. Cambridge: Cambridge University Press.

588 Lavie, D., 2006. The competitive advantage of interconnected firms: An extension of the resource-
589 based view. *Academy of Management Review* 31(3), 638-658.

590 Lazega, E., Mounier, L., Snijders, T.A.B., Tubaro, P., 2012. Norms, status and the dynamics of
591 advice networks: A case study. *Social Networks* 34(3), 323-332.

592 Lee, S., Monge, P., 2011. The coevolution of multiplex communication networks in organizational
593 communities. *Journal of Communication* 61(4), 758-779.

594 León-Bravo, V., Caniato, F., Caridi, M., Johnsen, T., 2017. Collaboration for sustainability in the
595 food supply chain: A multi-stage study in Italy. *Sustainability* 9(7), 1253.

596 Lin, Z., Yang, H., Arya, B., 2009. Alliance partners and firm performance: resource
597 complementarity and status association. *Strategic Management Journal* 30(9), 921-940.

598 Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Searchinger, T., 2013. Reducing Food
599 Loss and Waste. World Resources Institute, Washington DC (Working Paper).

600 Lomi, A., Pattison, P., 2006. Manufacturing relations: An empirical study of the organization of
 601 production across multiple networks. *Organization Science* 17(3), 313-332.

602 Lozano, R., 2008. Developing collaborative and sustainable organisations. *Journal of Cleaner*
 603 *Production* 16(4), 499-509.

604 Lusher, D., Koskinen, J., Robins, G., 2013. *Exponential Random Graph Models for Social*
 605 *Networks*. Cambridge: Cambridge University Press.

606 Mena, C., Adenso-Diaz, B., Yurt, O., 2011. The causes of food waste in the supplier–retailer
 607 interface: Evidences from the UK and Spain. *Resources, Conservation and Recycling* 55, 648-658.

608 Mourad, M., 2016. Recycling, recovering and preventing “food waste”: competing solutions for
 609 food systems sustainability in the United States and France. *Journal of Cleaner Production* 126,
 610 461-477.

611 Municipality of Ferrara, 2014. La storia di A21 a Ferrara. Available at:
 612 <http://servizi.comune.fe.it/4136/la-storia-di-a21-a-ferrara>. Accessed 20 January 2018.

613 Newman, L., Dale, A., 2007. Homophily and Agency: Creating Effective Sustainable Development
 614 Networks. *Environment, Development and Sustainability* 9(1), 79-90.

615 Niesten, E., Jolink, A., de Sousa Jabbour, A.B.L., Chappin, M., Lozano, R., 2017. Sustainable
 616 collaboration: The impact of governance and institutions on sustainable performance. *Journal of*
 617 *Cleaner Production* 155, 1-6.

618 Papargyropoulou, E., Lozano, R., Steinberger, J.K., Wright, N., Ujang, Z.B. (2014). The food waste
 619 hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner*
 620 *Production* 76, 106-115.

621 Piras, S., Pancotto, F., Righi, S., Vittuari, M., Setti, M., 2018. Food waste as a (negative) measure
 622 of social capital. A study across Italian Provinces. DEMB Working Paper Series, N. 127.

623 Priefer, C., Jörissen, J., Bräutigam, K.-R., 2016. Food waste prevention in Europe - A cause-driven
624 approach to identify the most relevant leverage points for action. *Resources, Conservation and*
625 *Recycling* 109, 155-165.

626 Putnam, R.D., 2000. *Bowling alone: The collapse and revival of American community*. New York:
627 Simon & Schuster.

628 Rank, O.N., Robins, G.L., Pattison, P.E., 2010. Structural logic of intraorganizational networks.
629 *Organization Science* 21(3), 745-764.

630 Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H.,
631 Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural
632 resource management. *Journal of Environmental Management* 90(5), 1933-1949.

633 Reed, M.S., Stringer, L.C., Fazey, I., Evely, A.C., Kruijsen, J.H.J., 2014. Five principles for the
634 practice of knowledge exchange in environmental management. *Journal of Environmental*
635 *Management* 146, 337-345.

636 Refsgaard, K., Magnussen, K., 2009. Household behaviour and attitudes with respect to recycling
637 food waste e experiences from focus groups. *Journal of Environmental Management* 90(2), 760-
638 771.

639 Regione Emilia-Romagna, 2015. Disposizioni a sostegno dell'economia circolare, della riduzione
640 della produzione di rifiuti urbani, del riuso dei beni a fine vita, della raccolta differenziata e
641 modifiche alla Legge Regionale 19 Agosto 1996 n. 31 (Disciplina del tributo speciale per il
642 deposito in discarica dei rifiuti solidi). Regional Law n. 16/2015.

643 Ribeiro, A.P., Rok, J., Harmsen, R., Carreón, J.R., Worrell, E., 2019. Food waste in an alternative
644 food network – A case-study. *Resources, Conservation and Recycling* 149, 210-219.

645 Risvik, E., Finne, H., 2018. The Role of Change Agents in Public Sector Innovation. Paper
 646 presented at ISPIIM Connects Fukuoka – Building on Innovation Tradition, Fukuoka (Japan), 2-5
 647 December 2018.

648 Robins, G., Snijders, T., Wang, P., Handcock, M., Pattison, P., 2007. Recent developments in
 649 exponential random graph (p^*) models for social networks. *Social Networks* 29(2), 192-215.

650 Saint Ville, A.S., Hickey, G.M., Phillip, L.E., 2017. How do stakeholder interactions influence
 651 national food security policy in the Caribbean? The case of Saint Lucia. *Food Policy* 68, 53-64.

652 Scott, J., Carrington, P.C., 2011. *Handbook of social network analysis*. London: Sage.

653 Shipilov, A.V., Li, S.X., 2012. The missing link: the effect of customers on the formation of
 654 relationships among producers in the multiplex triads. *Organization Science* 23(2), 472-491.

655 Simpson, C.R., 2015. Multiplexity and strategic alliances: The relational embeddedness of
 656 coalitions in social movement organisational fields. *Social Networks* 42, 42-59.

657 Snijders, T.A.B., Pattison, P.E., Robins, G.L., Handcock, M.S., 2006. New Specifications for
 658 Exponential Random Graph Models. *Sociological Methodology* 36(1), 99-153.

659 Spigel, B., 2017. The relational organization of entrepreneurial ecosystems. *Entrepreneurship*
 660 *Theory and Practice* 41(1), 49-72.

661 Steiner, B., Lan, K., Unterschultz, J., Boxall, P., 2017. Applying the resource-based view to alliance
 662 formation in specialized supply chains. *Journal of Strategy and Management* 10(3), 262-292.

663 Thyberg, K.L., Tonjes, D.J., 2015. A Management Framework for Municipal Solid Waste Systems
 664 and Its Application to Food Waste Prevention. *Systems* 3, 133-151.

665 Uzzi, B., 1997. Social structure and competition in interfirm networks: The paradox of
 666 embeddedness. *Administrative Science Quarterly* 42(1), 35-67.

667 Vance-Borland, K., Holley, J., 2011. Conservation stakeholder network mapping, analysis, and
668 weaving. *Conservation Letters* 4(4), 278-288.

669 Vaqué, L.G., 2015. Food Loss and Waste in the European Union: A New Challenge for the Food
670 Law. *European Food and Feed Law Review* 10(1), 20-33.

671 Walia, B., Sanders, S., 2019. Curbing food waste: A review of recent policy and action in the USA.
672 *Renewable Agriculture and Food Systems* 34(2), 169-177.

673 Wang, P., 2013. ERGM extensions: models for multiple networks and bipartite networks. In: D.
674 Lusher, J. Koskinen, G.L. Robins (Eds.), *Exponential Random Graph Models for Social Networks:
675 Theories, Methods and Applications*, pp. 115-129. Cambridge: Cambridge University Press.

676 Wang, P., Robins, G., Pattison, P., 2009. PNet: program for the simulation and estimation of
677 exponential random graph models. Melbourne School of Psychological Sciences, The University of
678 Melbourne.

679 Williamson, O.E., 1993. Calculativeness, trust, and economic organization. *The Journal of Law &
680 Economics* 36(1, Part 2), 453-486.

681 Xu, W., Zhou, C., Cao, A., Luo, M., 2016. Understanding the mechanism of food waste
682 management by using stakeholder analysis and social network model: An industrial ecology
683 perspective. *Ecological Modelling* 337, 63-72.

684

685

693 Figure 3. Resource sharing network.

694

695 Legend: square nodes are public authorities; circle nodes are NGOs; triangle nodes are private enterprises.

696 Figure 4. Cooperative projects network.

697

698 Legend: square nodes are public authorities; circle nodes are NGOs; triangle nodes are private enterprises.

699

700

701 Table 1. Bivariate ERGMs configurations.

Configuration	Hypothesis tested	Visualization
EdgeA
EdgeB
EdgeC
EdgeAB	H1a
EdgeAC	H1b
EdgeBC	H1c
TriangleAAB	H2a
TriangleAAC	H2b
TriangleBBC	H2c
TriangleABB	H2a
TriangleACC	H2b
TriangleBCC	H2c
AT-ABA	H2a
AT-ACA	H2b

AT-BCB

H2c

AT-BAB

H2a

AT-CAC

H2b

AT-CBC

H2c

MatchA_cat

MatchB_cat

MatchC_cat

MatchA_exp

MatchB_exp

MatchC_exp

MatchAB_cat

H3a

MatchAC_cat

H3a

MatchBC_cat

H3a

MatchAB_exp

H3b

MatchAC_exp

H3b

MatchBC_exp

H3b

702 Legend: Information exchange relationship = solid line; resource sharing relationship = dash line; cooperative
703 projects relationship = square dot line.

704

705 Table 2. Bivariate ERGMs estimates.

	Information exchange (A) & Resource sharing (B)		Information exchange (A) & Cooperative projects (C)		Resource sharing (B) & Cooperative projects (C)	
	Estimate (SE)	t-ratio	Estimate (SE)	t-ratio	Estimate (SE)	t-ratio
EdgeA	-2.956 (0.388)*	0.012	-3.732 (0.515)*	-0.017		
EdgeB	-4.904 (0.789)*	0.066			-4.706 (0.753)*	0.076
EdgeC			-3.648 (0.491)*	-0.016	-2.896 (0.381)*	0.074
EdgeAB	3.995 (0.835)*	0.048				
EdgeAC			2.391 (0.539)*	-0.015		
EdgeBC					3.223 (0.694)*	0.077
TriangleAAB	0.160 (0.120)	-0.005				
TriangleAAC			0.008 (0.125)	-0.050		
TriangleBBC					-0.205 (0.206)	0.060
TriangleABB	-0.270 (0.239)	0.011				
TriangleACC			0.017 (0.113)	-0.048		
TriangleBCC					0.176 (0.126)	0.062
AT-ABA	0.175 (0.435)	0.036				
AT-ACA			0.935 (0.456)*	-0.032		
AT-BCB					0.457 (0.472)	0.069
AT-BAB	0.860 (0.494)	0.020				
AT-CAC			0.487 (0.463)	-0.029		
AT-CBC					0.681 (0.541)	0.067
MatchA_cat	0.559 (0.475)	-0.002	0.677 (0.576)	-0.028		
MatchB_cat	2.280 (0.878)*	0.086			1.416 (0.846)	0.075
MatchC_cat			0.816 (0.516)	-0.037	0.383 (0.440)	0.085
MatchA_exp	0.503	0.014	-0.624	0.019		

	(0.466)		(0.704)		
MatchB_exp	-0.408 (0.887)	0.041		-1.038 (1.171)	0.091
MatchC_exp			-0.310 (0.595)	0.025	0.535 (0.414)
MatchAB_cat	-2.461 (1.033)*	0.044			
MatchAC_cat			-1.097 (0.834)	-0.019	
MatchBC_cat					-1.198 (1.017)
MatchAB_exp	0.367 (1.000)	0.026			
MatchAC_exp			1.569 (0.922)	0.027	
MatchBC_exp					0.961 (1.274)

* = Significant parameter, in bold.

711 **Appendix 1: Questionnaire**

712 This Appendix illustrates the structure of the questionnaire that has been used for the data collection
713 in the City of Ferrara as part of the EU Interreg Project 'ECOWASTE4FOOD'. Section 3
714 (COLLABORATIONS) present a different version of the roster which has been used to collect
715 network data: because of privacy constraints, it is not possible to show the full name list of
716 stakeholders that have been identified in the research. Therefore, we have anonymized the roster,
717 using ID numbers instead of real names of the organizations.

718

719 1) GENERAL INFORMATION

720 a) Organization: _____

721 b) Categoria di appartenenza:

722 ☐ Non profit organization

723 ☐ Foundation

724 ☐ Public authority

725 ☐ Private enterprise

726 ☐ School

727 Others _____

728 c) Number of employees _____

729 d) First and family name of the respondent:

730 _____

731 e) Role in the organization: _____

732

733 2) ACTIVITIES

734 In the following table, please indicate the level of commitment of your organization in the
735 development of the following activities related to the Circular Economy:

	No commitment	Low	Medium	High
Management ecosystem services	☐	☐	☐	☐
Challenge food waste	☐	☐	☐	☐
Short supply chain experiences	☐	☐	☐	☐
Water and energy saving initiatives	☐	☐	☐	☐
Waste management initiatives	☐	☐	☐	☐

736 How do you judge the performance of your organization in the development of the following
737 activities related to the Circular Economy?

	Not at all	Poor	Sufficient	Good	Excellent
Management ecosystem services	☐	☐	☐	☐	☐
Challenge food waste	☐	☐	☐	☐	☐
Short supply chain experiences	☐	☐	☐	☐	☐
Water and energy saving initiatives	☐	☐	☐	☐	☐
Waste management initiatives	☐	☐	☐	☐	☐

738

739 3) COLLABORATIONS

740 In the following table are listed the local organizations operating in activities aimed to reduce food
741 waste. Please indicate with which organizations your organization has established relationships in
742 the last five years, specifying the type of relationship (Information exchange; Resource sharing;
743 Creation of cooperative projects). It is possible to indicate multiple relationships with the same
744 organization. The three types of relationships are defined as:

- 745 - Information exchange: information regarding events, fairs, new technologies or innovation
746 related to food waste reduction;
- 747 - Resource sharing: sharing of spaces or human resources.

748 - Creation of cooperative projects: formal agreements (contractualized) aimed to the
749 development of specific projects.

750 You can add other organizations, not presented in the list, with which your organization had one
751 or more relationships in the last five years by filling the last rows of the matrix. You can add a
752 maximum of five additional organizations.

CONFIDENTIAL

Organization	Specify organization (for “Other” answers)	Type of relationship established in the last 5 years. It is possible to indicate multiple relationships with the same organization.		
		Information exchange	Resource sharing	Creation of cooperative projects
ID1		☐	☐	☐
ID2		☐	☐	☐
ID3		☐	☐	☐
ID4		☐	☐	☐
ID5		☐	☐	☐
ID6		☐	☐	☐
ID7		☐	☐	☐
ID8		☐	☐	☐
ID9		☐	☐	☐
ID10		☐	☐	☐
ID11		☐	☐	☐
ID12		☐	☐	☐
ID13		☐	☐	☐
ID14		☐	☐	☐
ID15		☐	☐	☐
ID16		☐	☐	☐
ID17		☐	☐	☐

ID18		☐	☐	☐
ID19		☐	☐	☐
ID20		☐	☐	☐
ID21		☐	☐	☐
ID22		☐	☐	☐
ID23		☐	☐	☐
ID24		☐	☐	☐
ID25		☐	☐	☐
ID26		☐	☐	☐
ID27		☐	☐	☐
ID28		☐	☐	☐
ID29		☐	☐	☐
ID30		☐	☐	☐
ID31		☐	☐	☐
ID32		☐	☐	☐
ID33		☐	☐	☐
ID34		☐	☐	☐
ID35		☐	☐	☐
ID36		☐	☐	☐

ID37		☐	☐	☐
ID38		☐	☐	☐
ID39		☐	☐	☐
ID40		☐	☐	☐
ID41		☐	☐	☐
ID42		☐	☐	☐
Other (specify):	_____	☐	☐	☐
Other (specify):	_____	☐	☐	☐
Other (specify):	_____	☐	☐	☐
Other (specify):	_____	☐	☐	☐
Other (specify):	_____	☐	☐	☐

753 **Appendix 2: Goodness-of-fit results**

754 Goodness-of-fit results for the bivariate network ‘Information exchange (A) & Resource sharing
755 (B)’.

Statistic	Observed	Mean	Std. Dev.	t-ratio
EdgeA	58	60.412	18.808	-0.128
2-StarA	395	397.44	219.326	-0.011
3-StarA	1037	946.318	719.237	0.126
TriangleA	56	58.135	40.338	-0.053
AAS-A(2.00)	158.481	165.28	68.52	-0.099
AKTA(2.00)	85.854	86.342	43.952	-0.011
A2PA(2.00)	236.197	228.734	87.33	0.085
T3uAA-expertise	21	22.296	16.283	-0.08
T2uA-expertise	93	90.872	62.916	0.034
T1uA-expertise	128	125.077	85.358	0.034
O3uA-expertise	121	122.794	68.41	-0.026
O2auA-expertise	388	378.863	204.003	0.045
O2buA-expertise	178	164.275	88.089	0.156
O1auA-expertise	307	287.075	155.181	0.128
O1buA-expertise	532	515.976	276.878	0.058
RbA-expertise	26	26.473	8.33	-0.057
RA-expertise	80	78.885	23.958	0.047
Matching A-cat	19	19.682	6.016	-0.113
Mismatching A-cat	39	40.73	14.031	-0.123
EdgeB	39	40.464	13.239	-0.111
2-StarB	182	183.48	98.902	-0.015
3-StarB	353	302.328	216.935	0.234
TriangleB	18	19.462	11.91	-0.123
AAS-B(2.00)	89.501	94.713	42.403	-0.123
AKTB(2.00)	39.375	42.467	22.702	-0.136
A2PB(2.00)	142.156	141.403	66.109	0.011
T3uAB-expertise	6	6.945	5.052	-0.187
T2uB-expertise	26	28.664	18.384	-0.145
T1uB-expertise	38	40.474	24.566	-0.101
O3uB-expertise	53	54.168	31.795	-0.037
O2auB-expertise	166	167.761	92.175	-0.019
O2buB-expertise	74	73.852	38.896	0.004
O1auB-expertise	136	128.334	69.565	0.11
O1buB-expertise	229	234.578	122.761	-0.045
RbB-expertise	17	17.274	6.114	-0.045
RB-expertise	52	51.943	16.944	0.003
Matching B-cat	15	15.568	4.812	-0.118
Mismatching B-cat	24	24.896	9.718	-0.092
EdgeAB	32	33.436	12.666	-0.113
2-Star-AB	530	543.191	293.244	-0.045
3-Star-AAB	2071	1955.285	1433.951	0.081
3-Star-ABB	1424	1335.24	957.223	0.093

Triangle-AAB	114	124.168	80.337	-0.127
Triangle-ABB	80	86.605	53.225	-0.124
Isolate-AB	2	0.663	0.94	1.422
AKTABA(2.00)	57.01	60.723	29.045	-0.128
AKTBAB(2.00)	58.563	62.873	33.781	-0.128
mr-expertise	15	15.312	6.037	-0.052
mb-expertise	46	44.831	16.542	0.071
Matching	10	10.452	4.325	-0.105
EdgeAB-cat				
Mismatching	22	22.984	9.476	-0.104
EdgeAB-cat				
Std Dev degree	3.658	2.862	0.591	1.347
distA				
Skew degree	0.768	0.235	0.404	1.319
distA				
Global	0.425	0.398	0.093	0.292
ClusteringA				
Mean Local	0.468	0.381	0.117	0.743
ClusteringA				
Variance Local	0.083	0.061	0.027	0.809
ClusteringA				
Std Dev degree	2.742	2.274	0.457	1.024
distB				
Skew degree	1.207	0.481	0.465	1.56
distB				
Global	0.297	0.302	0.066	-0.074
ClusteringB				
Mean Local	0.284	0.289	0.099	-0.047
ClusteringB				
Variance Local	0.098	0.077	0.035	0.597
ClusteringB				

756

757

758 Goodness-of-fit results for the bivariate network ‘Information exchange (A) & Cooperative projects
759 (C)’.

Statistic	Observed	Mean	Std. Dev.	t-ratio
EdgeA	58.000	65.101	15.752	-0.451
2-StarA	395.000	451.242	165.012	-0.341
3-StarA	1037.000	1096.530	511.815	-0.116
TriangleA	56.000	65.933	26.122	-0.380
AAS-A(2.00)	158.481	183.659	54.954	-0.458
AKTA(2.00)	85.854	101.261	32.465	-0.475
A2PA(2.00)	236.197	258.324	75.042	-0.295
T3uAA-expertise	21.000	24.763	11.423	-0.329
T2uA-expertise	93.000	101.555	41.305	-0.207
T1uA-expertise	128.000	140.776	54.396	-0.235
O3uA-expertise	121.000	134.620	52.266	-0.261
O2auA-expertise	388.000	422.343	152.104	-0.226
O2buA-expertise	178.000	182.052	63.337	-0.064
O1auA-expertise	307.000	324.964	116.232	-0.155
O1buA-expertise	532.000	579.083	201.068	-0.234
RbA-expertise	26.000	28.025	6.836	-0.296
RA-expertise	80.000	84.608	19.364	-0.238
Matching A-cat	19.000	21.055	5.261	-0.391
Mismatching A-cat	39.000	44.046	12.022	-0.420
EdgeC	62.000	69.589	17.224	-0.441
2-StarC	443.000	513.448	194.561	-0.362
3-StarC	1150.000	1315.252	639.876	-0.258
TriangleC	65.000	79.053	33.249	-0.423
AAS-C(2.00)	174.353	200.800	61.203	-0.432
AKTC(2.00)	92.961	111.642	36.728	-0.509
A2PC(2.00)	249.680	272.421	78.452	-0.290
T3uAC-expertise	20.000	30.252	14.455	-0.709
T2uC-expertise	93.000	123.181	52.930	-0.570
T1uC-expertise	137.000	169.670	69.814	-0.468
O3uC-expertise	127.000	155.512	61.493	-0.464
O2auC-expertise	400.000	484.363	179.904	-0.469
O2buC-expertise	181.000	209.121	75.287	-0.374
O1auC-expertise	307.000	369.701	136.565	-0.459
O1buC-expertise	576.000	662.355	239.161	-0.361
RbC-expertise	28.000	30.216	7.411	-0.299
RC-expertise	83.000	90.643	21.142	-0.362
Matching C-cat	21.000	23.493	5.940	-0.420
Mismatching C-cat	41.000	46.096	12.651	-0.403
EdgeAC	43.000	48.595	13.161	-0.425
2-Star-AC	836.000	969.635	355.111	-0.376
3-Star-AAC	3137.000	3523.811	1629.555	-0.237
3-Star-ACC	3271.000	3745.912	1759.468	-0.270
Triangle-AAC	187.000	215.708	83.763	-0.343
Triangle-ACC	198.000	228.533	90.944	-0.336

Isolate-AC	2.000	0.655	0.985	1.365
AKTACA(2.00)	95.916	110.413	35.000	-0.414
AKTCAC(2.00)	92.680	106.651	33.219	-0.421
mr-expertise	23.000	24.786	6.522	-0.274
mb-expertise	64.000	68.365	17.291	-0.252
Matching				
EdgeAC-cat	14.000	15.708	4.553	-0.375
Mismatching				
EdgeAC-cat	29.000	32.887	10.084	-0.385
Std Dev degree				
distA	3.658	3.117	0.389	1.390
Skew degree				
distA	0.768	0.256	0.440	1.164
Global				
ClusteringA	0.425	0.434	0.043	-0.195
Mean Local				
ClusteringA	0.468	0.436	0.079	0.409
Variance Local				
ClusteringA	0.083	0.062	0.032	0.646
Std Dev degree				
distC	3.760	3.220	0.404	1.338
Skew degree				
distC	0.412	0.133	0.417	0.670
Global				
ClusteringC	0.440	0.453	0.049	-0.271
Mean Local				
ClusteringC	0.424	0.442	0.082	-0.213
Variance Local				
ClusteringC	0.101	0.058	0.031	1.395

760

761

762 Goodness-of-fit results for the bivariate network 'Resource sharing (B) & Cooperative projects
763 (C)'.

Statistic	Observed	Mean	Std. Dev.	t-ratio
EdgeB	39.000	38.550	13.983	0.032
2-StarB	182.000	173.919	98.245	0.082
3-StarB	353.000	282.039	206.876	0.343
TriangleB	18.000	18.427	11.760	-0.036
AAS-B(2.00)	89.501	90.081	43.351	-0.013
AKTB(2.00)	39.375	39.742	22.379	-0.016
A2PB(2.00)	142.156	132.398	66.117	0.148
T3uBB-expertise	6.000	6.972	5.439	-0.179
T2uB-expertise	26.000	28.455	19.785	-0.124
T1uB-expertise	38.000	39.377	25.573	-0.054
O3uB-expertise	53.000	54.043	34.623	-0.030
O2auB-expertise	166.000	165.557	98.960	0.004
O2buB-expertise	74.000	72.848	42.193	0.027
O1auB-expertise	136.000	124.967	72.494	0.152
O1buB-expertise	229.000	226.935	127.574	0.016
RbB-expertise	17.000	16.922	6.994	0.011
RB-expertise	52.000	50.444	18.970	0.082
Matching B-cat	15.000	14.646	5.621	0.063
Mismatching B-cat	24.000	23.904	9.494	0.010
EdgeC	62.000	61.633	18.710	0.020
2-StarC	443.000	416.091	212.758	0.126
3-StarC	1150.000	1009.111	684.262	0.206
TriangleC	65.000	62.849	38.626	0.056
AAS-C(2.00)	174.353	170.253	67.761	0.061
AKTC(2.00)	92.961	91.075	43.030	0.044
A2PC(2.00)	249.680	233.969	87.366	0.180
T3uBC-expertise	20.000	26.005	17.558	-0.342
T2uC-expertise	93.000	103.059	65.526	-0.154
T1uC-expertise	137.000	138.277	85.130	-0.015
O3uC-expertise	127.000	136.697	74.375	-0.130
O2auC-expertise	400.000	413.257	215.065	-0.062
O2buC-expertise	181.000	178.284	92.047	0.030
O1auC-expertise	307.000	306.931	157.644	0.000
O1buC-expertise	576.000	549.605	278.401	0.095
RbC-expertise	28.000	27.857	9.184	0.016
RC-expertise	83.000	81.586	25.295	0.056
Matching C-cat	21.000	20.787	6.594	0.032
Mismatching C-cat	41.000	40.846	13.280	0.012
EdgeBC	33.000	32.601	12.885	0.031
2-Star-BC	560.000	541.734	288.970	0.063
3-Star-BBC	1486.000	1309.170	918.946	0.192
3-Star-BCC	2219.000	2003.278	1371.689	0.157
Triangle-BBC	88.000	85.761	52.481	0.043
Triangle-BCC	132.000	129.222	78.234	0.036

Isolate-BC	2.000	0.719	0.989	1.295
AKTBCB(2.00)	62.531	61.491	33.140	0.031
AKTCBC(2.00)	61.992	61.176	28.984	0.028
mr-expertise	16.000	15.924	6.823	0.011
mb-expertise	47.000	44.928	18.006	0.115
Matching				
EdgeBC-cat	12.000	11.755	5.060	0.048
Mismatching				
EdgeBC-cat	21.000	20.846	8.877	0.017
Std Dev degree				
distB	2.742	2.266	0.535	0.891
Skew degree				
distB	1.207	0.438	0.453	1.698
Global				
ClusteringB	0.297	0.293	0.089	0.042
Mean Local				
ClusteringB	0.284	0.262	0.105	0.213
Variance Local				
ClusteringB	0.098	0.072	0.035	0.751
Std Dev degree				
distC	3.760	2.955	0.643	1.252
Skew degree				
distC	0.412	0.206	0.404	0.511
Global				
ClusteringC	0.440	0.414	0.099	0.267
Mean Local				
ClusteringC	0.424	0.397	0.121	0.228
Variance Local				
ClusteringC	0.101	0.063	0.029	1.319

764

765

766

767

768

769

770

771

772