Mapping the landscape of Consumer Food Waste

Abstract

Since 2015 there has been a surge of academic publications and citations focused on *consumer food waste*. To introduce a special issue of *Appetite* focused on the drivers of consumer food waste we perform a transdisciplinary and historical review of the literature through a co-citation network analysis and topic modelling approach. We show that the rapid increase in publications is largely attributable to an urgency caused by the Sustainable Development Goals and climate change. Topic modelling reveals that the dramatic quantitative increase of publications has also produced a variety of evolving themes, and that a metaphorical *Cambrian Explosion* is occurring after decades of academic inactivity. Network analysis results show that consumer food waste features in thousands of articles and hundreds of journals, but that the citation practices of academics are becoming highly concentrated, as 20% of journals attract over 80% of citations. Finally, by examining the burstiness and transdisciplinary structure of citation networks we show that though the field has historically been dominated by empirical articles, it is now starting to show signs of maturity as a flurry of review papers help to consolidate knowledge.

Keywords

Food waste, Consumer behaviour, Consumer Food Waste, Co-citation network, Topic Modelling

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Introduction

Wasting food evokes a strong negative emotion in many people. If you are reading this special issue, you are likely one of them. For many of us, eliminating food waste is the single biggest contributor that can reduce our carbon footprint (Project Drawdown, 2020). Yet global food waste continues unabated, reaching scales so gargantuan they are difficult to comprehend (931 million tonnes annually, according to United Nations Environment Programme, 2021). Despite such abundance being wasted, hundreds of millions of people in both high and low-income countries still do not get enough food. Given the destructive environmental impact of food waste, that people overwhelmingly do not want to waste food, and that millions of people are still hungry, this special issue brings together research that examines why consumer food waste is still so persistent and what can be done about it.

Blame for food waste is often pointed at production, but in middle/high-income countries over 50% of food supply losses occur in distribution and consumption (Kummu *et al,* 2012). The mundane everyday decisions taken by people around the world when they search for, evaluate, purchase, prepare, eat, and discard food have profound social and environmental consequences. The *Sustainable Development Goals* include an explicit food waste reduction target, arguing fundamental changes to the way societies consume are indispensable for achieving global sustainable development (United Nations, 2015). Yet, the UN's own recent research suggests, *"without additional focus, it is unlikely that these targets will be achieved"* (United Nations, 2019, p.7). Some have gone further, suggesting that global food waste statistics (including FAO) may be underestimating consumer food waste (van de Bos *et al.*, 2020) and the associated greenhouse gases (Tubiello *et al.*, 2021). Similarly, though the Paris climate agreement made no explicit mention of food waste (UNFCC, 2015), its current targets are likely to be missed (Liu and Raftery, 2021; Roelfsema *et al.*, 2021), with global food system emissions a major cause of why its goals are precluded (Clark *et al.*, 2020). The requirement to reduce consumer food waste is therefore urgent. If these issues are ever to be solved it's clear that structural transformation is needed, but the small and seemingly humdrum acts of consumption we all make every day demand attention too. This necessarily requires a multi-disciplinary endeavour, as much about understanding the social

antecedents of food waste as the consumer behaviour that accompanies it at the individual level. The submissions made to this special issue of *Appetite* draw from a range of disciplines to bolster our understanding of where and how food is wasted, how the social framing of food affects the judgement of waste, how surplus food might avoid becoming wasted, and a series of prevention strategies for shaping consumer behaviour. In the following section, we provide a brief commentary on the contributions made in the special issue, before then situating these contributions within the broader literature by performing a transdisciplinary review to illustrate the burgeoning field of consumer food waste studies.

The growing field of Consumer Food Waste Studies

The term 'consumer food waste' appeared at least as early as 1944. In a war report entitled *'Effectiveness of Campaigns in Minimizing Consumer Food Waste'* the United States focused on intervening in consumer behaviour, advocating that '*better utilisation of food has been required because of its importance as a weapon of war'* (Cottam, 1944). In the following half century the term remained relatively obscure, with few exceptions of academic work (e.g. Gallo, 1980) using the same consumerist framing when studying food waste. In the past decade this dramatically changed. By 2011 Isenhour (2011) had already recognised an increasing focus on consumer responsibility within the food sustainability literature, and the broader implications of a narrative trend towards 'responsibilisation' or 'individualisation' of food consumption, where previously food waste at the consumption level might have been seen instead as a problem of citizenship. Noting too that a conflated framing of the '*citizen-consumer'* within the food system had proliferated. This framing results in a notion of 'divided citizenship', in which people are supposed to use their decisions to contribute to the common good while simultaneously pursuing private interests (Beck, 2000). The conceptualisation of 'consumer' food waste is therefore not without detractors, but the explosion of multi-disciplinary food waste literature with a consumption focus, demonstrates both the political urgency and academic interest its study is now afforded. It is to this interest that we now turn.

Eight articles were selected for publication within this special issue, which vary in their empirical context, methods, and disciplinary backgrounds as follows: **Conceptualisation -** Boulet *et al.* (2021) perform a comprehensive review of how household food waste is conceptualised, arguing that the ontological positioning of food waste must be broadened to enable more effective multi-level approaches; **How food *becomes* wasted**

- through ethnographic study Aleshaiwi and Harries (2021) examine the culturally-specific food serving and sharing practices through which food becomes 'unwanted'; the antecedent to it being wasted. Dyen et al. (2021) focus on temporalities to better understand the habits and routines through which households attempt to reduce food waste; **The relation between the managerial and the behavioural -** Ceryes et al. (2021) examine the factors that influence frontline workers' and department managers' food waste decision-making at the store level; findings underscore the connection between managerial and behavioural waste drivers; **The social influence of the pandemic -** Rodgers et al. (2021) examines individuals' perceived changes in food waste behaviours since the start of the Covid-19 pandemic in the USA and Italy. Results demonstrate a reduction in food waste and important cross-cultural differences, illustrating how changes and differences are attributable to pandemic-related circumstances (e.g. country specific restrictions) rather than the duration and intensity of the pandemic itself; ***Alternative* practices and prevention strategies -** Le Borgne et al. (2021) note that although most consumers hate wasting and do not intend to waste, they still end up wasting food. By focusing on routines that prevent waste rather than on waste behaviours, and by defining and measuring consumer concern for food waste (CFW), their study helps to resolve this apparent contradiction. Finally, Smith and Harvey (2021) examine 'social eating initiatives', which address both food waste and social inclusion by using surplus food to prepare meals that people can eat together in a communal setting. The results highlight how commensality brings social benefits that extend beyond food waste to improve social relations, connectedness and wellbeing.

To help characterise the contributions made by the articles appearing in the special issue and situate them among the broader literature we perform a transdisciplinary review including a co-citation network analysis, and topic modelling approach. There are numerous existing literature reviews covering consumer food waste, particularly focused on household consumer food waste (e.g. Principato, 2018; Principato *et al.,* 2021; Schanes *et al.,* 2018; do Carmo Stangherlin and de Barcellos, 2018; Hebrok and Boks 2017; Roodhuyzen *et al.,* 2017; Reynolds *et al.,* 2019), indeed an excellent example focused on household waste features in this special issue (Boulet *et al.,* 2020). Our aim is not to reproduce the findings of these reviews which seek qualitative synthesis of previous work. Instead we aim to quantitatively chart the evolution and dynamics of the field through a co-citation analysis (See Trujillo and Long, 2018), a means of understanding the transdisciplinary interactions between researchers studying consumer food waste. Specifically, we pose the following three research questions:

RQ1: Are consumer food waste articles heterogeneous in their framing?

Given the recent surge of academic research on consumer food waste, we are interested in understanding how varied the framings of these studies are, and whether these framings concentrate across discrete academic disciplines and journals. We use Latent Dirichlet Allocation (LDA) - a computational topic modelling approach, to unravel the hidden thematic structure and framing (conceptual, theoretical or epistemological perspective) of a corpus of journal abstracts (Blei, 2012). Topic modelling algorithms such as Latent Dirichlet Allocation (LDA), Latent Semantic Analysis (LSA) and Non-negative Matrix Factorization (NMF) have been used for capturing underlying structures for various applications, including identifying key topics in technology and innovation (Lee and Kang, 2018), recommending scientific articles (Wang and Blei, 2011), or discovering daily routines from mobile data (Farrahi and Gatica-Perez, 2008). LDA has proven particularly useful for automatically extracting 'semantically meaningful decompositions' from large volumes of text data (Chang et al., 2009:1). LDA generates a joint sample from two underlying distributions - one representing the proportion of topics for each document and the other representing the probability distribution of topics across the words in the corpus (Blei, 2012:79). Topics, in this case, are collections of dominant words that explicitly represent the content of the abstracts in the corpus, with each abstract expressing multiple topics to varying degrees.

RQ2: Do consumer food waste articles connect into transdisciplinary citation and co-citation networks?

In the past decade, the topic of 'consumer food waste' has seen dramatic growth, with numerous existing literature reviews particularly focused on food waste in the household. Little is known, however, about the coming together of disciplines, and the cross-pollination of methods, concepts, or research frameworks. Drawing on bibliometric research, we use co-citation analysis to identify and describe transdisciplinary connections focused on consumer food waste. Ultimately, analysing these cross-disciplinary connections 'enables identification of relevant literature and scholarly communities that may be overlooked in standard approaches to literature searching', helping to visualise gaps in scholarly knowledge, and expedite 'knowledge integration' and 'consilience across disciplines' (Trujillo and Long, 2018: 1).

RQ3: How have the citation practices of consumer food waste articles evolved over time?

Bibliometric methods are often used to unravel 'the structure and the process of scholarly communication' represented in the form of networks (Meireles, Cendon and de Almeida, 2014:148). While co-citation clusters

correspond to thematic structures in the scientific literature, transformative changes can also be identified via specific structural and temporal properties of citations. Critical transitions in the historical development of a field can be found by looking for articles that (1) rapidly accrue citations and (2) connect 'otherwise disparate patches of knowledge' (as theorised by Chen *et al.* and captured in the 'sigma' metric - Chen *et al*, 2009, Chen, 2006). Chen *et al*.'s metric extends structural hole theories to imply that an article with a high citation count may continue to get more citations over time but does not necessarily introduce novel contributions to the field. A transformative scientific contribution, on the other hand, would '*span over an intellectual structural hole'* (Chen et al, 2009:13) and bring fresh insights to an existing field, as denoted by its high betweenness centrality (Freeman, 1977) and burstiness of citations over time (Kleinberg, 2003).

Methods: Data collection and identification, screening, eligibility, and inclusion of articles

We draw on Principato's (2018, p.4) definition of consumer food waste, which itself derives from multiple sources (HLPE, 2014; Gustavsson *et al.*, 2011) and refers to consumer food waste as "*food appropriate for human consumption being discarded or left to spoil at consumer level - regardless of the cause. At later stages of the food supply chain, the term food waste is applied and generally relates to consumers' behavioural issues"*. In this conceptualisation consumer food waste occurs through two modes: *Household* and *Away from home.* Household food consumption refers to *"all the sources of food and drinks that are consumed within the home, including retail and contributions from home-grown food and takeaways"* (Parfitt *et al.* 2010, p3073). Away from home refers to "*(i) the restaurant industry, which includes restaurants, bars and cafeterias that offer table service, along with (ii) catering services, that is food served within private or public canteens, catering and hotels, and (iii) within counter service and fast food"* (Principato, 2018, p.5). Away from home food waste happens on two levels: preparation and service (or consumption), the latter of which forms the focus here.

Following this definition we performed a keyword search which focused on the more explicit term "consumer food waste" but also instances of "food waste" paired with "consumer behaviour" OR "consumer behavior" (UK/US spelling). One dominant academic database (Google Scholar) was explored to identify articles on consumer food waste. Previous research has shown that Google Scholar is the most comprehensive and

exhaustive academic search engine in terms of number of articles *and* citations mapped between them (Gusenbauer, 2018), which are both critical to the method of co-citation analysis performed as part of the review.

As described in Figure 1, a total of 10,290 records were identified through the Google Scholar keyword search and matched with their abstracts, authorship and publication information on Semantic Scholar. Each article returned as part of the search corpus was screened for retrievability, duplicates and English language, leaving 8,651 unique records. For each article returned as part of the search corpus, a series of eligibility criteria were applied: (1) has it been cited at least 3 times?; (2) does the work have a consumer focus?; (3) has it been co-cited at least 2 times?; (4) is it peer-reviewed?; (5) does the work citing it have a consumer focus? Articles were excluded if they: (1) provide summaries or evaluation of food waste across all sectors of a society (e.g. a nation) or throughout entire supply chains, with consumption only incidental to the analysis and/or the study does not examine the relationship between production and consumption explicitly; (2) focus on the managerial issues related to retailing and distribution, rather than how retail changes might affect consumer behaviour directly through, for example, a consumer focus in the empirical work; or (3) focus on food packaging waste or extending the life of products before they reach consumers, unless the primary emphasis is on consumer food waste or the effects of packaging on consumer food waste. These eligibility criteria left 215 unique articles and abstracts for inclusion in the analysis stage, including co-citation analysis, analysis of transformative changes in the literature and topic modelling of article abstracts.

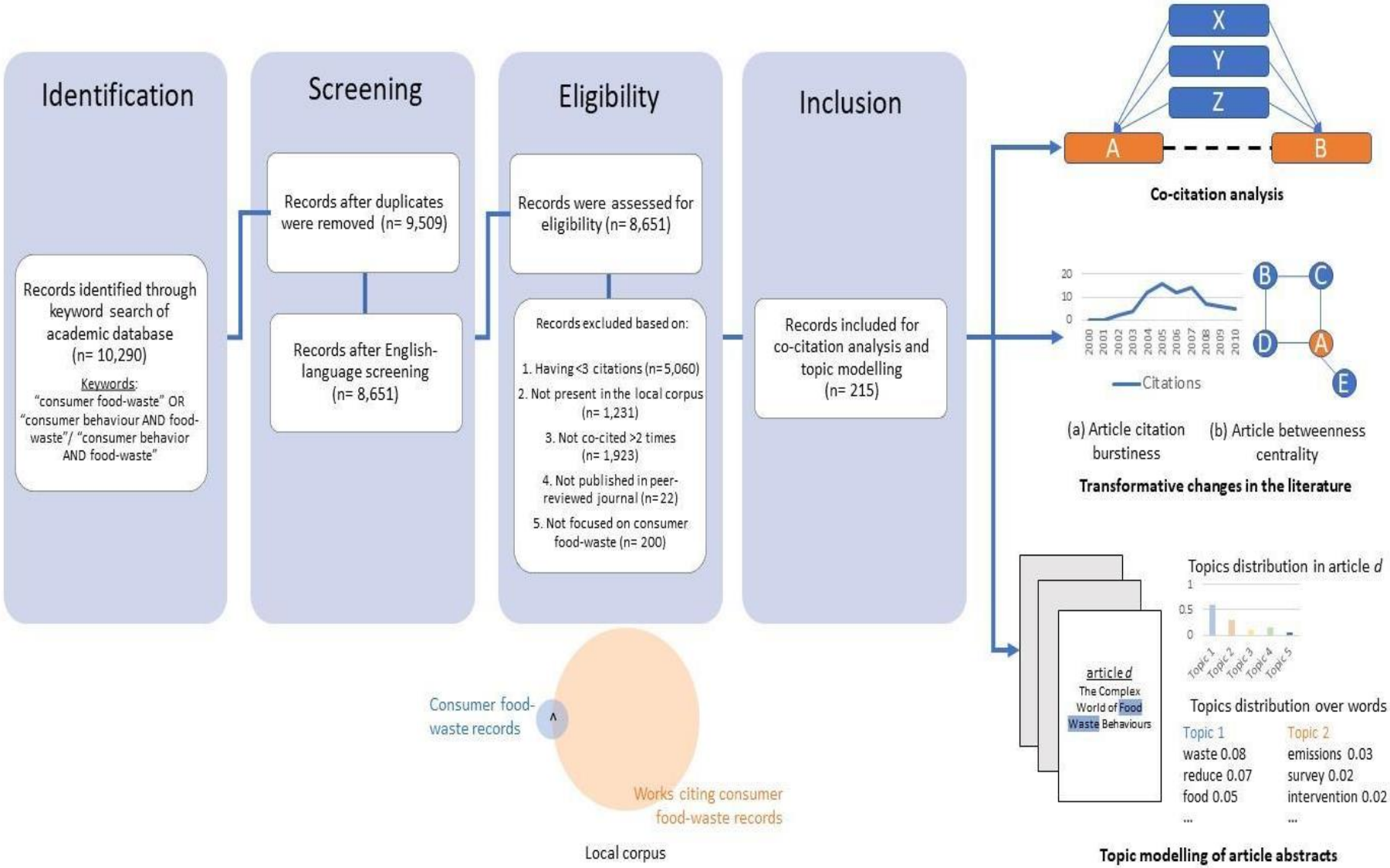

Figure 1 - PRISMA flow diagram for the identification, screening, eligibility, and inclusion of articles (Moher et al., 2009)

Topic modelling

We used Latent Dirichlet Allocation (LDA) to unravel the hidden thematic structure and framing of a corpus of 215 journal articles, using the Gensim package from the Python programming software (Řehůřek and Sojka, 2011). Since an article's abstract typically summarises the background, objective, methodology and findings of the study, we used each article's abstract as input for LDA, as visualised in Figure 1. Prior to performing the topic modelling, the abstracts were pre-processed to reduce the noise in the text. We started by transforming all characters into lowercase. As the word frequencies in the corpus followed a power-law distribution with a small number of words accounting for a sizable portion of the corpus (Zipf's law, 1932), we proceeded by removing redundant words. These included stopwords - articles and prepositions, which don't hold semantic meaning, as well as frequent occurrences present in more than 30% of abstracts (e.g., 'consumer'), which would have limited the interpretability of the results. Punctuation and digits were also removed, and the next step involved lemmatisation. This process reduces the words in the corpus to their roots (e.g., *consumers* to *consumer*, *reducing* to *reduce*), helping limit the dictionary of words to a manageable size, whilst maintaining word meaning and interpretability (Manning, Raghavan and Schutze, 2008). The final pre-processing step was to transform the abstracts into bags-of-words, which represent each abstract by the frequency of its words. These representations provide 'coarse summaries' of the abstracts in the corpus by retaining word co-occurrences and relative frequencies, rather than word order (Roberts, Stewart and Airoldi, 2016: 988).

Given the inductive nature of this enquiry, we then set out to identify the most likely number of topics or frames present in the corpus of abstracts. In order to determine the number of topics *k*, we varied it from 1 to 100 in stepped increases of 3, with the model automatically learning the best values for the model parameters as it is trained on more and more data, and optimised an objective metric called coherence score. One commonly used metric is the perplexity - or how well the model predicts a previously unseen document. It has been shown, however, that model perplexity is an unreliable metric of model performance, even having a negative correlation with model interpretability (Chang et al., 2009). Alternatively, measures of the internal coherence of topics have been shown to correlate with human interpretations of topic quality. These are based on how often the most probable words of a given topic actually co-occur close to each other in the original documents (Mimno et al., 2011). After testing different *k* values, we decided to use 5 topics identified after 10 passes through the entire

corpus, corresponding to high U-Mass and CV-coherence scores. Topic interpretation - one of the most challenging tasks in topic modelling is labelling and interpreting the emerged topics. As labelling topics based on their most frequent words is not always straightforward (Lee and Kang, 2018), the interpretation was carried out by two of the authors who independently read the 215 abstracts and ratified the topic selection and labelling. These 5 topics serve as the basis of the subsequent interpretation in this study.

Co-citation network analysis

Document co-citation analysis (DCA) was used to describe transdisciplinary connections focused on consumer food waste and to identify transformative changes in the scientific literature. Drawn from the final sample of 215 articles, DCA measured the frequency of jointly-cited articles. Figure 1 visualises the steps taken to draw a co-citation network from bibliographic data. Articles X, Y and Z jointly cite documents A and B, with the dashed line connecting these jointly-cited articles being weighted by the number of times articles were cited together. In this case, we only kept nodes that had been co-cited at least 2 times, as it helped reveal articles that corresponded to coherent thematic foci and had received peer recognition (Trujillo and Long, 2018). To identify critical transitions in the development of the field, we then calculated the betweenness centrality and sigma metric for each article in the final corpus in 1-year increments.

Results and Discussion

The first paper to meet the inclusion criteria for the final (local) corpus appeared in 2009 and was the only paper published in that year. Only a single other paper was published in the following year too, but following these initial years the number of papers grew quickly, culminating in 59 papers published in 2018. In 2011 the local corpus accrued only 4 citations within a year, yet only 8 years later in 2019 this had exploded to over 1422 citations per year. The sharp growth witnessed in these figures illustrates the surge in academic attention given to consumer food waste in the past decade.

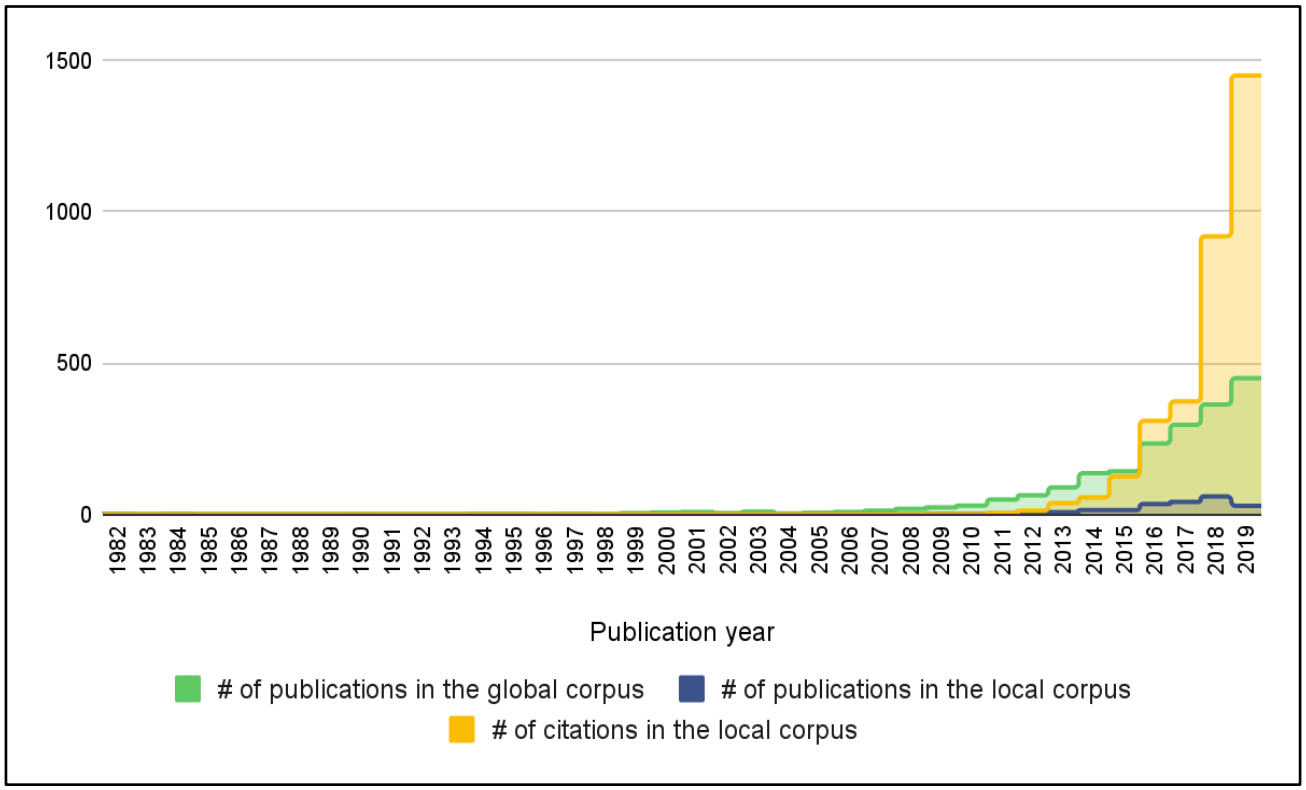

Figure 2 - Publications and citations in the consumer food waste corpora (global and local)

The global corpus (articles that mention consumer food waste but do not meet all inclusion criteria), exhibits occasional publications from 1982 onwards, but these are rare and typically number no more than one per year until the early 2000s. A dramatic increase in the number of papers published focused specifically on consumer food waste (local corpus) occurred in 2015. A similar sharp spike in citations accrued in 2017 onwards (the lagging is likely attributable to lengthy academic review and publications schedules). Though there are many contributing factors, one of the leading drivers of academic interest appears to have been the publication of the UN's Sustainable Development Goals, which were released in 2015. Since that year a large number of articles

can be found in the global corpus mentioning SDGs (For example, articles mentioning "*SDG*" & "*consumer behaviour*" & "f*ood waste*" = 521; "*SDG*" & "*consumer food waste*" = 307; "*SDG*" &"*consumer behavior*" and "*food waste*" = 438). The upward trend shows no likely signs of diminution in the coming years, indeed further analysis reveals both a rapid quantitative increase in the number of papers being published on consumer food waste *and* the emergence of a broad heterogeneity of focal topics within the subfield. The simultaneous quantitative increase in papers and the emergence of qualitative variety is dramatic and resembles a kind of '*Cambrian Explosion*'. After decades of inactivity, we are now witnessing an intense burst of publications, as the issue takes on a new moral urgency.

Framing of Consumer Food Waste articles

Most articles within the corpus are empirical investigations (87%), with 6% synthesising existing ideas and concepts, and 7% presenting qualitative reviews of the consumer food waste literature. On average, conceptual papers attracted 30 citations per article, literature reviews - 25 citations, and empirical investigations - 19 citations. To gain further insight into the explosion of articles we examined the thematic framing of the articles included in corpus and how they concentrate across discrete disciplines and journals. The types of topics identified in the consumer food waste corpus can be categorised as themes, methods employed, empirical contexts being studied, or combinations of these. Through topic modelling we extracted and labelled 55 broad topics of consumer food waste research and their 10 most probable words. Table 1 illustrates these topics, showing significant words, indicative papers and journals in which each topic has the highest proportion (discrete assignment), as well as the number of articles within each topic and the respective citations accrued.

The corpus topics overlap in some instances, but the review shows that there are important burgeoning themes within the literature, these include: Studies identifying individual characteristics and attitudes towards food waste; Product and marketing solutions for reducing consumer food waste; Psychological and behavioural antecedents to food waste; Case studies and approaches for reducing food waste; and interventions / reviews of waste prevention behaviours. The present *Appetite* special issue features articles that cover the breadth of these topics and contribute to each respectively. We find that 33% of articles in the review corpus fall into the first topic, which tends to include articles with an empirical focus or critical discussion around the role of individual consumers in reducing food waste, whereas the remaining topics attract a similar number of publications

(ranging between 15-22% respectively). The associated citations across the topics are similarly balanced, suggesting that academic audiences for these topics are similarly broad, and that no single topic receives a disproportionate share of attention.

Topic	Significant words	Indicative papers	Interpretation	Share of articles	Share of citations
Topic 1	consumption, behaviour, increase, identify, analysis, factor household food, purchase, provide, level	Fanelli (2019); von Kameke and Fischer (2018); Aschemann-Witzel, Giménez and Ares (2019); do Carmo Stangherlin and Barcellos (2018); Principato, Secondi and Pratesi (2015); Evans (2012a)	Studies identifying individual characteristics and attitudes towards food waste, as well as factors that may help reduce the waste of food in the home. High proportion of articles in the *Journal of Consumer Behaviour* and Resources, *Conservation and Recycling* are about this topic.	72 (33%)	1,342 (31%)
Topic 2	product, provide, analysis, information, survey, base, intervention, household food, attitude, factor	Aschemann-Witzel and Peschel (2019); Boxstael et al. (2014); Filimonau et al (2017); Hall-Phillips and Shah (2017); Lazell (2016); Stancu, Haugaard and Lähteenmäki (2016)	This topic is about product marketing solutions (price, packaging) for changing individuals' attitudes and behaviours towards the wastage of food - in and away from the home. *Journal of Food Products Marketing* and *Food Quality and Preference*.	32 (15%)	795 (18%)
Topic 3	behavior, different, level, household food, price, consumption, impact, perception, model, practice	Aschemann-Witzel et al. (2017); Symmank, Zahn and Rohm (2018); Aschemann-Witzel et al. (2019); Djekic (2019); Farr-Wharton, Foth and Choi (2012); Quested, Parry, Easteal and Swannell (2011)	Case studies and approaches for reducing food waste, including motivating food waste avoidance, strengthening consumer abilities, as well as altering consumer food choice contexts and raising awareness of the issue. The majority of articles in *Appetite* are about this topic.	33 (15%)	820 (19%)
Topic 4	social, reduce food, survey, base, shop, household food, behaviour, significant, product, factor	Østergaard and Hanssen (2018); Szabó-Bódi, Kasza and Szakos (2018); Young et al. (2017); Filimonau et al. (2020); Koivupuro et al. (2012); Jansen, Vries, Boer and Kremer (2017)	Psychological and behavioural antecedents to food waste frequently published in the *International Journal of Consumer Studies* and *Journal of Food Products Marketing*.	30 (14%)	505 (12%)
Topic 5	social, intervention, behavior, consumption, factor, model, behaviour, home, change	Cox et al. (2010); Lim et al. (2017); Aschemann-Witzel, Giménez and Ares (2018); Evans (2018); Michelini, Principato and Iasevoli (2018); Evans, Welch and Swaffield (2017)	Reviews of waste prevention behaviours across the stages of food management - planning, in-store, consumption and disposal. Frequently published in *PloS ONE*, *International Journal of Consumer Studies* and *Food Quality and Preference.*	48 (22%)	860 (20%)

Table 1 - Consumer food waste topic descriptions

When averaging topic assignments across the journals in the corpus, we found that some of the publishers were more similar to each other in terms of topic distributions. Figure 3 (A) shows the heatmap of journal similarity based on topic distributions in journals with at least 2 consumer food waste articles via a dendrogram obtained from hierarchical clustering. Cluster 1 includes *Appetite*, and the *Journal of the Association for Consumer Research*. Cluster 2 features *Environment, Development and Sustainability*, *Italian Review of Agricultural Economics* and *Trends in Food Science and Technology*. Cluster 3 includes *Resources, Conservation and Recycling*, *Waste Management*, *Sustainability*, and *British Food Journal* - with a strong environmental focus. Cluster 4 includes *Journal of Cleaner Production*, *Food Quality and Preference*, *Waste Management and Research*, and *PloS ONE* - with wider thematic focus.

Figure 3B illustrates discrete topic assignments across the most prolific journals within the corpus. The results demonstrate that the highest-ranking journals do not simply publish the most consumer food waste articles they also cover the full breadth of emergent topics. For example, the top 5 journals have published on all 5 topics, which suggests that there is limited disciplinary confinement to the study of consumer food waste, and that those articles within publications which themselves have an openly multi- or interdisciplinary focus are attracting the greatest share of academic readership and impact.

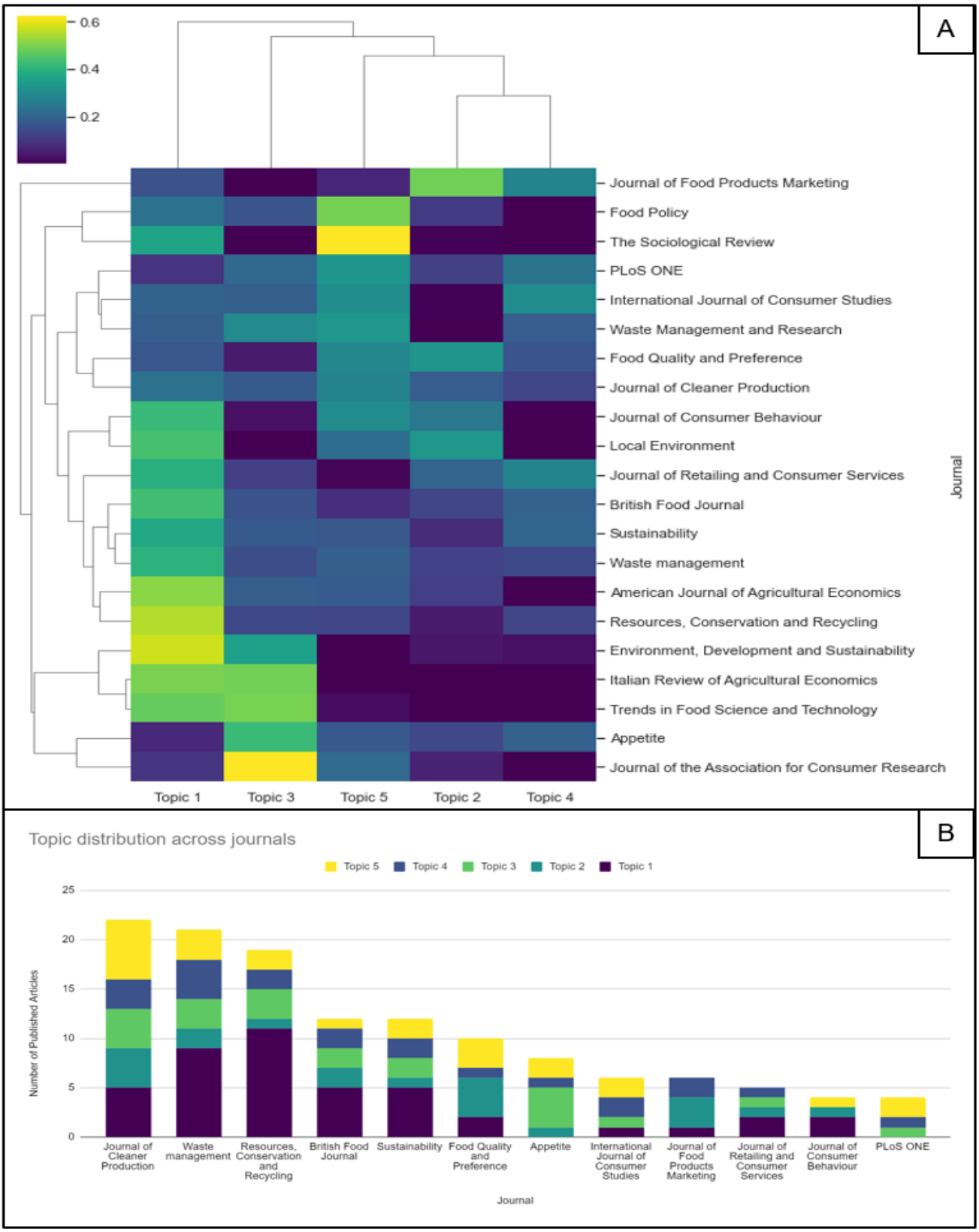

Figure 3: (A) Dendrogram showing clusters of publishers based on *fractional* topic assignments averaged across 23 journals in the corpus with at least 2 consumer food waste articles (B) *Discrete* topic assignments across top journals in the corpus (frequency of articles published)

Transdisciplinary Citation and Co-citation Network Analysis

The second research question concerns the structure of the citation and co-citation networks resulting from the consumer food waste search corpus. Key insights were gained through an exploratory network analysis and visualisation using specialised software, including Python's *networkx* library and Gephi (Bastian, *et al.,* 2009). Among the 215 papers specifically focused on consumer food waste, 77 (36%) accounted for 80% of citations. Some seminal articles including Quested et al. (2013), Stefan et al. (2013), Graham-Rowe, Jessop and Sparks (2014), Stancu, Haugaard and Lähteenmäki (2016), and Aschemann-Witzel et al. (2015) accrued 20% of citations in the past decade, covering all of the key topics, as can be seen in Figure 4. The network visualisation presents a radial axial layout whereby articles are represented as nodes, which are sized and sorted in a circular distribution according to number of co-citations (edges) and coloured according to discrete topic membership. The figure demonstrates that the topics identified span across the full distribution and no single theme dominates.

The average degree in the citation network of all records is 8.66 (+/-16.49). Further examination of in-degree (number of times an article was cited, M= 4.33 +/-14.62) and out-degree (number of times an article cited others, M= 4.33 +/-6.44) indicates that the network is generally balanced and shows a very weak assortative structure (degree assortativity coefficient of 0.067). This indicates that frequently cited articles are slightly more likely to connect to each other, but also accrue more citations over time. To further explore aspects of interconnectivity in the citation network, we interrogated its level of clustering, which shows how cohesively articles are connected with each other (Watts and Strogatz, 1998). At a network level, the clustering coefficient is the average likelihood of two documents citing a third article also being cited together, or directly connected by a network tie (Newman et al., 2002). In this case, the consumer food waste citation network showed low clustering (0.064) and a small number of weakly connected components, which is common in transdisciplinary communities (Xian and Madhavan, 2014). Extending this finding to discussions around innovation in scholarship, we believe that there are both benefits and limitations to scientific knowledge embedded in less clustered networks. Articles in a less clustered network may not benefit from the stable structure, trust and sharing that typically occur in more clustered networks (Uzzi and Lancaster, 2004). The higher the clustering, however, the more prone networks are to recirculating redundant information, limiting 'the chance of

discovering novel recombinations of knowledge', and creating 'entry barriers for outsiders with heterogeneous knowledge background' (Shi and Guan, 2016:328).

Of the 2,360 articles resulting from the consumer food waste search corpus initially included following eligibility screening, 437 were co-cited at least 3 times, with a final sample of 215 records being included for further analysis on the basis of peer-review and consumer focus (criteria 3, 4 and 5). Document co-citation analysis (DCA) was used to describe transdisciplinary connections focused on consumer food waste and to identify transformative changes in the scientific literature. Drawn from the final sample of 215 articles, DCA measured the frequency of jointly cited articles. The structure of the network is slightly disassortative (degree assortativity coefficient of -0.161), while showing moderate clustering (clustering coefficient of 0.669). While the former indicates that co-citations mostly occur between articles with different levels of popularity, the latter may indicate the thematic homogeneity of the final corpus.

A similar accumulation of knowledge can be observed in the case of the most frequently cited journals, with 18 (20%) of journals accruing 80% of citations. The citation distribution across journal titles demonstrates 10 journals capture 50% of publications: the *Journal of Cleaner Production* and *Waste Management* each account for 10% of articles, *Resources, Conservation and Recycling* - 8.6%, *British Food Journal* and *Sustainability* 5.5% each, *Food Quality and Preference* 4.6%, *Appetite* - 3.6%, *International Journal of Consumer Studies*, *Journal of Food Products Marketing*, *Journal of Retailing and Consumer Services*, and *PloS ONE* - between 2-3% of articles. The highest ranked journals in citations and co-citations are largely similar in rank order, though there are a few outlier journals within the top 20 that have achieved higher co-citation scores relative to their citations suggesting that they are achieving proportionally higher transdisciplinary relevance, knitting different social scientific disciplines more effectively. This is particularly true for *British Food Journal; Journal of Consumer Behaviour; Journal of the Association for Consumer Research; Journal of Food Products Marketing;* and *Local Environment*, each of which achieved especially high co-citation scores relative to their overall citations. The long-tailed nature of both the citation and co-citation distributions are similar to other social and technological networks (Albert and Barabási, 2002; Harvey et al, 2020). What stands out, however, is the recent rapid growth in this area of research in the past 5 years. The rapidity of growth raises further questions about the field's structural and temporal properties, which we now examine in depth.

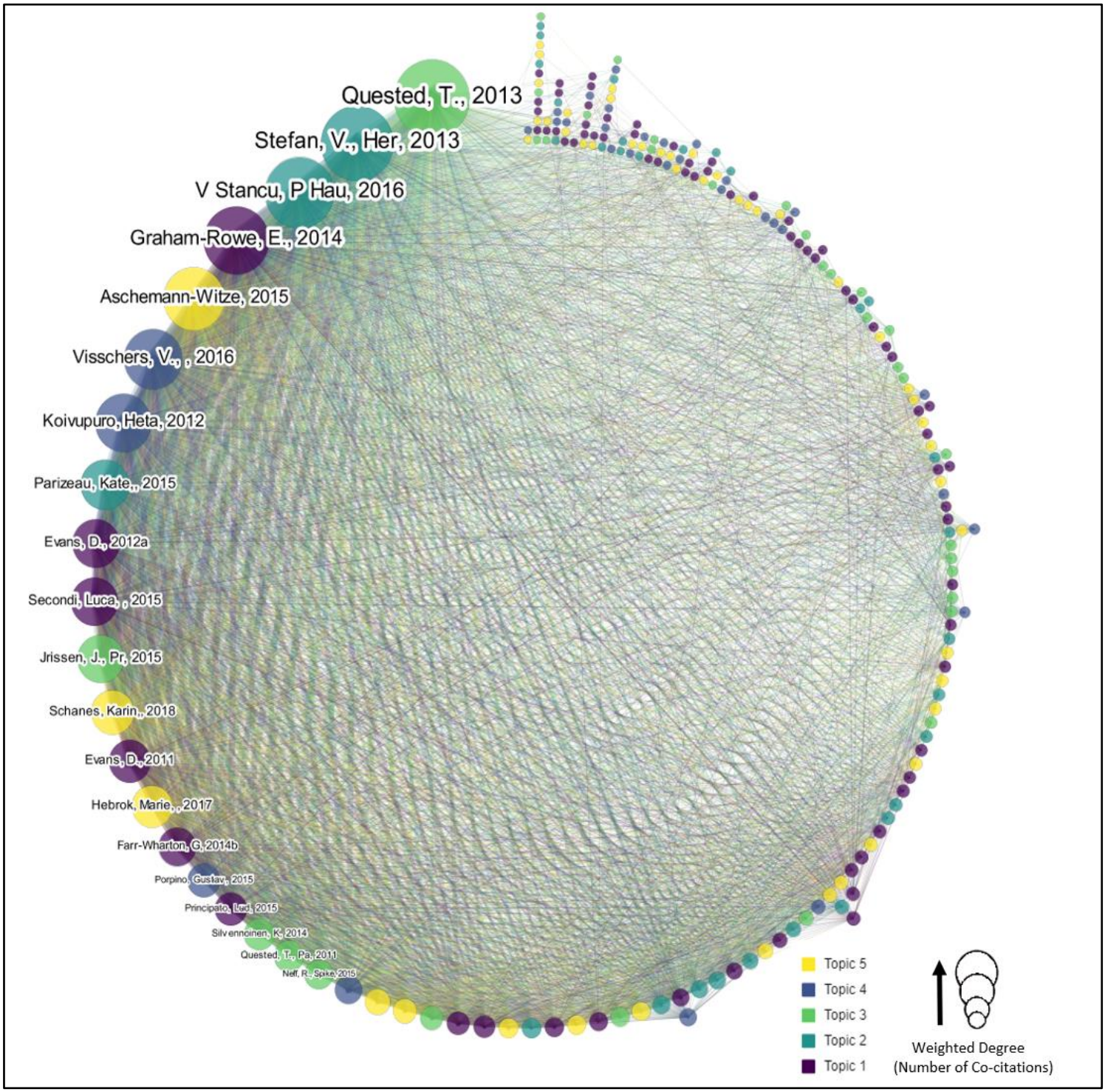

Figure 4: Co-citation network of individual papers

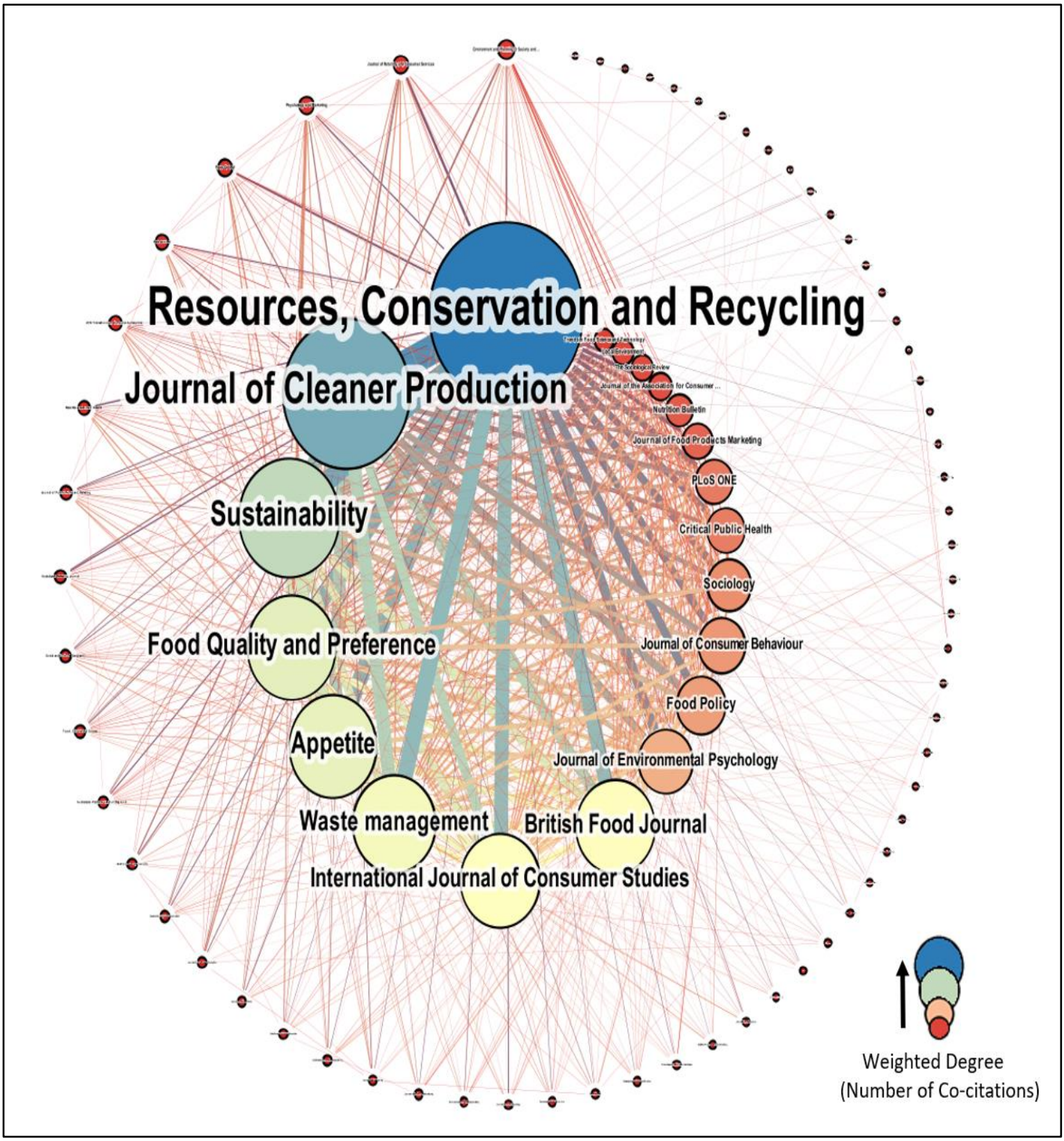

Figure 5: Co-citation at journal level

The Evolution of Consumer Food Waste Literature

This question is concerned with identifying critical transitions in the history of the development of the consumer food waste field by looking for articles that (1) rapidly accrue citations and (2) connect 'otherwise disparate patches of knowledge' in the co-citation network (Chen et al, 2009:1). This measure assumes that each paper in the co-citation network conveys an idea, and joint citations between two papers indicate a relation between them. As papers become jointly cited more frequently the sigma metric captures the connection of ideas present in a field, as well as the speed at which critical transitions happen. We used Python's bibliometric library *Tethne* (Peirson et al, 2016) to calculate the burstiness and betweenness centrality of each article in the co-citation network, and to estimate the sigma metric over a period of 9 years, from 2011 until 2020 (Chen et al, 2009). Figure 4 illustrates the top 50 articles identified as transformative for the study of consumer food waste in the past decade, sorted by their year of publication, with the height indicating the normalised number of citations received in a given year, and the colour indicating their sigma value.

In the years preceding 2015 sigma scores within the corpus were extremely low. Some papers garnered a high number of citations, particularly those of a more critical sociological focus (e.g. Evans, 2011, 2012a), but as few papers had high betweenness centrality in the co-citation network, this indicates the citation practices around consumer food waste at that time were highly fragmented and largely confined to specific disciplines. After the 2015 surge in published articles and citations we see that the papers with the most citations also yield the highest sigma scores across each respective topic (when modelled discretely rather than fractionally), suggesting that these papers had, and continue to have, a seminal effect on transdisciplinary citation practices more broadly. The highest sigma scores across 2016 and 2017 (Quested *et al.,* 2013; and Koivupuro *et al.*, 2012) cover topics 3 and 4; in 2018 (Visschers *et al.,* 2016; and Graham-Rowe *et al.*,2014) cover topics 4 and 1; in 2019 (Aschemann-Witzel *et al.*, 2015; and Stefan *et al.*, 2013) cover 5 and 2; and in 2020 (Stancu *et al.*, 2016; and Visschers *et al.*,2016) cover 2 and 4. Of the top 50 yearly sigma scores in the corpus we note that 48 are from papers with three or more authors, suggesting that regardless of focal topic, the truly transdisciplinary impact of consumer food waste research is heavily team-driven.

Despite having the lowest number of published articles and citations within the corpus we find that those articles

with the highest sigma in *Topic 4* (typically focused on the psychological and behavioural antecedents to food waste) and *Topic 2* (which tend to emphasise intervention or changing individuals' attitudes and behaviours towards the wastage of food), have nonetheless had a wide transdisciplinary impact. These papers offer promising contributions for transdisciplinary knowledge that can help solve the practical challenges of reducing consumer food waste. Such a focus seems likely to be increasingly important in the coming years given the climate impact of food waste, echoing the old Marxist idea that the point of good research philosophy is not merely to just describe or interpret the world, but to actually change it.

We also note that in the past few years the field has seen a notable increase in the number of published systematic reviews and summary papers focusing on consumer food waste. 66% of review articles in the corpus were published in 2017 or later and 91% of the total citations for review articles have occurred in that same period, suggesting that though the field has historically been dominated by empirical articles, it is now starting to show signs of maturity as a flurry of review papers help to consolidate knowledge. From 2017 onwards there is also a trend for co-citations to become more concentrated across a few key journals, suggesting that these journals are gaining a reputation for the study of consumer food waste. The right hand side of Figure 7 shows how the relative share of citations has concentrated into fewer and fewer publications over time. Just 12 journals captured 65% of citations in 2019 compared with 25% in 2013. This is in part due to: (1) the sheer number of publications published in some of the leading journals, which pursue a more aggressive publication schedule than many smaller outlets; and (2) a likely preferential attachment phenomenon whereby journals that have established a reputation throughout the past decade are cited more, and thus by virtue of their existing citations become more likely to receive more new citations.

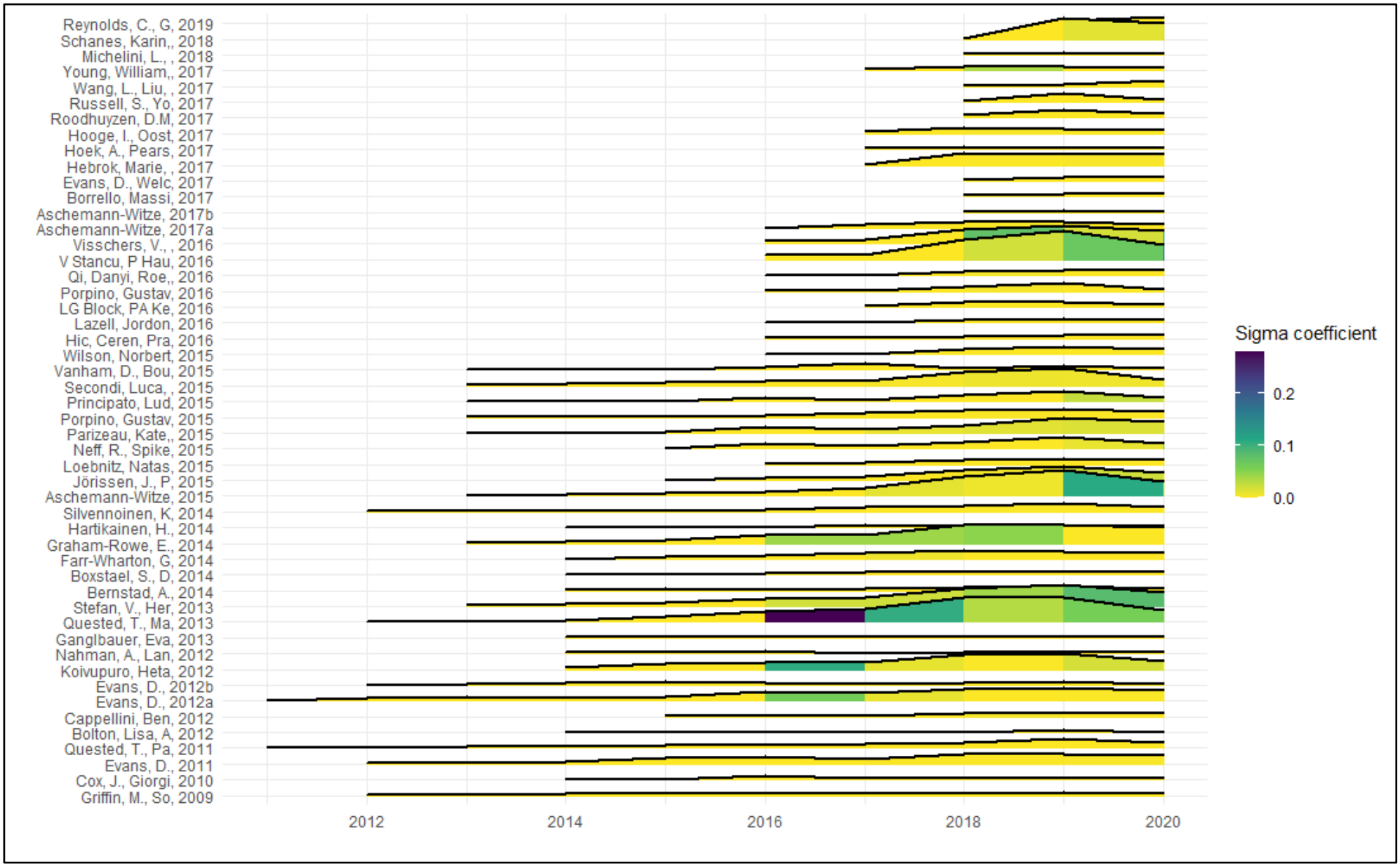

Figure 6: Article co-citation sigma timeline

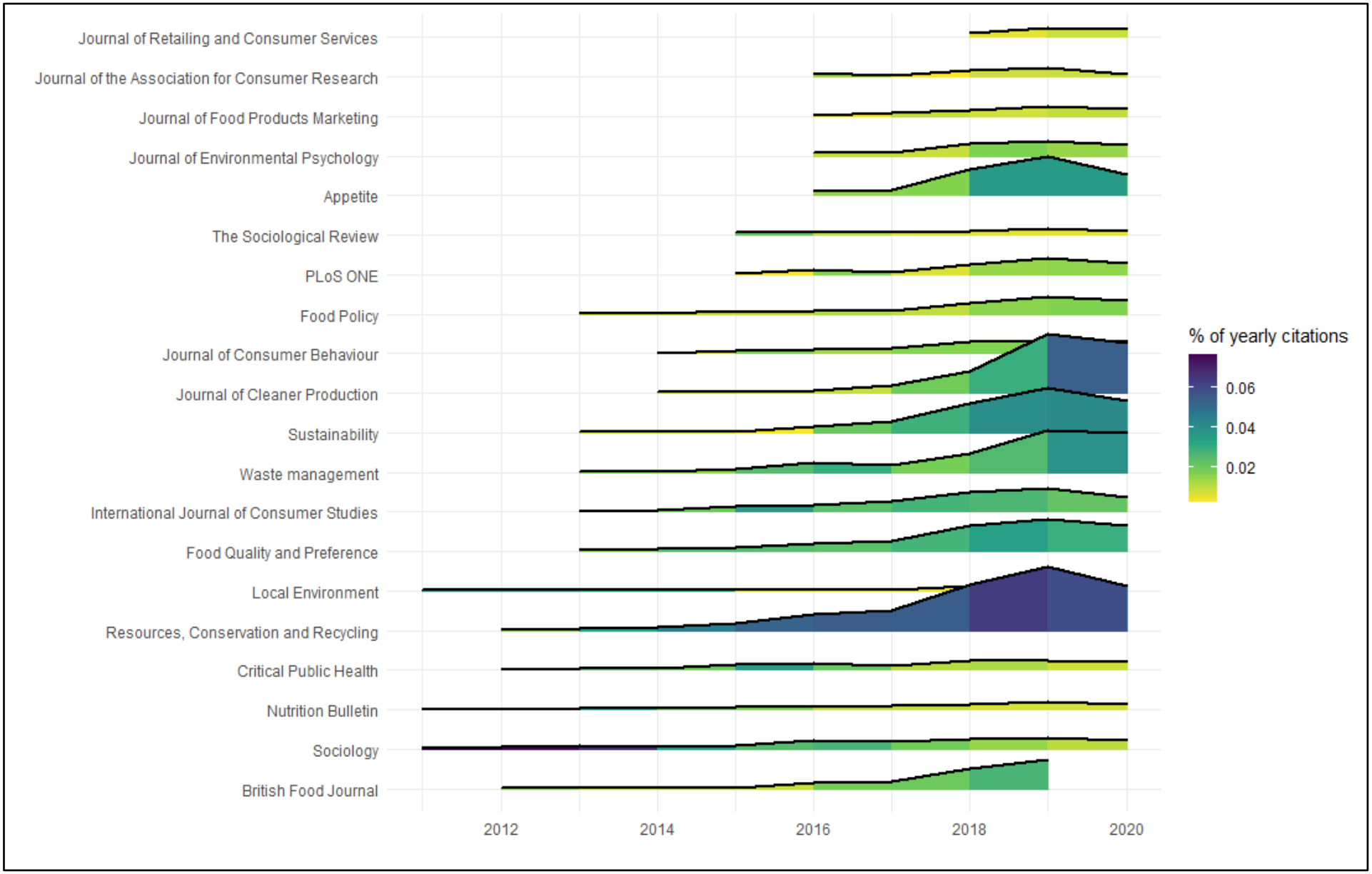

Figure 7: Journal co-citation frequency timeline

Limitations and Future Research

To the best of our knowledge, the review provides the first transdisciplinary co-citation analysis of the consumer food waste literature, but we nonetheless recognise there are some limitations both with the approach taken and with the corpus itself. Corpus generation depended on English keywords to initiate the review process and there is thus inevitably an Anglophone bias to the corpus, which may exclude contradictory narratives beyond the English-speaking world. Similarly, though additional care was taken to include as broad a starting corpus as possible of consumer food waste studies, there may be some extant literature that focuses on consumption in spirit if not in name, preferring instead to refer to it obliquely. Nonetheless, we hope that the insight we provide on the extant themes, connections and academic impact of articles within this body of research will help stakeholders in the research community to orientate of future work that seeks to generate novel and influential knowledge.

We also stress here that most of the final corpus - like much academic literature within the social sciences generally - has a WEIRD sampling bias i.e. Western, Educated, Industrialised, Rich, and Democratic (Heinrich *et al*, 2010). This is not strictly a limitation of the method chosen to conduct the review, rather the consumer food waste literature more broadly, which we believe should cause reason to pause and reflect about the inclusivity of this growing domain of research. If consumer food waste studies are to have a transformative impact on the way people eat around the world, the field should look to include empirical work, citations, and collaborations from further afield. Just as existential questions posed by World War 2 prompted international mobilisation efforts to reduce consumer food waste through the actions of individuals, so too the climate emergency requires global consideration of the varied and often inequitable roles that people play at meal times, regardless of where they live.

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