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Development of a digital Net-Map tool to analyse multi-stakeholder networks in risk analysis of emerging food safety issues

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ABSTRACT

The circular economy brings sustainability benefits but also causes potential food safety issues as recycling can introduce new contaminants to food contact materials. These circular food safety issues cause changes in the risk analysis network. So far, social network analysis studies relevant to food safety investigated specific parts of the risk analysis network (such as risk assessment) and its formal stakeholders such as Food Safety Authorities. However, the risk analysis network also consists informal stakeholders, each with their own knowledge and views. A comprehensive analysis of risk analysis networks addressing circularity-related food safety issues from a multi-stakeholder perspective is yet lacking. This study aimed to explore the complex risk analysis network for paper recycling in Belgium. An adjusted and digitalised network mapping methodology, Net-Mapping, was developed to identify the stakeholders, to assess their goals and influence, to determine the different linkages types between them, and to elicit constraints. Forty-one identified stakeholders from science, policy, and society were interconnected through four linkage types ('legally required information sharing', 'voluntary information sharing', 'data generation request', and 'public communication'). Results show federal policy stakeholders are central in all networks, whereas science and society stakeholders gain influence in the informal networks. Barriers hindering collaboration in the networks are a lack of data and challenges in information exchange. The Net-Mapping insights can assist scientists in gathering risk assessment data, guide policymakers in targeting interventions, and raise stakeholder awareness of collaborations. Future research could compare risk analysis networks across countries for the same food safety issue, or examine the risk analysis networks for different food safety issues in the same country.

1. Introduction

The circular economy is a double-edged sword as despite its potential environmental benefits, it also introduces potential food risks. Worldwide, more than 12000 chemicals are used in food contact materials (FCM), with approximately 2000 potentially having safety concerns (Groh et al., 2021). Re-use and recycling potentially increase this number further (Bignardi et al., 2017; Bradley & Coulier, 2007). However, circularity is seen as a fundamental aspect of the European Green Deal, therefore there is an increased need for risk analysis to identify and limit the risks from both FCM made from recycled materials, as well as re-used and recycled FCM. For this study, we will collectively refer to these as rFCM.

The risk analysis encompasses risk assessment, management and communication (Regulation, 2002), and the risk analysis network consists of stakeholders who perform different activities within this process. Science stakeholders perform risk assessments by identifying hazards and conducting exposure assessments, while governmental bodies set policy and control options for risk management. Risk communication is the interactive exchange of this information among academia, industry, consumers, and policy stakeholders (Regulation, 2002). The cooperation and information exchange of these stakeholders within risk analysis shape the risk analysis networks. On the national level, risk analysis networks comprise ministries, food safety authorities, research institutes, and societal stakeholders working together, but such networks also exist on an international level e.g. through the focal point network of the European Food Safety Authority (EFSA) (Donohoe et al., 2018). The exact structure of the risk analysis networks varies between

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countries (Alesina et al., 2013). Risk analysis networks for specific countries are described on an administrative level. The German Risk Assessment Bureau (Bundesinstitut fur Risikobewertung (BfR)) analysed the organisational structure of the administrative framework for various EU-countries.[1] This administrative framework includes legally mandated stakeholders, such as scientific bodies for risk assessment, and governmental organisations such as food safety authorities and ministries tasked with risk management. However, the formal risk analysis network may overlook other stakeholders and how they are connected, whereas each stakeholder has its own knowledge and view on how to solve issues. While including informal stakeholders increases complexity, research (e.g. Clarke & MacDonald, 2019) shows that a multi-stakeholder approach can be beneficial offering, for example, greater access to knowledge and influence in the network. A comprehensive understanding of the entire risk analysis network as a complex system is still lacking.

The risk analysis network is not only complex but also dynamic as it is affected by events. For example, the dioxin crisis in Belgium in 1999 led to the creation of the Federal Agency for the Safety of the Food Chain (Covaci et al., 2008), and combined with other crises in the 1990s such as BSE (Bovine Spongiform Encephalopathy) led to the creation of the European Food Safety Authority (EFSA) on EU-level.[2] The way countries react to crises as they emerge, and consequently, the mandate assigned to each stakeholder to act on the crisis change these risk analysis networks (Boudia & Jas, 2007). To understand how the transition to a circular economy impacts risk analysis networks, it is important to first get insights into the existing structure of the complex risk analysis networks. Recent studies analysed networks related to food safety or risk analysis. Ng et al. (2022) investigated the risk assessment system in Australia, Canada, China, New Zealand and the USA in a comparative study looking at, amongst others, the standards used for risk assessment and the collaboration with other assessment and management stakeholders. This qualitative study aimed to identify potential improvements to the food safety system in China. Nogales et al. (2023) mapped source countries in notifications within the Rapid Alert System for Food and Feed (RASFF). The quantitative study used network analysis to identify countries with effective food policies, potentially providing new policy collaboration between Member States. The studies investigated risk assessment or risk management networks to improve the food safety system but did not investigate the complex risk analysis system as a whole.

To systematically investigate the qualitative and quantitative aspects of complex networks, Schiffer and Hauck (2010) described a tool called Net-Mapping. This tool goes beyond the pure structure-driven analysis of most network analyses, and has proven useful in investigating networks in many different fields and layers such as participatory policy development on a local level (Schröter et al., 2018), implementation of EU directives on a regional level (Musacchio et al., 2020), and identifying key stakeholders in transboundary river management (Urban et al., 2018). For food safety networks, Net-Map analysis has been applied to local networks responsible for street food safety (Pilamala Rosales et al., 2023). However, it has not been applied to investigate the larger and more complex risk analysis networks using a multi-stakeholder perspective.

This study investigated and mapped a complex risk analysis network of a circularity-related food safety issue by adjusting and validating the Net-Mapping methodology. The case of the risk analysis network for paper recycling for rFCM in Belgium was selected because a) scientific literature indicated potential risks of circular paper use, with many studies performed in Belgium (Mertens et al., 2017; Van Bossuyt et al., 2016; Van Hoeck et al., 2017), b) paper and paperboard are not (yet) harmonised on EU-level, c) limited legislation exists in Belgium on paper and paperboard for food contact use which generally follow the requirements of the EU FCM regulation 1935/2004.[3] We propose that Net-Mapping can be a powerful tool to unravel the complexity of the risk analysis network going beyond the administrative framework and elicit constraints that exist within these networks. This will address both gaps discussed: the lack of studies investigating the full risk analysis system rather than focussing on risk assessment or management, and the lack of multi-stakeholder perspectives within a dynamic and complex risk analysis system.

The study is expected to enhance understanding of risk analysis networks that extend beyond the administrative framework, encompassing a wide range of stakeholders involved in the risk analysis process. Highlighting the current structure and constraints can help foster collaboration, increase stakeholder participation, and support using the network for multi-stakeholder participation processes. Leveraging each stakeholder's expertise and insights could serve as a foundation for more effective multi-stakeholder collaboration in implementing circular economy policies and potentially addressing or preventing food safety issues related to paper recycling for rFCM use.

2. Research methodology

This study was performed as part of the FoodSafety4EU-project in which various stakeholders from different parts of society aim to create a 'multi-stakeholder' platform for the future food safety system. Within the context of this study, 'stakeholder' is defined as a natural or legal person or entity acting in the risk analysis network, that contributes to the goal of the food safety system.

2.1. Multi-stakeholder approach

Within the FoodSafety4EU-project, all stakeholders are categorised according to the arena in which they (mainly) operate. Stakeholders are distinguished in performing a science function, a policy function, or a society function. Science refers to those stakeholders who generate the knowledge to address a particular issue, such as universities or research institutes. Policy refers to those stakeholders that manage or direct governmental affairs, such as inspection services or ministries. Finally, society refers to all other stakeholders such as companies and consumer organisations. Combined, these stakeholder categories make up the science-policy-society system, or SPS-system. These categories are not mutually exclusive; for example, commercial research institutes can be classed as both science and society.

2.2. Net-Map methodology

2.2.1. Original methodology

Social Network Analysis as a science has been around since the 1950s to analyse how different groups of stakeholders are connected (Barnes, 1954). In 2007, Eva Schiffer and Jennifer Hauck developed the Net-Mapping methodology involving a participatory interview technique for stakeholder identification and categorisation, investigating the type of links between stakeholders in the networks (e.g. financial support), mapping the stakeholder influence in the network, and assessing stakeholders' goals. Net-Mapping is specifically designed to (1) analyse the interplay of formal and informal networks, (2) expose potential

[1] See for the almanac in multiple languages: https://www.bfr.bund.de/en/publication/almanac-192693.html.

[2] Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority (EFSA) and laying down procedures in matters of food safety.

[3] KB of 11 May 1992 appendix 4 describes a general migration limit of 60mg/6 dm^2, following the general requirement of Regulation (EC) No 1935/2004. Additionally there are several general limitations; for example fillers are limited to SiO2 and other silicates containing Al, Ca, Na, Mg, and K.

points of conflict or cooperation, (3) facilitate knowledge exchange, and (4) develop future scenarios. As such, it should prove a suitable tool to investigate a risk analysis system within the Circular Economy setting. A pre-analysis is performed to define the terminology and the different linkage types that exist, either based on previous knowledge or by clearly defining the area of analysis and research question (Schiffer & Hauck, 2010).

2.2.2. Adjusted Net-Map methodology

Several adjustments were made to the original methodology to make Net-Mapping suitable to analyse risk analysis networks. Instead of performing one-on-one interviews, all information for the Net-Maps was gathered from a single multi-stakeholder workshop. This allowed for an immediate multi-stakeholder debate on any results. Secondly, the workshop was digitalised to enable high-level experts from different regions to provide input without having to travel to a central location. Thirdly, the order of the steps was changed so that first all stakeholders and their goals were identified, before linking them on a network level, creating a flow from the stakeholder level to nearby stakeholders, to the network level. This was done because during the pilot there was some confusion on why first stakeholders themselves were named, then zooming out to network level to connect stakeholders, then zooming back in on stakeholder goals. Finally, a step of identifying constraints within the network was added, so that the identified and characterised network can be used to provide direct input for intervention studies to mitigate these constraints. After describing the constraints for the different linkage types, workshop participants could assign scores with 5 being the most urgent and 1 being the least urgent but still a priority. Each score (1, 2, 3, 4, or 5) could be assigned once, or not at all, allowing for up to 15 points per participant. Scores were summed to indicate high-priority constraints.

2.3. Designing the Net-Map workshop

2.3.1. Pre-analysis

Exploratory interviews with over 30 expert interviews from 17 different countries were performed as part of the FS4EU-project. These revealed that similar organisations sometimes perform very different roles in their respective countries. To identify the possible differences in these roles, pre-identified goals were established following the overall structure in risk analysis: assessing the risk through generating data either due to legal obligations or (voluntary) data generation, sharing this with scientists and policymakers for research and risk management, and communicating these risks to society. The goals were discussed with experts within the FS4EU consortium to come to the following final list.[4] Risk Assessment consists of the activities: risk identification (RA1), data collection (RA2), and performing risk assessment (RA3). Risk Management consists of policy development (RM1), setting/proposing legislation (RM2), and enforcement (RM3). Risk Communication consists of the development of risk communication (RC1), dissemination of risk communication (RC2), and evaluation of the impact/efficiency of risk communication (RC3).

All stakeholders attempt to reach and/or fulfil these goals by working with other stakeholders in the network. From the pre-analysis common reasons that were mentioned to achieve the goals were, for example, inspections carried out due to legal requirements, public communication about food safety, or scientific collaboration. Based on this information, the linkage types 'regulatory responsibility', 'consultation/providing data/information', 'communication to/from society', and 'other' were defined. After piloting the methodology, these linkages types were adjusted to 'legally required information sharing' and 'voluntary information sharing' as not all information sharing was found to be on a mandatory basis, but rather could also be through voluntary cooperation. In this sense, there is a distinction made between the formal network of information streams as prescribed in law, and the informal network that exists next to it based on voluntary information exchange. The other linkages included 'data generation requesting' and 'public communication'. The category 'others' was skipped as the linkage type was not used in the piloting of the methodology for any stakeholder connection.

In the protocol, pre-defined stakeholders were defined to speed up the stakeholder identification step. The following generic pre-defined stakeholders were offered to participants during the workshop. For science: (agricultural) universities, research institutes, reference labs. For policy: food safety authorities, the Ministry of Health (or equivalent), and certification bodies. For society: consumer organisations, (agricultural) cooperatives, and supermarket chains.

2.3.2. Case study selection

Two potential cases were identified based on expert interviews and literature analysis previously conducted within the FS4EU project: 1) increased mycotoxin prevalence as a result of climate change effects, and 2) food safety effects rFCM (results available on the CORDIS portal.[5]). For the Net-Mapping workshop, described in this paper, case study 2 specifically paper recycling in Belgium was selected. Researchers from the University of Ghent hosted the workshop.

2.3.3. Design of the digital environment

MIRO was used to simulate a whiteboard for all participants to work on in a digital workshop (http://www.miro.com/). This whiteboard replaces the interview setting that is used in the original methodology.

The Net-Map protocol supporting the execution of the workshop in the digital environment was tested in a pilot setting with FS4EU consortium partners, consisting of governmental bodies, industry organisations, and consumer organisations to reflect a realistic setting. Based on the feedback from this pilot session the protocol was refined.

2.3.4. Recruitment of high-level experts participants

In collaboration with the host, a list of participant criteria was drafted: participants should be either involved in risk analysis, linked to the relevant organisation, and/or know the specific case study. Further participants were searched by using the networks of the people contacted. Table 1 shows an anonymised list of workshop participants, their role in the risk analysis process, and years of expertise in the field. All participants signed a consent form before participation.

2.3.5. Preparing and conducting the workshop

As the workshop was attended only by participants from Flanders, the Dutch-speaking part of Belgium, the workshop itself was done in Dutch. The hosts were trained in the workshop protocol by the authors. The first author was present during the workshops as a silent observer in case any questions arose. A detailed protocol can be found in the

[4] Starting with the risk analysis steps laid down in Reg. 178/2002 recital 10: risk assessment, risk management, and risk communication. Risk assessment consists of hazard identification, hazard characterisation, exposure assessment and risk characterisation. Risk management consists of weighing policy alternatives, selecting prevent and control options. Risk communication consists of exchange of information from and to all stakeholders involved. These steps were reformulated to become concrete principal steps in the risk analysis process as some (parts) are potentially outsourced. For risk assessment these consist of hazard identification, collecting scientific data to perform a risk assessment, and performing the risk assessment itself. For risk management the distinction is made between policy development, regulatory development, and regulatory implementation and monitoring. For risk communication the distinction is made between the development of risk communication materials, dissemination of the materials, and communication impact assessment.

[5] Full report on the Community Research and Development Information Service: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5ea69774e&appId=PPGMS.

Table 1
Anonymised list of workshop participants.

Area of organisation	Role	Expertise in field
Food Safety Authority	Senior expert in risk assessment	~30 years
Food Safety Authority	Scientific expert	~20 years
Public Health Institute	Scientific expert	~20 years
Public Health Institute	Scientific expert	~15 years
Industry	Food safety trainer	~25 years
Industry	Quality manager	~5 years
Industry	Food policy advisor	~5 years
Industry	Senior advisor	~10 years
Academia	Professor in food safety	~15 years

supplementary materials. The first task was to identify all possible stakeholders that contribute to any of the risk analysis steps by either creating or communicating information related to the risk analysis process, starting with the pre-defined stakeholders expanding the list from there, and categorising them into the science-policy-society framework. These results were discussed in plenary for immediate validation. Secondly, the participants collectively assessed the goals of all stakeholders. In the third step, the participants identified plenary all linkages. Menti was used to assess the influence of the stakeholders individually after all linkages had been established. Finally, participants were asked to individually assign barriers that exist within the network, and assign scores to the barriers. The total workshop duration was approximately 3 h, plus an additional 2 h for validation.

2.4. Data analysis

2.4.1. Transferring MIRO data

After the workshop, the data was manually transferred from MIRO to a spreadsheet file for data processing. Data included the stakeholder's name, SPS-category, risk analysis code, linkages to other stakeholders, stakeholder influence, and constraints.

2.4.2. Data processing

In the original Net-Map methodology, the final Net-Map was constructed by combining all the separate Net-Maps that were produced during the interviews. In our adapted methodology the Net-Maps were generated by processing the data from the different MIRO frames. The hosts transferred all MIRO data to an Excel-based adjacency matrix for each linkage type. This file was sent to the authors by email for further data analysis. Data visualisation and centrality calculations were performed using Gephi version 0.10.1.

2.4.3. Calculations of centrality measures

The different ways stakeholders can influence the network can be expressed in centrality measures as first theoretically described by Friedkin (1991). A basic centrality value is the degree centrality, based on the number of direct links a stakeholder has in the network; either the incoming links from other stakeholders ('in-degree'), the outgoing links to other stakeholders ('out-degree'), or the total links. Often the degree centrality is normalised, meaning the value is given as a fraction of the highest number of connections in the network, giving values between 0 and 1 for easier comparison. For this study, all centrality calculations were normalised.

Eigencentrality indicates how influential stakeholders are. Stakeholders gain influence by either being connected to other influential stakeholders (i.e.: with a high Eigencentrality themselves), or by being connected to many other stakeholders, or both. The calculation is an iterative process as these values depend on the Eigencentrality values of the connected stakeholders, which will change as the calculations are performed. For this research, the number of iterations is set to 100.

The structure of the network can be relatively simple, with a large number of stakeholders being only connected to a coordinating stakeholder, or stakeholders can have a high degree of interconnectivity. One way to express this complexity is by using transitivity. Transitivity calculates the probability that if two nodes are both connected to the same node, what is then the likelihood that the two nodes themselves are also connected.

3. Results & discussion

3.1. Identified stakeholders and goals in the workshop

The first step of the workshop consisted of identifying the different stakeholders, their appropriate SPS-category, and their goals. Table 2 shows the identified stakeholders categorised into science (blue), policy (red), and society (yellow). Mixed colours are used if stakeholders are assigned to more than one SPS-category. Participants identified 43 stakeholders within the risk analysis network for paper recycling in Belgium, and 41 were connected to other stakeholders using any linkage. Of these 41, 15 were classified as science stakeholders; including the 2 science-policy (purple) and 4 science-society (green) stakeholders. Ten policy stakeholders were identified, including the earlier-mentioned science-policy stakeholders. Twenty-two stakeholders were classified as society stakeholders, including the previously mentioned 4 science-society stakeholders. No stakeholders were classified as policy-society.

Table 2 shows that stakeholders classified as science such as EFSA (Sci4) and Universities (Sci9) tend to focus on risk assessment activities (RA1, RA2, and/or RA3), and nearly all science stakeholders have a task in communicating the results (RC2). Most policy stakeholders such as the FAVV (Pol3) and FOD-G (Pol4) focus on risk management tasks (RM1, RM2, and/or RM3). For society stakeholders there is a larger variety in risk analysis goals; some are involved in all risk assessment tasks, such as industry which are required to assess the risks of their intermediates and products (Sci12-Sci15, Soc4, Soc10, Soc11). Others focus on risk management and risk communication tasks such as umbrella organisations FEVIA (Soc7) and inDUfed (Soc8), and a few only deal with risk communication e.g., the (social) media stakeholders Influencers (Soc13), and Media and Press (Soc14). While the 4 science-society stakeholders (Sci12, Sci13, Sci14, and Sci15) are principally identified as societal stakeholders by the participants, they are mainly assigned to risk assessment in their goals, with other societal stakeholders also conducting risk management tasks such as the Food packaging industry (Soc11), or communication such as Testaankoop and other consumer organisations (Soc17). A likely explanation for this is that Sci12-15 are stakeholders that are involved in research & development on paper recycling for FCM, in contrast with the other industry stakeholders, such as the Food Industry (Soc10) and Supermarkets (Soc16) who are their customers and do not perform extensive research on the specific case study topic. Furthermore, stakeholders for which science is a product with a commercial basis such as Commercial labs (Sci2) and Consultants (Sci3), are also perceived as primarily science stakeholders by participants.

3.2. Net-Maps using the identified linkages

3.2.1. Combined Net-Map

Fig. 1 shows the combined Net-Map including all the reported stakeholders and their linkages for all types in the risk analysis network. The stakeholder size is based on the sum of both incoming and outgoing linkages per stakeholder which gives an initial indication of the importance/influence of the stakeholder in the network. In the combined network 41 stakeholders are perceived to be linked to at least one other stakeholder by the workshop participants through 269 (bi-) directional links. In the case of multiple linkage types (e.g. stakeholders linked to each other more than once such as legally required information sharing and public communication), this is counted as one link between the 2 stakeholders.

Fig. 1 indicates that two stakeholders (Pol3 and Pol4) are larger than the others, indicating these have the highest number of linkages. They

Table 2
Identified stakeholders in the risk analysis network for paper recycling in Belgium.

Full name of the organisation	Code	SPS Category	RA1	RA2	RA3	RM1	RM2	RM3	RC1	RC2	RC3
Belgian Packaging Institute (IBE-BVI)	Sci1	Science	X	X	X					X	
Commercial labs	Sci2	Science		X							
Consultants	Sci3	Science	X		X						
European Food Safety Authority (EFSA)	Sci4	Science	X	X	X				X	X	X
National Reference Laboratory for Food Contact Materials (NRL-FCM)	Sci5	Science	X	X	X					X	
Research institutes/laboratories	Sci6	Science		X							
Sciensano	Sci7	Science	X	X	X					X	
Scientific Committee of FAVV (SciCom)	Sci8	Science	X		X					X	
Universities	Sci9	Science	X	X	X					X	
European Chemicals Agency (ECHA)	Sci10	Science-Policy	X	X	X					X	
European Union Reference Laboratory for Food Contact Materials (EURL-FCM)	Sci11	Science-Policy					X				
Ink Industry	Sci12	Science-Society	X	X	X					X	
Pack4Food	Sci13	Science-Society	X	X						X	
Paper Board Converting industry	Sci14	Science-Society	X	X	X					X	
Paper Board Industry	Sci15	Science-Society	X	X	X					X	
Codex Alimentarius Commission (CAC)	Pol1	Policy				X	X			X	
European Commission (EC)	Pol2	Policy				X	X	X			
Federal Agency for the Safety of the Food Chain (FAVV/AFSCA/FASFC)	Pol3	Policy		X	X		X	X	X		X
Federal Public Service for Health, Food Chain Safety and Environment FOD-G)	Pol4	Policy		X		X	X	X		X	
National accreditation bodies	Pol5	Policy						X			
Other Member States/The Council of the European Union	Pol6	Policy				X	X	X			
Political actors	Pol7	Policy					X			X	
Superior Health Council (HGR)	Pol8	Policy	X	X						X	
Associations	Soc1	Society		X						X	
Auto control systems	Soc2	Society									
Certification bodies	Soc3	Society						X			
Chemical industry (inks, varnishes, glues…)	Soc4	Society	X	X	X			X		X	
Consumers	Soc5	Society									
Distribution/Retail industry	Soc6	Society								X	
Federatie van de Belgische Voedingsindustrie (FEVIA)	Soc7	Society				X	X		X	X	
Federatie van duurzame industrieën (Federation of Sustainable Industries) (InDUfed)	Soc8	Society				X	X		X	X	
Food contact article industry	Soc9	Society									
Food industry, Food/feed producers	Soc10	Society	X	X	X			X		X	
Food packaging industry	Soc11	Society	X	X	X			X		X	
Fost Plus, Valipac	Soc12	Society									
Influencers	Soc13	Society								X	
Media and Press	Soc14	Society								X	
Nature organisations	*	Society								X	
Non-disclosure agreement agencies	*	Society									
Recycling companies	Soc15	Society									
Supermarkets	Soc16	Society	X	X	X			X			
Testaankoop and other consumer organisations	Soc17	Society		X						X	X
Waste management industry: Ivago, Ecowerf	Soc18	Society									

Colours highlight Science (blue), Policy (red), or Society (yellow) categorisation.
Stakeholders that have roles in multiple SPS categories are indicated as such, with the stakeholder highlighted in the additive colour.
* = stakeholder was identified, but never connected in the Net-Map.
Main tasks: RA1:risk identification; RA2:data collection; RA3:performing risk assessment; RM1:policy development; RM2:setting/proposing legislation; RM3:enforcement; RC1:risk communication development, RC2:dissemination of risk communication; RC3:evaluation of the impact/efficiency of risk communication.

are the federal stakeholders, namely the Federal Agency for the Safety of the Food Chain ((Pol3) with 38 total links) and the Federal Public Service for Health, Food Chain Safety, and Environment ((Pol4) with a total of 32 links). The high connectivity of these two stakeholders in the network is because they are primarily responsible for food safety in Belgium. The FAVV is the national food safety authority and the main inspection service for food hygiene.[6] Tasks such as setting of national norms fall under the Federal Public Service for Health, Food Chain Safety, and Environment (FOD-G), the EFSA Focal Point for Belgium. Sciensano (Sci7) has a moderate size node as the participants assigned 15 links to other stakeholders. Sciensano is a federal research institute providing scientific advice and research, but it appears relatively unconnected in the network compared to the 2 federal stakeholders, FAVV and FOD-G. Participants indicated that Sciensano has a more advisory role, and part of its tasks are performed through the Superior Health Council (HGR, Pol8). Another notable stakeholder is the food contact article industry (Soc9) as it has 12 incoming and only 5 outgoing links, while for most other stakeholders the amount of incoming and outgoing links are roughly equal. Possibly this is due to food contact articles often consisting of multiple materials and as a result having multiple suppliers, but a limited number of customers.

The combined network gives a first insight into the structure of the risk analysis network for recycled paper FCM in Belgium as a whole, as the results are based on all existing connections between stakeholders.

3.2.2. *Net-Maps of specific linkage types: legally required information sharing*

By law, companies such as supermarkets and food producers have to report any risk issues to the national food safety authority, the FAVV. Fig. 2 shows that in the risk analysis network for paper recycling in Belgium, virtually all stakeholders are either directly or indirectly connected to the FAVV (Pol3) through legally required information sharing, with 15 incoming and 12 outgoing connections. The FOD-G (Pol4) is also highly connected and central in the network, with 11 incoming and 11 outgoing connections. The third most connected actor is the food industry (Soc10) with 10 incoming and 10 outgoing connections. The food industry is an end-user in the food production chain before food is placed on the market; they source materials and foodstuffs from most of the other societal stakeholders and have the legal responsibility to ensure their food is safe. These observations are also reflected in the Eigencentrality value, showing not just a high degree of connectivity but also indicating a high degree of influence within the network. The most influential stakeholder according to the Eigencentrality value is the FAVV (1.00), followed by the food industry (0.92) and FOD-G (0.79). The legally required information-sharing network is relatively complex, with an average degree of 3.59 connections, and a transitivity of 0.227. These results affirm the central role of the FAVV that is expected from its

[6] Wet houdende oprichting van het federaal Agentschap voor de Veiligheid van de voedselketen art. 4§1, see http://www.ejustice.just.fgov.be/eli/wet/2000/02/04/2000022108/justel.

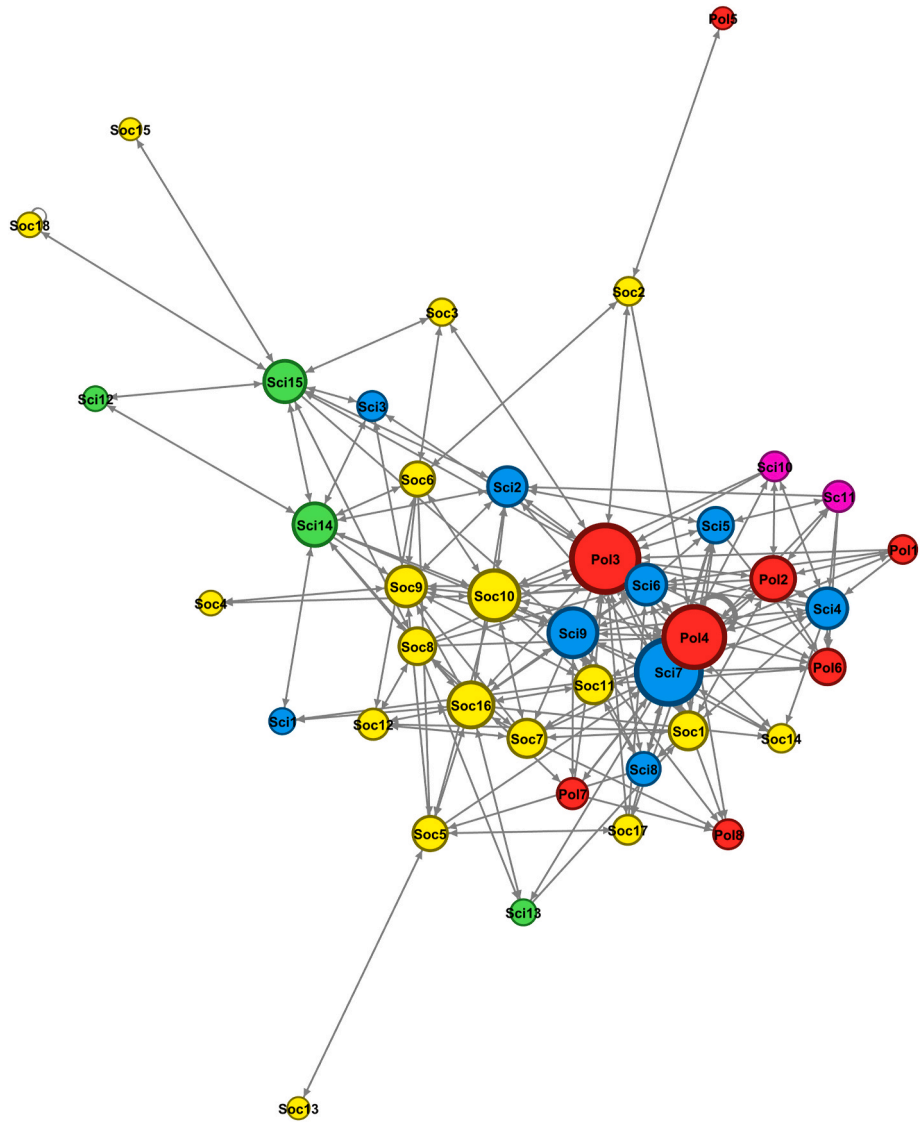


Fig. 1. Combined links in the risk analysis network for paper recycling in Belgium. Colours indicate SPS-category (Science = blue, Policy = red, Society = yellow, Science/Society = green, Society/Policy = purple). The stakeholder codes are listed in Table 2. Node size indicates the total number of incoming and outgoing connections.

mandate.

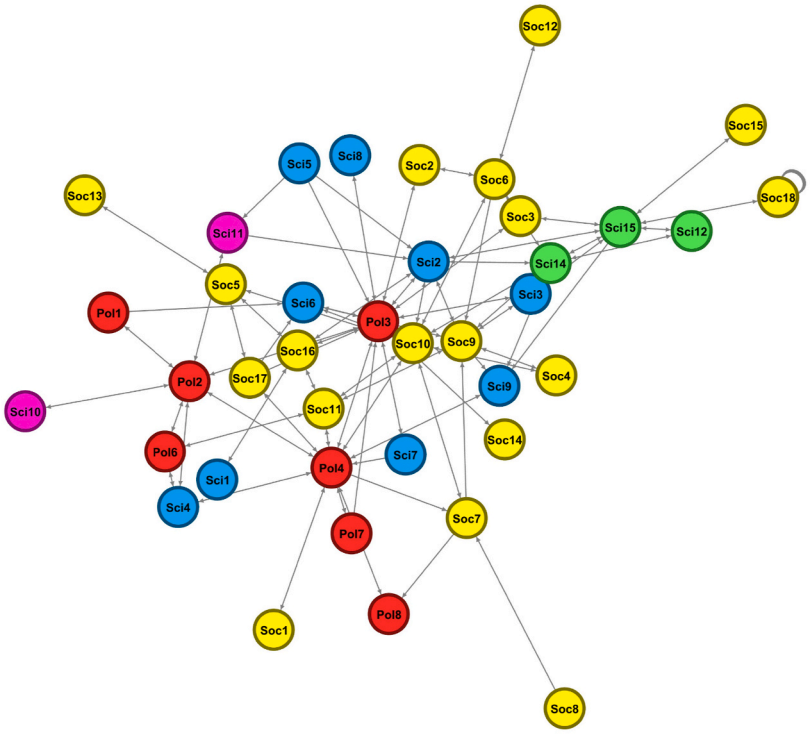
3.2.3. *Net-Maps of specific linkage types: voluntary information sharing*

Apart from legally required information sharing, stakeholders may also exchange information voluntarily. Fig. 3 shows that the voluntary information-sharing network is more centralised around the science stakeholders compared to the legally required information-sharing network (Fig. 2). Of the 35 stakeholders engaged in this voluntary exchange, the most connected stakeholders are Sciensano (Sci7) with 17 incoming and 20 outgoing connections, and universities (Sci9) with 8 incoming and 9 outgoing connections. Sciensano has a coordinative role in scientific advice and research, which is reflected in being connected to virtually all science and policy stakeholders. Universities are connected to research institutes (Sci6), Sciensano (Sci7), the scientific committee of FAVV (Sci8), and the food contact article industry (Soc9), food industry (Soc10), food packaging industry (Soc11) and supermarkets (Soc16), seemingly indicating they serve as a partner for scientific questions for both science and industry. Based on the Eigencentrality value, Sciensano is by far the most influential stakeholder (1.00), with universities relatively influential (Eigencentrality 0.54). Despite a more limited number of connections, with 7 incoming and 7 outgoing connections, the FAVV is still relatively influential in the network for voluntary information sharing as well, with an Eigencentrality value of 0.57. The network complexity is comparable to that of legally required information sharing, with an average degree of connections of 3.54 and a transitivity of 0.246.

The above results show that within the voluntary information-sharing network Sciensano and Universities take a more central role.

3.2.4. *Net-Maps of specific linkage types: data generation request*

Emerging risks require new information and/or data to deal with the issue. This forms the basis of the third network type: the data generation request. Within the workshop, 33 stakeholders were identified to be involved, through 59 total connections. Fig. 4 demonstrates that the FOD-G (Pol4) and FAVV (Pol3) are the most connected stakeholders in the network, with 6 incoming and 8 outgoing, and 5 incoming and 6 outgoing connections respectively. This too can be attributed to their central coordinative role when it comes to food safety and health risks, and their mandate to request the generation of new scientific data. Sciensano is interesting in that it only has incoming connections, indicating that it is a stakeholder that other stakeholders rely on to generate the data. The fact that these requests come from coordinating



Belgian Packaging Institute	Sci1
Commercial labs	Sci2
Consultants	Sci3
European Food Safety Authority	Sci4
Research institutes/laboratories	Sci6
Sciensano	Sci7
Scientific Committee of FASFC	Sci8
Universities	Sci9
European Chemicals Agency	Sci10
European Union Reference Laboratory for Food Contact Materials	Sci11
Ink Industry	Sci12
Pack4Food	Sci13
Paper Board Converting industry	Sci14
Paper Board Industry	Sci15
Codex Alimentarius Commission	Pol1
European Commission	Pol2
Federal Agency for the Safety of the Food Chain	Pol3
Federal Public Service for Health, Food Chain Safety and Environment	Pol4
Other Member States/The Council of the European Union	Pol6
Political actors	Pol7
Superior Health Council	Pol8
Associations	Soc1
Autocontrol systems	Soc2
Certification bodies	Soc3
Chemical industry (inks, varnishes, glues…)	Soc4
Consumers	Soc5
Distribution/Retail industry	Soc6
Federatie van de Belgische Voedingsindustrie	Soc7
Food contact article industry	Soc9
Food industry, Food/feed producers	Soc10
Food packaging industry	Soc11
Fost Plus, Valipac	Soc12
Influencers	Soc13
Media and Press	Soc14
Recycling companies	Soc15
Supermarkets	Soc16
Testaankoop and other consumer organisations	Soc17
Waste management industry: Ivago, Ecowerf	Soc18

Number of stakeholders (nodes)	39	Average degree	3.59
Number of linkages (edges)	140	Average path length	2.69
Network density	0.094	Transitivity	0.227

Fig. 2. Net-Map for legally required information sharing in the risk analysis network for paper recycling in Belgium.

stakeholders, such as the FOD-G and FAVV, but also other EU member states (Pol6), EFSA (Sci4) and the Scientific Committee of the FAVV (Sci8), results in having the highest Eigencentrality value (1.00). Other science stakeholders are also generating data, such as the research institutes (Sci6, Eigencentrality 0.70) and the National Reference Laboratory for FCM (Sci5, Eigencentrality 0.61). The relatively low number of connections results in a less complex network than that for legally required and voluntary information sharing, with an average degree of 1.79 and a transitivity of 0.167. The data generation request network demonstrates the coordination role of the FAVV and FOD-G within the network.

3.2.5. *Net-Maps of specific linkage types: public communication*

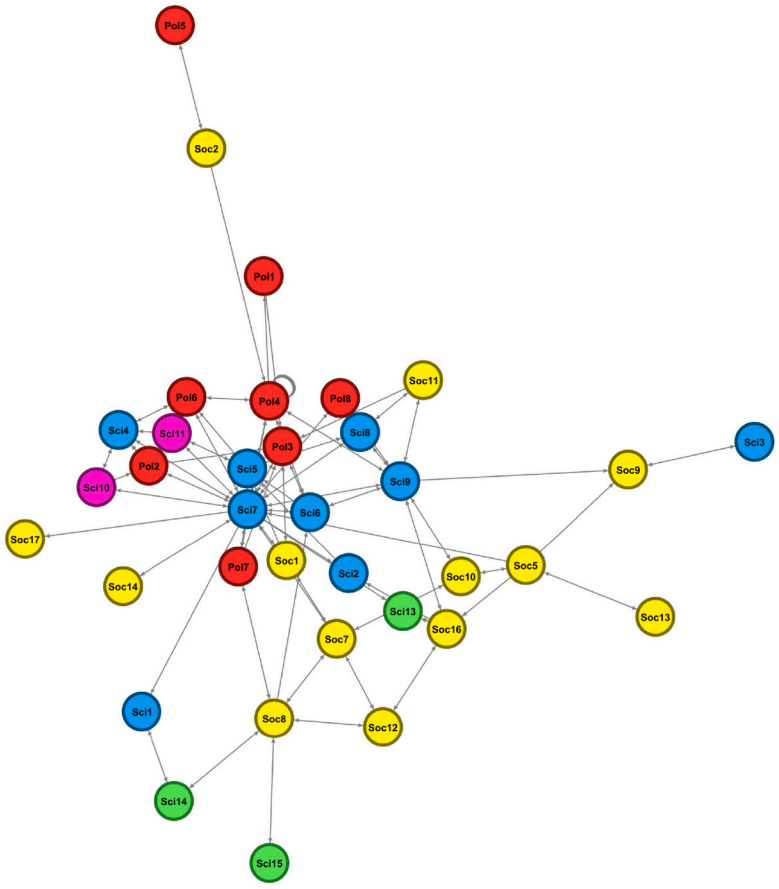
The last network type reflects the final step in the risk analysis process; communication. In this research, the focus lies on those communications that are made publicly either between stakeholders or from stakeholders to the general public. With only 26 of the 41 connected stakeholders involved in public communication, through 39 connections, it is the smallest network identified in this study. Fig. 5 illustrates that it is also the only network type that consists of two separate sub-networks, one with commercial labs (Sci2), the National Reference Laboratory for FCM (Sci5) and the European Union Reference Laboratory for FCM (Sci11), and one with the rest of the 26 stakeholders. Within the larger sub-network, the FAVV (Pol3) is again the most connected stakeholder, with 5 incoming and 6 outgoing connections. The media and press (Soc14) and consumers (Soc5) are the primary recipients of the communication, with 5 and 4 incoming connections respectively, and no outgoing connections. This is also reflected in the Eigencentrality values, with media and press (1.00) and consumers (0.95) scoring the highest, followed by the FAVV (0.56). Network complexity is low, with 1.50 average connections, and a transitivity of 0.043, the lowest of all the networks. The public communication network illustrates that a limited number of stakeholders is engaged in public communication about food safety risks involving paper rFCM.

3.3. *Perceived influence vs. calculated influence*

Participants were also asked to score stakeholders depending on the influence within the network as perceived by themselves. Table 3 presents the Eigencentrality values for several stakeholders, calculated for each linkage type, and the perceived influence score as indicated by the participants during the workshop. The influence of stakeholders as directly indicated by the participants gives insights into both the formal and informal power the stakeholder has within the network.

Table 3 shows that based on the Eigencentrality values, the Federal Agency for the Safety of the Food Chain (FAVV, Pol3) is very influential in all networks (maximum normalised Eigencentrality = 1.00, minimum = 0.39). This is as expected as the FAVV is the stakeholder responsible for food safety in general, and in coordinating research and communication on the topic, as well as being able to independently conduct investigations.[7] The calculated influence of the FAVV is also in line with the perceived overall influence as declared by workshop participants, who scored the FAVV overall influence with an 8.0 (out of 10). The other main federal stakeholder in the network, the FOD-G (Pol4), was deemed as influential as the FAVV by workshop participants (score = 8.0) and is indeed quite influential based on the different Eigencentrality measures being roughly similar for legally required information

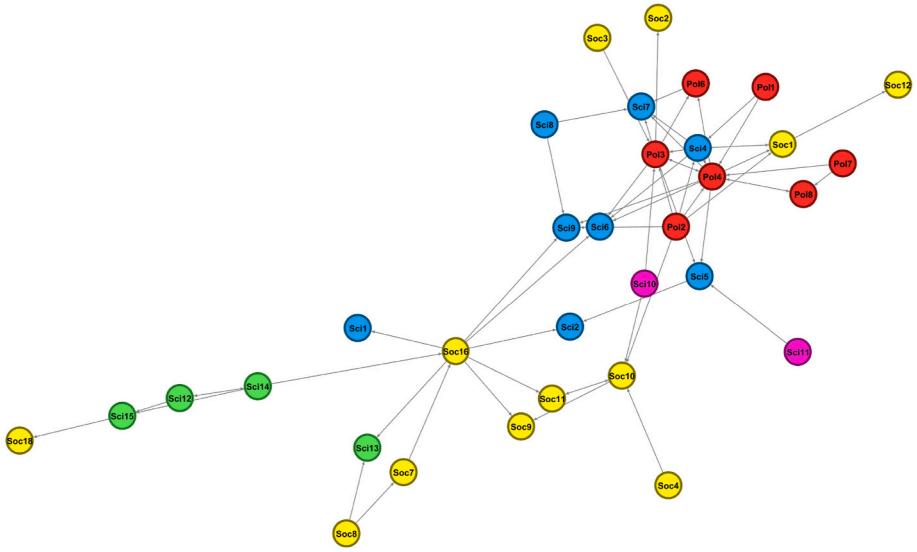
[7] Wet houdende oprichting van het federaal Agentschap voor de Veiligheid van de voedselketen art. 4, 7 and 8, see http://www.ejustice.just.fgov.be/eli/wet/2000/02/04/2000022108/justel.



Belgian Packaging Institute	Sci1
Commercial labs	Sci2
Consultants	Sci3
European Food Safety Authority	Sci4
National Reference Laboratory for Food Contact Materials	Sci5
Research institutes/laboratories	Sci6
Sciensano	Sci7
Scientific Committee of FASFC	Sci8
Universities	Sci9
European Chemicals Agency	Sci10
European Union Reference Laboratory for Food Contact Materials	Sci11
Pack4Food	Sci13
Paper Board Converting industry	Sci14
Paper Board Industry	Sci15
Codex Alimentarius Commission	Pol1
European Commission	Pol2
Federal Agency for the Safety of the Food Chain	Pol3
Federal Public Service for Health, Food Chain Safety and Environment	Pol4
National accreditation bodies	Pol5
Other Member States/The Council of the European Union	Pol6
Political actors	Pol7
Superior Health Council	Pol8
Associations	Soc1
Autocontrol systems	Soc2
Consumers	Soc5
Federatie van de Belgische Voedingsindustrie	Soc7
Federatie van duurzame industrieën (Federation of Sustainable Industries)	Soc8
Food contact article industry	Soc9
Food industry, Food/feed producers	Soc10
Food packaging industry	Soc11
Fost Plus, Valipac	Soc12
Influencers	Soc13
Media and Press	Soc14
Supermarkets	Soc16
Testaankoop and other consumer organisations	Soc17

Number of stakeholders (nodes)	35	Average degree	3.54
Number of linkages (edges)	124	Average path length	2.60
Network density	0.104	Transitivity	0.246

Fig. 3. Net-Map for voluntary information sharing in the risk analysis network for paper recycling in Belgium.



Belgian Packaging Institute	Sci1
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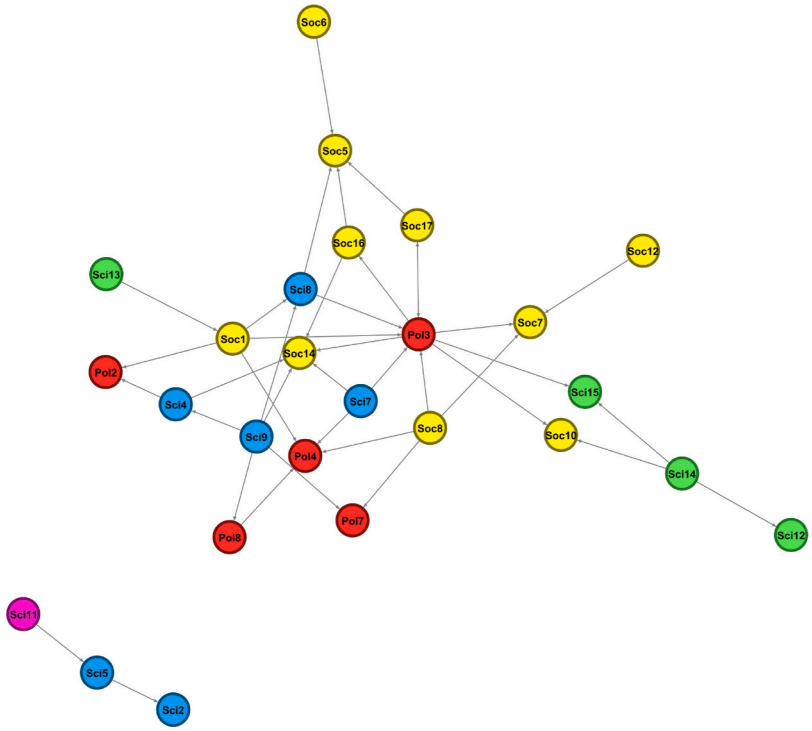
Food contact article industry	Soc9
Food industry, Food/feed producers	Soc10
Food packaging industry	Soc11
Fost Plus, Valipac	Soc12
Supermarkets	Soc16
Waste management industry: Ivago, Ecowerf	Soc18

Number of stakeholders (nodes)	33	Average degree	1.79
Number of linkages (edges)	59	Average path length	1.91
Network density	0.056	Transitivity	0.167

Fig. 4. Net-Map for data generation requests in the risk analysis network for paper recycling in Belgium.



Commercial labs	Sci2
European Food Safety Authority	Sci4
National Reference Laboratory for FCM	Sci5
Sciensano	Sci7
Scientific Committee of FASFC	Sci8
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European Union Reference Laboratory for FCM	Sci11
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Food industry, Food/feed producers	Soc10
Fost Plus, Valipac	Soc12
Media and Press	Soc14
Supermarkets	Soc16
Testaankoop and other consumer organisations	Soc17

Number of stakeholders (nodes)	26	Average degree	1.50
Number of linkages (edges)	39	Average path length	1.73
Network density	0.060	Transitivity	0.043

Fig. 5. Net-Map for public communication in the risk analysis network for paper recycling in Belgium.

Table 3
Eigenvector centrality measures for several key stakeholders in the four different link types.

Stakeholder	Net-Map code	LRIS: Eigenvector centrality	VIS: Eigenvector centrality	DGR: Eigenvector centrality	PC: Eigenvector centrality	Combined links Eigenvector centrality	Perceived influence
Sciensano	Sci7	0.18	1.00	1.00	0.00	0.91	5.5
Universities	Sci9	0.42	0.54	0.41	0.00	0.72	3.1
Paper Board Converting industry	Sci14	0.54	0.06	0.04	0.00	0.27	2.2
European Commission	Pol2	0.46	0.27	0.00	0.06	0.53	8.7
Federal Agency for the Safety of the Food Chain	Pol3	1.00	0.51	0.39	0.56	1.00	8.0
Federal Public Service for Health, Food Chain Safety and Environment	Pol4	0.79	0.57	0.52	0.08	0.96	8.0
Food contact article industry	Soc9	0.63	0.11	0.19	NA	0.55	NA
Food industry, Food/feed producers	Soc10	0.92	0.15	0.15	0.53	0.69	1.3
Food packaging industry	Soc11	0.53	0.15	0.19	NA	0.48	2.6

(LRIS: Legally Required Information Sharing; VIS: Voluntary Information Sharing; DGR: Data Generation Request; PC: Public Communication). NA = not available (not part of the network or not scored).

sharing, voluntary information sharing, and data generation requests networks with Eigencentrality valueranging between 0.52 and 0.79. However, when it comes to public communication, the Eigencentrality is relatively low at 0.08. The most influential policy stakeholder as perceived by workshop participants is the European Commission (scored influence 8.7, Pol2). However, based on the Eigencentrality measures (Table 3), it has far less influence than most other stakeholders; the highest Eigencentrality is 0.46 in legally required information sharing and 0.00 in public communication. The ascribed influence can be a result of the power the European Commission has as food safety is a harmonised domain meaning that the EU has the mandate to regulate many aspects of the field.[8] As such, the Commission has a high degree of decision power, while not directly being involved in contact with many of the identified stakeholders and instead relying on other EU institutions for this. In the case of paper recycling for food contact use, these are EFSA[9] and ECHA[10]. The science stakeholders Sciensano (Sci7) and universities (Sci9) received an influence score of 5.5 and 3.1, respectively whereas they appeared to be quite influential in the networks dealing with voluntary information sharing and data generation requests. This discrepancy could be due to the voluntary nature of the

[8] Regulation 178/2002 (EC) of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety.

[9] Regulation 178/2002 (EC), article 23§c: [The tasks of the Authority shall be the following …] to provide scientific and technical support to the Commission in the areas within its mission and, when so requested, in the interpretation and consideration of risk assessment opinions.

[10] Regulation 1907/2006 (EC), article 77§1: The Agency shall provide the Member States and the institutions of the Community with the best possible scientific and technical advice on questions relating to chemicals which fall within its remit and which are referred to it in accordance with the provisions of this Regulation.

connections in voluntary information sharing and data generation requests.

3.4. Identified constraints within the network

A final addition to the original Net-Map methodology is the inclusion of the identification of constraints within the network. Constraints were defined as any situation where linkages do exist, but do not function optimally. These can be constraints for specific stakeholders, such as a lack of manpower, a lack of in-house knowledge, etc., or constraints between stakeholders, for example, a lack of trust to cooperate. A total of 39 constraints were identified by the workshop participants of which 20 were scored. Table 4 shows all constraints that were identified that scored at least 1 point by workshop participants. Most constraints were stakeholder-specific, such as a lack of resources for both federal stakeholders.

The highest scoring constraints were 'The lack of knowledge and data available to stakeholders to perform adequate risk analysis' (15 points) and 'The flow of information through the chain where this knowledge is available' (12 points). According to the experience of the participants, data for risk analysis or its outcome is often known, but not shared with other stakeholders in the network for various reasons, such as confidentiality on specific steps or materials used in a new recycling process. Another constraint was described as 'The tendency of risk analysis to take a "zero-risk society" approach, leading to a focus on specific issues with relatively low societal gain' (15 points). The participants argued that in the current debates, there is too much focus on eliminating specific known risks. For example, in completely removing all traces of specific contaminants rather than using these resources to reduce the risk of other issues with a higher impact on the general population. Furthermore, 'The lack of harmonised regulations on FCM on EU-level for paper & board and other relevant FCM' (11 points) was mentioned as an important constraint. Harmonised regulations only exist for (recycled) plastics.[11] For paper(-board) FCM there are no specific EU regulations, despite these products being available in other member states through the single market. This was seen as a problem by participants from all SPS categories for both risk analysis and the competitiveness of rFCM in general, as less strict legal requirements in other member states make it harder for companies to compete as it disrupts the level playing field, and information for risk analysis tends to be more localised in the member state itself. Finally, it was stated there is a general 'Lack of resources' to address the emerging issues for multiple stakeholders. A full list of constraints and their summed score can be found in the supplementary materials.

Overall it is noteworthy to see that the main constraints for science stakeholders were limited to the exchange of information and retaining those that gathered the information, and the lack of resources to carry out the assessments. The lack of knowledge is only attributed to being a barrier to the FOD-G, indicating that the knowledge exists, but it does not reach (part of) the policy domain. The policy stakeholders are also highlighted to be those that experience the most constraints of urgency; especially the FAVV seems to experience multiple highly-scored constraints. The only scored constraint on the network level is 'Unclear or insufficient information/different interpretations', which seems to be an accurate summary of the constraints in general; a lack of exchanging of information due to different reasons, and unclarity of what to expect in the future.

3.5. Evaluation of the Net-Map methodology

The change to a single workshop instead of individual interviews is considered efficient and effective as all experts individually provided their input and discussed plenary the shared outcomes. Moreover, the online setting was seen as a great advantage as it allowed high-level experts to join as they did not have to spend time travelling.

The generated Net-Maps were found to be an accurate description of reality according to the participants of the validation session. The central roles of the FAVV and FOD-G were confirmed, along with several newly identified stakeholders. Furthermore, the participants indicated that the Belgium risk analysis network for paper recycling could be characterised as technocratic, with a large influence and high connectivity for science and industry and very little politics involved in the current discourse. During the validation session, one participant confirmed they have quite some direct contact with governmental stakeholders. It is relatively easy for them to contact them if any issues arise, while colleagues in other countries (especially those in southern Europe) have more problems. After discussing the relatively great influence and connectivity of non-governmental stakeholders in the network, multiple participants indicated the high level of trust and accessibility of stakeholders in the network could be a strength in creating a more resilient network where stakeholders see the benefit of cooperating and sharing information. However, it can also cause problems; one participant stated that often new information is freely shared, for example through email, but in a very informal way. This results in recipients not forwarding this information to their contacts, as it was not a formal communique and potentially less urgent. The technocratic nature of the network is expected to change over time, as the sustainability aspects and potential health impacts of the circular economy are slowly generating political involvement.

Although participants deemed the results do indeed reflect reality, several limitations have to be considered. As the analysis is done for a specific case study in a specific national context, the results cannot be generalised. It is also unknown to which degree the Flemish-oriented composition of workshop participants influenced the identification of stakeholders, potentially excluding several in the Wallonia region of Belgium. Workshop participants agreed that if the workshop was done for a different topic, results might be very different due to the earlier mentioned technocratic nature of the network of paper recycling for rFCM use.

4. Conclusions

This study adjusted and digitalised the Net-Map methodology from Schiffer and Hauck (2010) to perform a network analysis in a national food safety context in a single workshop with high-level experts from science, policy, and society. The adjusted Net-Map methodology was used to analyse the risk analysis network for paper rFCM in Belgium. Forty-one connected stakeholders were identified and characterised, of which 7 were science, 1 science-policy, 4 science-society, 11 policy, and 21 society stakeholders. These stakeholders are connected through 4 identified linkage types: 'legally required information sharing', 'voluntary information sharing', 'data generation request', and 'public communication'. The perceived influence of each stakeholder is partly aligned with the mathematical influences as calculated using network theory. Constraints within the network related to resources, capabilities, relations, and others were mostly specific to stakeholders, with only a few specific stakeholders facing multiple types of constraints. The Net-Map methodology proved useful in unravelling the complexity of the network and shows that the risk analysis network is more complex than solely based on the administrative framework as established in legislation, which can be used to compare a theoretical expectation from the administrative framework with reality. The insights provided by the Net-Map can be also used by different stakeholders for various purposes; such as scientists understanding which stakeholder to approach to gather data, policymakers knowing where to focus interventions, and creating stakeholder awareness about potential collaborations.

When done at multiple points in time, the effect of interventions or systemic changes such as the circular economy, can be followed. Future

[11] Regulation (EU) 2022/1616 and Regulation (EU) 10/2011 for recycled and virgin plastics respectively.

Table 4
Identified constraints in the risk analysis network for paper recycling in Belgium.

		Points	Network level	Commercial labs	Universities	European Food Safety Authority	Paper Board Converting industry	European Commission	Federal Agency for the Safety of the Food Chain	Service for Health, Food Chain Safety,	Other Member States/The Council of the European Union	Political actors	Food contact article industry	Food packaging industry	Non-disclosure agreement agencies	Influencers
				Sci2	Sci9	Sci10	Sci14	Pol2	Pol3	Pol4	Pol6	Pol7	Soc9	Soc11	NA	Soc13
Capabilities	Lack of knowledge and data	15														
	Political sensitivities, public opinion	4														
	Lack of knowledge on unidentified hazards; not know what to request or how to interpret results	3														
Resources	Lack of harmonized EU Regulations	11														
	Lack of resources	9														
	Lack of qualified methods to assess combined exposure	7														
	Lack of definitions about which information should be transferred	4														
	Insufficient finances (for SMEs)	4														
	Expertise of people is not always available for long-term (short projects)	3														
	Legislation on different levels and regions	2														
Relations	The flow of information from industry to authorities, access to this information between authorities and foreign actors	12														
	Confidentiality of information	11														
	Difficult information exchange between different institutes	8														
	Fraud	6														
	Power play: difference in interpretation of information	6														
	Unclear or insufficient information/different interpretations	5														
	Unrealistic limits	1														
Other	Excessive tendency to zero-risk society	15														
	Consider all input of different stakeholders, causing a long waiting period for legislation	6														
	Fake/indiscriminate news sharing	3														

Colours indicate the stakeholder SPS category and applicability of the identified barrier. Colours highlight Science (blue), Policy (red), or Society (yellow) categorisation.

research could compare risk analysis networks across countries for the same food safety issue or examine the risk analysis networks for different food safety issues in the same country. Such a comparison could allow for the identification of best practices to increase network effectiveness. Considering the transition to a circular economy, Net-Maps could assist in monitoring changes within risk analysis networks over time.

CRediT authorship contribution statement

Niels van der Linden: Writing – original draft, Visualization. **Celine Meerpoel:** Writing – review & editing, Validation, Methodology, Investigation, Data curation. **Hanna Schebesta:** Methodology, Funding acquisition, Conceptualization. **Pieternel Luning:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2024.110975.

Data availability

Data is included in supplementary materials

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