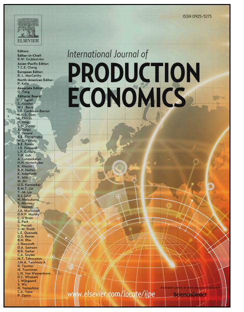

A Systematic Review of Research on Food Loss and Waste Prevention and Management for the Circular Economy

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Abstract

Circular Economy (CE) aims to retain the maximum value of products and materials for a longer time in a closed-loop manner, thereby decoupling natural resource usage from economic growth. Food waste reduction is one of the top priorities under the recent European Union's CE Package. It also contributes to achieving the United Nations' Sustainable Development Goals (SDG 12.3). While food loss and waste (FLW) prevention and management are well-studied in the literature, research in CE is more recent. Through a systematic literature review, this study creates a taxonomy that synthesises the key aspects of FLW under the CE. 297 papers were reviewed and analysed using keyword co-occurrence analysis (KCN) and structural dimension analysis. In KCN, three research themes emerge: impact assessment, biorefinery, and nutrient recycling. Structural dimension analysis reveals the types of research methods, types of FLW flows, FLW prevention and management options with associated opportunities and challenges, and the sustainability impact assessment (SIA) addressed in the literature. A taxonomy is presented and future research directions are highlighted under six research streams: i) FLW supply and quantification, ii) practices and technological aspects, iii) logistics and supply chain management, iv) market demand, v) SIA, and vi) policy and legislation. Combining insights from CE and FLW prevention and management, the taxonomy helps key stakeholders, including industry practitioners to grasp new business opportunities, politicians to set up support strategies and strategic development plans, society to recognise the benefits of waste-oriented bioeconomy, and consumers to raise their awareness and be actively involved in CE.

Highlights

- The proposed taxonomy is original because it takes a holistic approach to combine circular economy and food loss and waste.
- Six principles of circular economy integrated into food loss and waste prevention and management are recognised.
- A suitable list of sustainability impact indicators should be developed to evaluate the effective prevention and management routes.
- Policy and legislation play an instrumental role in shaping directions for food loss and waste prevention and management.
- Logistics and supply chain management, market demand and behaviours of involved actors require more consideration.

Keywords: circular economy, food waste management, biorefinery, sustainability, waste reduction, food redistribution

1. Introduction

A third of the annual food produced for human consumption (roughly 1.3 billion tons) is either wasted or lost along the food supply chain (FSC) (FAO, 2011; 2014). Food loss and waste (FLW) accounts for 24% of freshwater use, 28% of total global cropland area, 23% of global fertiliser use (Kummu *et al.*, 2012) and about 8% (3.3 Gtonnes of CO_2 equivalent) of total greenhouse gas (GHG) emissions (FAO, 2013). Halving the amount of FLW could contribute to reducing GHG emission from food production by 20-30% (Bajželj *et al.*, 2014). While about 10.7% of the world population (nearly 815 million) is undernourished (FAO *et al.*, 2018) and by 2050 9.6 billion people will need to be adequately fed (United Nations, 2017), wasting foods represents a contemporary economic, environmental, social and ethical challenge on a global scale, which requires urgent political attention (FAO, 2013; Teigiserova *et al.*, 2020). One of the novel efforts in preventing and managing FLW is the adoption of the circular economy (CE) concept that has been supported in the EU political agenda (European Commission, 2015). FLW prevention is identified as the top priority and an integral part of an EU Action Plan for its transition towards the CE. The CE Action Plan not only puts forward a series of actions to promote more sustainable production and consumption behaviours and patterns in EU food system, e.g. food donation and labelling awareness, but also fosters the adoption of bio-technologies and practices to convert FLW into a variety of valuable bio-based products for long-term socio-economic and environmental benefits (Maina *et al.*, 2017; Zabaniotou and Kamaterou, 2019). In the Action Plan, a common EU methodology for FLW quantification is also proposed to ensure the consistent quantification, monitoring, and analysis of FLW statistics. These measures support the EU on its trajectory towards meeting the United Nations' Sustainable Development Goal (SDG 12.3) to "*by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses*" (Flanagan *et al.*, 2018).

As the instrumental role in the transition towards the CE, FLW has gained momentum in the CE-related academic discourse with exponential growth in related publications over the last five years (Kyriakopoulos *et al.*, 2019). To better position our study and highlight our contribution to this significant and ever-increasing published research base, we have examined a considerable amount of extant literature that deals with FLW in the CE. Appendix 1 presents a summary of these studies, providing authors' names, year of publication, the number of articles reviewed and main focuses in term of stages of the supply chain, waste prevention and management options, and the considered evaluation criteria. The earliest was published in 2014. This extensive list is grouped into seven focused topic areas: *(i)* FLW conversion technologies *(ii)* biorefinery models *(iii)* life cycle assessment (LCA) methods for FLW prevention and management routes (*iv)* methods for quantifying the FLW flows *(v)* FLW-related policies *(vi)* the FLW hierarchy framework *(vii)* FLW prevention behaviours. The difference between the first two topics lies in the cascading concept, where the former focuses on a specific technology, while the latter aims at a combination of multiple technologies for a plethora of outputs. Although the prior literature reviews represent the crucial starting point for our study, two limitations are identified. First, their focus is constrained to a specific topic area, predominantly focused on technological feasibility in a fragmented manner. Since FLW in the CE thinking is a complex and multi-faceted issue that cannot be attributed to a single variable (Schanes *et al.*, 2018; Kyriakopoulos *et al.*, 2019), a singular or micro perspective is not recommended. Otherwise, the CE discourse is simply a refurbished notion of the triple R principle – reduce, reuse, recycle, where a single solution is chosen according to the environmental criteria (Cristóbal, Castellani, *et al.*, 2018; Ingrao *et al.*, 2018), while economic and social evaluations, as well as the optimal cascade of individual bioprocesses for the authentic transformation of the linear to the circular economy (Dahiya *et al.*, 2018) are completely neglected. Second, the review protocol in many cases is not illustrated. As such, most papers either do not mention the number of reviewed articles or review a limited set of articles with unclear selection criteria. This narrative method of synthesising previous studies is criticised as being devoid of replicability, transparency and thoroughness and thus can be biased by the researchers in making sense of extant literature (Tranfield *et al.*, 2003). We, therefore, attempt to overcome these limitations.

As shown in Appendix 1, our scope includes the above-mentioned topic areas in order to provide a comprehensive literature review. We considered 297 articles published in all areas of focus and all stages of the supply chain, irrespective of the chosen FLW prevention and management options that are linked to the CE and FLW. We have chosen a systematic literature review (SLR) method over other review approaches because of its replicable and transparent process, which contributes to giving a balanced and unbiased result (Tranfield *et al.*, 2003). The main objectives of this extensive review are threefold: *(i)* to offer an analytical overview of existing research relying on bibliometric tools, such as keyword co-occurrence analysis; *(ii)* to carry out the structural dimension analysis on research methodology, FLW types, FLW prevention and management options with the associated opportunities and challenges, and sustainability assessment indicators; *(iii)* to derive a taxonomy framework for the classification of the critical aspects of the reviewed papers and offer potential future research avenues.

After the introduction, the paper proceeds as follows. Theoretical background (Section 2) sheds light on the FLW definitional scoping, concept of CE and its relevant principles in FLW prevention and management. The SLR methodology is presented in Section 3, which is followed by a keyword co-occurrence network analysis to identify emerging research themes (Section 4) and structural dimension analysis to critically appraise different relevant dimensions (Section 5). The discussion (Section 6) encapsulates current research lines and proposes the research agenda. The conclusions and limitations of this study are presented in Section 7.

2. Theoretical background

2.1. FLW definitional scoping – A review boundary

Clearly stating the boundaries of the topic is essential when performing a SLR. This is of great importance due to a lack of consensus with reference to a precise definition of food loss and waste resulting in an interchangeable use of the concepts of loss and waste (FAO, 2019). The existence of multiple FLW definitions complicates the data collection and comparability of FLW levels (Corrado and Sala, 2018), challenges the measure of the distance towards the SDG 12.3 target (Teigiserova *et al.*, 2020), and hampers the analysis of FLW (FAO, 2019). FLW definitions are different in two major aspects: the types of wastes (edible and inedible[1] parts of foods) and the boundaries in the FSC to be included (Corrado and Sala, 2018). For instance, FAO (2019, p. 4) define FLW as “the decrease in quantity or quality of food along the food supply chain”, but distinguish food loss from food waste based on the stages of the FSC. Food loss refers to the amount of the edible parts of crops, livestock and fish leaving the upper part of the FSC – from the post-harvesting, slaughtering, and catching stage up to but not including the retail stage – by being discarded or disposed of or incinerated (FAO, 2019). These stages typically consist of storage, transportation, processing and importing activities. Food waste arises at the downstream stages from retail to the consumption points. Of note, the FLW’s scope under the FAO’s conceptual framework excludes not only inedible parts of foods but also the edible foods that are destined to an economically productive non-food use, such as animal feeds or industrial use. FUSIONS (2014), on the other hand, does include both edible and inedible parts of foods in its proposed FLW definition, but it does not distinguish food loss and food waste. FUSIONS

[1] For example: shells, peels, bones, pulps, husks, leaves, pomaces.

(2014, p. 6) defined food waste as foods that "*are removed from (lost to or diverted from) the food supply chain*" and flow into nine destinations. FUSIONS (2014) also highlighted the difference between *food surplus* and *food waste*. Although food surplus is still a part of FSC and fit for human consumption, it would end up as waste if no prevention or reuse is carried out. As a result, prevention and redistribution to humans are only applicable to food surplus (Ng *et al.*, 2019). While the paper acknowledges differences between various concepts, the scope of FLW terminology used hereinafter in this review paper will encompass food losses, food wastes, edible and inedible portions of food loss and wastes as well as food surplus that arise from all stages of the FSC.

2.2. Circular economy concept

A circular economy is defined as "*an industrial system that is restorative or regenerative by intention and design"* (Ellen MacArthur Foundation, 2012, p. 7). According to Bocken *et al.* (2016), the CE includes strategies for closing, slowing or narrowing resource loops. Closing completes a resource circle by connecting the post-use of a resource with the production stage via recycling, while slowing loops reduces the speed of resource flow by extending the in-use period with long-life design and/or maintenance, repairs, remanufacturing services. Finally, narrowing the loop means lowering resources embedded in each product.

The CE concept cannot be traced back to any particular authors or dates but is rather considered as the synthesis of various schools of thought, prominently cradle-to-cradle philosophy, performance economy, blue economy, biomimicry, and industrial ecology (Ghisellini *et al.*, 2016; Geissdoerfer *et al.*, 2017; Merli *et al.*, 2018). The cradle-to-cradle philosophy fosters the superior design of products for longer use, continuous recovery and re-utilisation (McDonough and Braungart, 2010). This philosophy regards all materials made of two distinct types of nutrients: technical and biological. Food is classified as consumable products made of non-toxic and beneficial *biological nutrients* that can be safely re-introduced to the biosphere, either directly or via a cascade of consecutive use, to build natural capital. This biological metabolism is in contrast with durable products made of *technical nutrients* (e.g. polymers, alloys) that are not suitable for returning safely to the biosphere and should be designed with minimal energy and the highest quality retention. Building upon cradle-to-cradle philosophy, the CE also drives a shift in the material composition of consumable items from technical towards biological nutrients to make products serving a restorative purpose, e.g. via the use of bio-degradable instead of single-use food packages. Building on performance economy, the CE focuses on the products' performance, such as having an extended life cycle and consuming less energy and resources (Stahel, 2010). Adopting the blue economy principles, the CE encourages the use of resources in a cascading manner and promotes the use of one person's wastes as resources for others, as well as minimising resource leakage (Pauli, 2010). The cascade principle urges the sequential and consecutive utilisation of resources to maximise economic returns. For instance, food waste is used to extract bioactive compounds first before the residues of this process are used for lower value energy and composting production. Stimulated by biomimicry, the CE aims at emulating a natural self-sustaining ecosystem where the movement of biomaterials follows a continuous circular flow without wastes (Benyus, 2009). Take a tree as an example. The dead leaves are decomposed into minerals to be absorbed by the tree to generate new leaves circularly. Ideally, our food system can be designed following this natural regenerative mechanism. Essential nutrients (e.g. nitrogen and phosphorous) that have been taken by plants and animals can be fed back into the environment. Inspired by industrial ecology, the CE supports the establishment of the industrial symbiosis concept, which involves the mutually beneficial exchanges of materials, energy, water, and wastes between parties with geographic proximity to design out waste (Graedel and Allenby, 2003).

2.3. Circular economy principles in FLW prevention and management

The essence of the CE provided in section 2.2 can be translated into FLW prevention and management following six principles outlined below:

(i) Circling longer principle: To keep foods in use longer by extending their shelf-life and re-distributing surplus foods for human consumption, which contributes to lowering the amount of FLW generated (inspired by the cradle-to-cradle philosophy and performance economy)

(ii) Cascading principle: To maximise economic value extracted from all substances of FLW in a cascaded manner following the biomass value pyramid[2], rather than converting all food waste products into low-value energy generation (inspired by the blue economy)

(iii) Regenerative principle: To re-introduce the biological nutrients back into the soil; promote the generation of renewable energy from FLW to reduce intake of virgin materials; and ideally eradicate resource leakage associated with incineration and landfills (inspired by biomimicry).

(iv) Inner circle principle: To promote surplus prevention and surplus reuse, followed by recycling and recovery so as to minimise the need for tapping into new materials.

(v) Pure circle principle: To preserve a certain quality level in FLW collection via separation and to encourage the use of short-lived products made of bio-based instead of fossil-based materials, e.g. biodegradable plastics (inspired by cradle-to-cradle philosophy).

(vi) Industrial symbiosis principle: To promote the exchange of FLW as resources at the local scale and regional scale (inspired by industrial ecology)

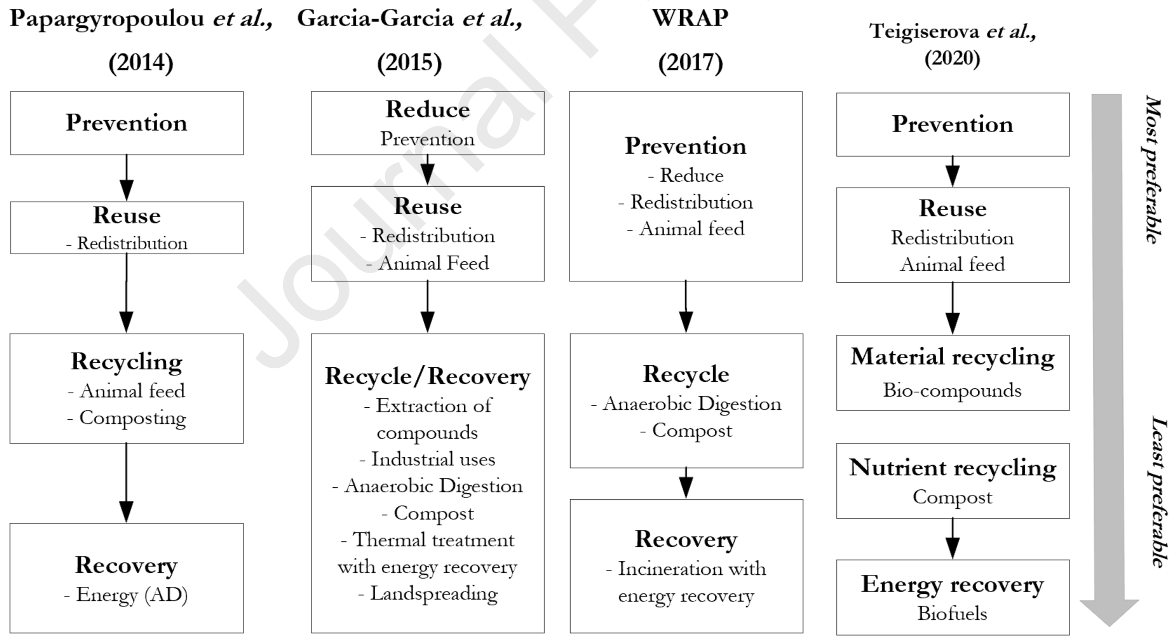


Figure 1: Food waste prevention and management options – Terminology review

Note: Disposal (landfill or incineration without energy returns) is not considered given that it represents resource leakage and should be eradicated (regenerative principle); WRAP: Waste and Resources Action Programme.

[2] Biomass value pyramid is presented in the paper of Berbel and Posadillo (2018) in the descending order of value as follows: fine and pharmaceutical products → food and feed → bulk chemicals → biofuels → composts → electricity and heat.

These underlying principles fundamentally transform FLW prevention and management under the CE landscape beyond the food waste hierarchy. The waste hierarchy, built upon the European Waste Framework Directive (WFD) dated back to 1975 (the current version in 2008 with an amendment in 2018), provides an order of preference for actions to reduce and manage waste (prevention→ reuse→ recycle→ recovery → disposal). This preference order is solely based on the overall environmental outcome. Although the hierarchy encourages the circling longer (prevention and reuse) and regenerative principle (recycle and recovery) of the CE, it disregards other principles, particularly the cascading principle where economic value is taken into consideration. In addition, the generic terminologies used in the waste hierarchy are open to different interpretations by users, especially when applied to a specific industry, such as the food sector (Teigiserova *et al.*, 2020), leading to discrepancies in the literature. To be consistent during the review process, we highlighted these discrepancies (Figure 1) and elucidated the meanings for different FLW prevention and management options used in this SLR. Our scoping encompasses both prevention and management of FLW, where the former is used to avoid food surplus generation while the latter refers to reuse, recycle and recovery. Reuse hereinafter only includes redistribution to people in the form of donations or food sharing, while recycling and recovery aim at converting FLW into a range of value-added products, following the biomass value pyramid. However, we are aware that a few studies might include the animal feed conversion option in reuse (Garcia-Garcia *et al.*, 2015; Teigiserova *et al.*, 2020), while prevention might consist of reuse, e.g. following the approach of the WRAP (House of Commons, 2017). This might be because both prevention and reuse aim to prevent surplus from turning into wastes. Notably, some papers such as Teigiserova *et al.* (2020), while distinguishing reuse from prevention, listed donation as a prevention initiative. Similarly, recycle and recovery options might not include the generation of higher value products, such as bioactive compounds (e.g. in Papargyropoulou *et al.* (2014) or WRAP (2017)). Finally, it is noted that two of the three resource management loops, the closing and slowing (extending and intensifying) resource loops, are firmly reflected in the FLW prevention and management. The third, namely narrowing the loop, is more pertinent to the forward food supply chain as it advocates more efficiency of production, distribution, and consumption activities. As such, narrowing the loops, though equally significant in the CE paradigm, falls outside the scope of this paper.

3. Research methodology

The SLR is a process of "*a systematic, explicit, and reproducible design for identifying, evaluating, and interpreting the existing body of completed and recorded work produced by researchers, scholars and practitioners*" (Fink, 2019, p. 6). The SLR enables a rigorous, impartial, and literature-wide assessment of extant studies' outcomes, quality and design. Following the seminal work for conducting the SLR by Tranfield *et al.* (2003) and the content analysis-based literature review method of Seuring and Gold (2012) that was built on the work of Mayring (2008), we organised our reviews in three phases:

(i) Material collection, which consists of the identification of keywords, construction of search strings, and choice of databases to be investigated.

(ii) Material selection and evaluation, which are designed to filter the relevant papers, known as "review sample", by applying a series of inclusion/exclusion criteria. An initial screening is carried out to observe the distribution of the review sample scientifically, chronically, and geographically.

(iii) Material evaluation, which aims at the appraisal of keywords and the relevant structural dimensions:

- A keyword co-occurrence network (KCN) is a powerful visualisation tool used to discover the research fronts by examining and visualising the links between keywords in the literature (Liu and Mei, 2016; Radhakrishnan *et al.*, 2017). VOSviewer is chosen to conduct KCN thanks to its straightforward and fast clustering and visualisation capability for a large number of journal articles (van Eck and Waltman, 2017). VOS in VOSviewer stands for visualisation of similarities – a mapping technique that is described in-depth in the paper of Van Eck and Waltman (2007). For clustering capability, the Smart Local Moving (SLM) algorithm is used. The detailed mathematical equation of the SLM algorithm is provided in Waltman and van Eck (2013).
- Structural dimension analysis: contents of full-text papers were broken down and coded into four dimensions; each dimension is further collapsed into associated analytical categories (Table 1). Of note, under the dimension of FLW prevention and management options, associated opportunities and challenges are coded and presented to further inform this dimension. NVIVO software is used for its effectiveness in quickly organising and coding a large number of articles in a rigorous and transparent manner in comparison with manual or Excel coding.

Table 1: Structural dimensions and analytical categories

Structural dimensions	**Analytical categories**
Research methodologies	- Experiment - Modelling - Literature review - Theoretical and conceptual - Survey
FLW flows	- Surplus - Heterogenous flow - Homogenous flow
FLW prevention and management options	- Prevention - Reuse - Bio-based material - Animal feed - Energy - Compost
Sustainability impact assessment	- Environment impact assessment - Economic impact assessment - Eco-environmental impact assessment - All three assessments

3.1. Material collection

The choice of keywords was thoroughly discussed and agreed by all authors to locate scientific contributions that fulfilled the paper's objectives. The keywords were divided into two categories and truncated terms (* sign) were used as recommended in Gimenez and Tachizawa (2012) to expand the range of possible studies found:

- **Keywords related to FLW topic:** (loss OR waste OR leftover OR surplus OR by-products) AND (food OR agri* OR agro*)
- **Keywords related to the Circular Economy topic:** ("circular economy" OR "circular bioeconomy" OR "industrial symbiosis" OR "circular*" OR "closed-loop" OR "reduce, reuse, recycle" OR "three R" OR "triple R" OR "waste hierarchy")

The keywords were queried on two databases, Scopus and Web of Science (WoS), which are considered the most comprehensive databases of peer-reviewed journals that store a broad range of scientific papers (Chadegani *et al.*, 2013; Nobre and Tavares, 2017; Mokhtar *et al.*, 2019). Additionally, both databases have been used extensively in producing SLR in the field of circular economy (Homrich *et al.*, 2018; Merli *et al.*, 2018; Türkeli *et al.*, 2018; Sehnem *et al.*, 2019) and FLW management (Chen *et al.*, 2015; Ferrazzi *et al.*, 2019; Gorzen-Mitka *et al.*, 2020). The merging of two databases is beneficial in order to increase the likelihood of finding all the relevant contributions and to provide a high level of rigour in searching and selecting the papers to be included in the subsequent analysis (Centobelli *et al.*, 2017). Of note, in WoS the research field was "Topic" (Title, Author Keywords, Abstract, Keyword Plus"), while in Scopus, the search field was "Title, Author, Keywords, Abstract". No chronological restriction was employed. The queries were performed on August 10, 2020. The search on Scopus returned 1276 papers and 1011 papers were obtained from WoS.

3.2. Material selection and evaluation

3.2.1. Inclusion and exclusion criteria

To focus the research on the topic under investigation, these papers are then screened in this step by applying a series of inclusion and exclusion criteria.

(i) Only select peer-reviewed articles written in English
  - o Excluding 357 papers in Scopus and 103 papers in WoS
  - o Including: 919 papers in Scopus and 908 papers in WoS

(ii) Duplication removal between two databases:
  - ⇨ Removing overlapping between Scopus and WoS (676 papers), keeping 243 papers exclusively found in Scopus and 232 papers exclusively found in WoS. The result suggested that 74.44 % of publications in Scopus were covered by WoS; 73.56 % of WoS records were covered by Scopus.
  - ⇨ Total papers for further review: 1151 papers in both sources**.**

(iii) Abstract screening focusing on two criteria:

- Food loss, food wastes and surplus are the central themes of the analysis. Other types of wastes: wastewater, sludge, urban wastes, or animal manures, wools, wood, etc that are not related to FLW prevention and management are excluded. Plastic wastes are only included if they are linked to the FLW discourse, such as the output products (bioplastics) or their role in reducing FLW.
- Articles that convey the key principles of the circular economy that are aligned with the six principles discussed in Section 2.3 and related terms, closed-loop supply chain, industrial symbiosis, triple R, and waste hierarchy.
  - ⇨ Only papers meeting two criteria are selected leaving us with 365 papers.

(iv) Full-text papers are then retrieved and thoroughly reviewed for their relevance with the research objectives.
  - o Irrelevant papers: 78 papers
  - o Total full-text papers retained for review: 287 papers.

(v) All references in the papers in our sample in step (iv) were checked. This led to an addition of 21 papers, out of which 10 were found relevant and added to the sample.
  - o A final sample size: **297 papers**

This entire selection process is done by three reviewers to remove the selection bias associated with the subjective judgment of the inclusion/exclusion process (Tranfield *et al.*, 2003).

3.2.2. Initial screening

Initial screening aims to observe the historical development, the commonly targeted journals for publications, and geographical distribution of the articles in the research topic. Prior to 2014, studies in this area were scarce. The first publication was recorded as early as 2002 by Moen (2002) who investigated the eco-circularity concept to convert FLW into compost in local areas. Five years later, Man and Wenhu (2007) constructed a theoretical circular agricultural system where FLW like crop straws are utilised to produce fertilisers and energy. Zhao *et al.* (2009) optimised the circular production for paddy rice, fungus, fertilisers and biogas considering economic and ecological benefits. Li *et al.* (2010) underlined the role of earthworms in the CE transition by turning food wastes into feeds, fertilisers, and input materials for biochemical and pharmaceutical sectors. It was not until 2015 – right after the introduction of the CE Action Plan in Europe in 2014 – that interest in the FLW and the CE began to take off in academia (Figure 2).

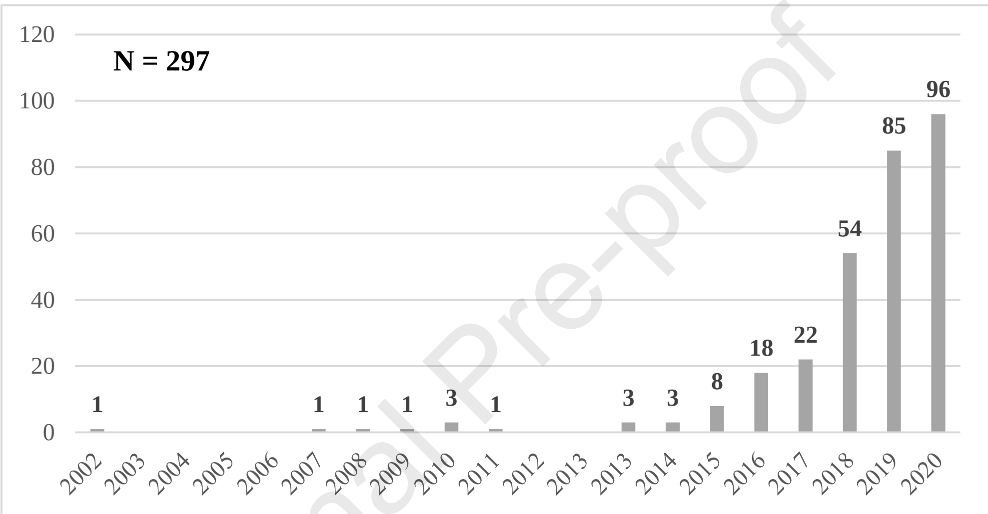


Figure 2: Research evolution on the topic of FLW management in the circular economy

In term of targeted journals (Figure 3), the Journal of Cleaner Production attracted the highest number of publications, followed by Bioresource Technology, Resource Conservation and Recycling, Waste Management, Sustainability, Renewable and sustainable energy reviews. These journals combined account for more than 30% of total publications in the review sample. Although the FLW topic under the CE landscape can be linked to multiple research fields, the topics of the review papers fit well within the scope of these journals, which epitomises biotechnological advances and the sustainability paradigm.

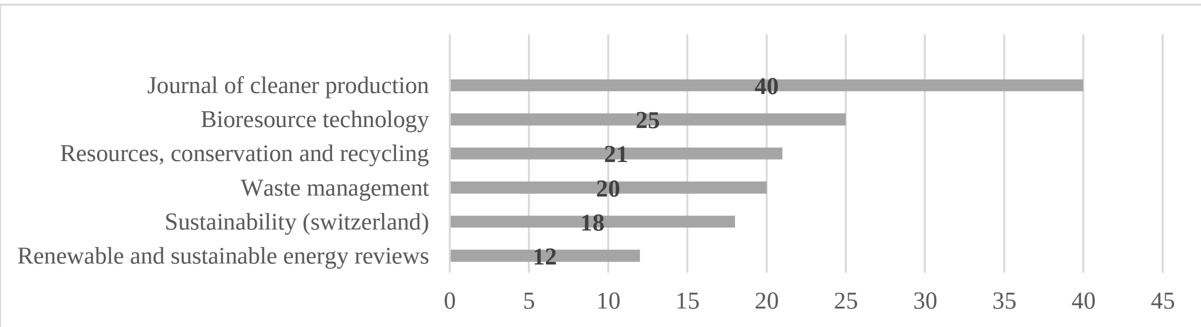
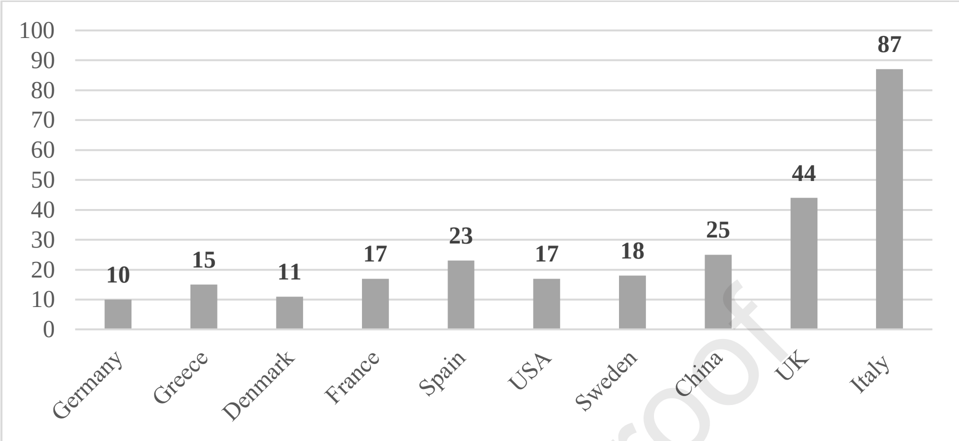
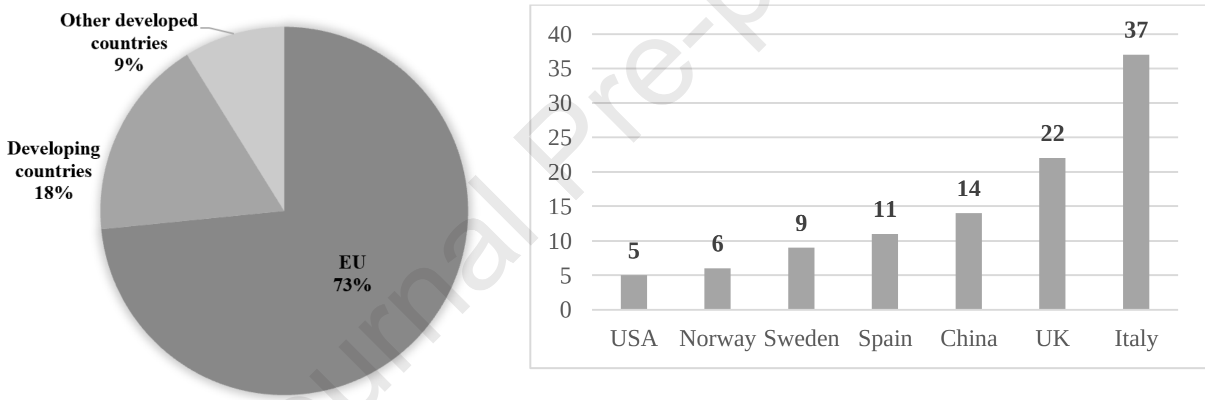


Figure 3: The number of articles per Journal (Journals with more than ten publications)

In term of geographical distribution, the majority of the articles are linked to European countries, particularly Italy and the UK (Figure 4a). The USA and China are the only two non-European countries in the top ten countries with the highest number of affiliations. It is noted that only 158 papers specified the country where the research took place (Figure 4b); and 73% of these studies were carried out in the EU, notably in Italy and the UK. 9% of the studies are linked to developing countries. The popularity of the publications in the EU and China reflects the alignment with increased interest from companies and policymakers in these regions. This finding is also consistent with other CE literature review papers (e.g. in Geissdoerfer *et al.*, 2017).



(a) Distribution of papers by affiliation countries (top ten countries)



(b) Distribution of papers by countries where the research took place (with more than five papers)

Figure 4: Geographical distribution of the review sample

4. Keyword co-occurrence analysis

KCN treats each keyword as a node and each co-occurrence of a pair of words as a link between those two words. Keywords are extracted from Author Keywords and Index Keywords fields in the Scopus and WoS database of the review sample. The use of keywords requires the pre-processing step. Words that are in structured abstracts (e.g. 'articles', 'industry', 'analysis', 'priority journal') were removed. Words that offer the same meaning but in different formats are adjusted using a thesaurus file (e.g. anaerobic-digestion and anaerobic digestion, by-products and byproducts, fertiliser and fertilizers).

The VOSviewer's SLM algorithm divided keywords into clusters that determine the relatedness of the keywords; this implies that the larger the number of articles in which two terms are both found, the stronger the relationship between the terms is. If keywords are grouped in the same cluster represented by the same colour in the map (Figure 5), they are relatively strongly related to each other and therefore tend to reflect the same topic. Each keyword is signified by a circle with the attached labels, and some labels are not visible to avoid overlapping and ease visualisation. The larger size of the circle reflects the more frequent occurrence of the keyword, while the distance between two keywords offers an approximate indication of the relatedness of the keywords. In other words, keywords with a higher rate of co-occurrence tend to be found closer to each other. It should be underlined that the SLM algorithm allows one keyword to be assigned to one cluster only; hence, two keywords in different clusters, if found close to each other, are still strongly related. A total of 2927 keywords were extracted from 297 articles of which 52 keywords occurred nine or more times and were retained in the map (Figure 5). The setting of the threshold of nine excludes the keywords with low frequencies, and thus the network was more concentrated. These keywords are divided into three clusters covering three themes: *(i)* impact assessment *(ii)* biorefinery *(iii)* nutrient recycling. Keywords with a high number of occurrences (greater than 20) are also provided for each cluster (Table 2).

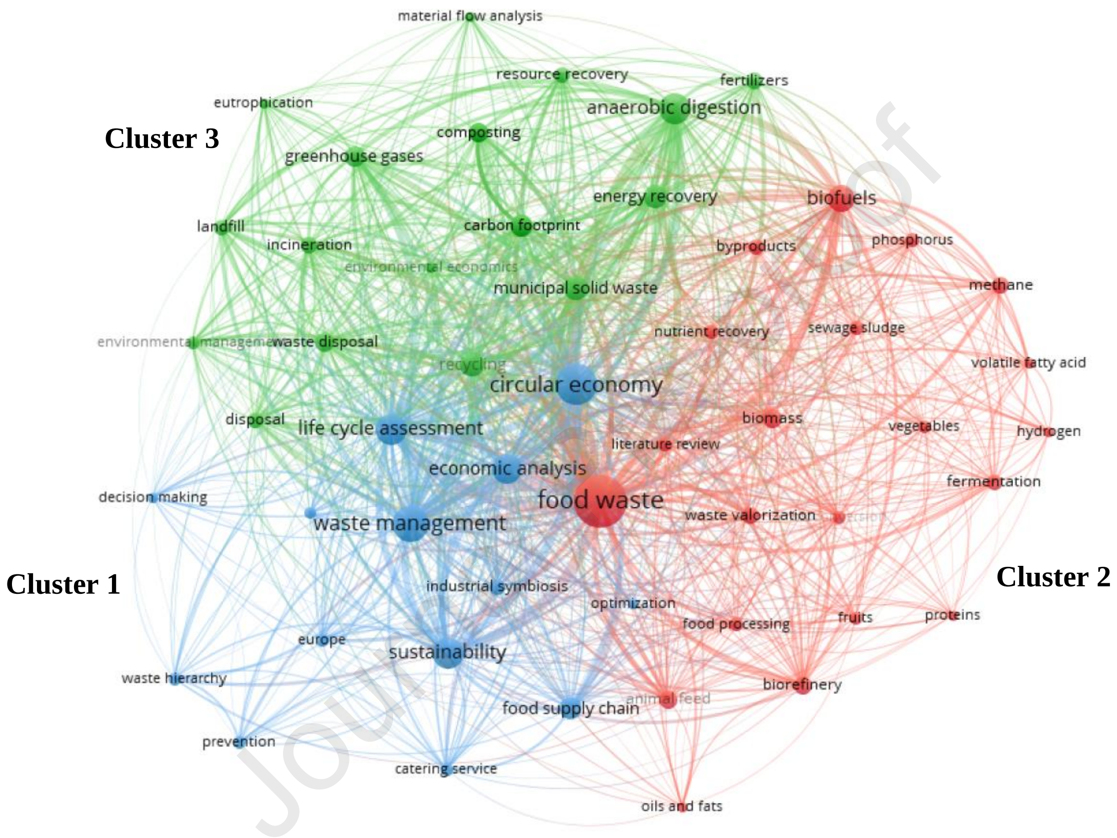


Figure 5: Keyword co-occurrence analysis

Table 2: Keywords with high occurrences in each cluster

Cluster 1 (Blue) 14 keywords	**Cluster 2 (Red) 21 keywords**	**Cluster 3 (Green) 17 keywords**
Circular economy (137) Waste management (101) Life Cycle Assessment (79) Sustainability (76) Economic analysis (71) Industrial symbiosis (20)	Food waste (220) Biomass (30) Bio-refinery (28) Animal feed (27) Waste valorisation (25) By-products (20)	Anaerobic Digestion (76) Municipal solid waste (49) Recycling (48) Energy recovery (42) Greenhouse gases (34) Carbon footprint (30) Waste disposal (31) Incineration (24) Composting (24) Landfill (20)

The number in the bracket represents the number of occurrences

4.1. Cluster 1: Impact assessment (Sustainability, LCA, economic analysis)

A close interlink between the CE and sustainability in the food sector has been emphasised in many studies. For instance, Jurgilevich *et al.* (2016) cast light on the integration of the CE concept in the FSC that contributes to promoting sustainable production and consumption and FLW management practices. Genovese *et al.* (2017) illustrate how the CE pushes the frontiers of sustainability by using a circular FSC (waste cooking oil for biodiesel production) where materials can be used over and over again, and the biosphere is not a sink for residuals. Kiss *et al.* (2019) demonstrated the linkage between the CE and sustainability in the promotion of short FSCs. Resource exchanges at the local scale following the industrial symbiosis principle are increasingly emphasised as the interface between the circular economy and sustainability (Imbert, 2017).

This relationship has been quantitatively measured using LCA and economic analysis tools, as revealed by the keyword list (Table 2). These tools aid the decision-making process to determine optimal FLW prevention and management options considering environmental and economic performance. Detailed analysis of how LCA and economic analysis have been applied is presented in Section 5.4.3. It is noted that the economic analysis keyword appears in 71 articles in the review sample, but many of these articles are experimental studies taking the laboratory process efficiency (e.g. yield) as an economic indicator.

4.2. Cluster 2: Biorefinery (biomass, valorisation, animal feeds)

Biorefinery is the cornerstone in the transition from linear to the CE (Maina *et al.*, 2017; Dahiya *et al.*, 2018), which is aligned with the cascading principle of the CE. The biorefinery process synergises multiple mono-processes to produce multiple output products for multiple markets, such as food supplements, bioplastics, cosmetics and pharmaceuticals, and biofuels, contributing to the diversification of product portfolio and revenue gains (de la Caba *et al.*, 2019; Teigiserova *et al.*, 2019). Although the bio-refinery plant using biomass, e.g. corn or sugarcane to replace petroleum-based refinery is not a new topic, the food versus fuel dilemma has sparked a growing interest in utilising FLWs as alternative feedstocks over the last few years (Venkata Mohan *et al.*, 2016). However, the technology remains novel, necessitating further investigation into pre-treatment technologies (hydrolysis or fermentation) and the process efficiency enhancement (Barampouti *et al.*, 2019).

In this cluster, biorefinery is closely associated with valorisation and animal feed production. Valorisation refers to the conversion of FLW into high-value bio-compound and animal feed (FUSIONS, 2014) while full valorisation means a cascading biorefinery before energy and soil restoration options (Ellen MacArthur Foundation, 2012). Valorisation receives considerable attention in the review sample (i.e. Mirabella *et al.*, 2014; Zabaniotou and Kamaterou, 2019) and is normally applicable to manage the "homogeneity of the waste flows" (Corrado and Sala, 2018, p. 129) e.g. by-products at the processing plants. Insect-rearing on plant-based FLW, such as fruits and vegetables, for feed production is also a type of valorisation (Barbi *et al.*, 2020); and this trend marks a shift away from simple thermal food-to-feed conversion (Cappellozza *et al.*, 2019; Conti *et al.*, 2019).

4.3. Cluster 3: Nutrient recycling (Anaerobic Digestion, fertilisers)

Interest in the stand-alone decentralised technology like Anaerobic digestion (AD) is prominent in the review sample. AD is a mature technology, particularly in Europe with many operational plants (Slorach *et al.*, 2019b) to recover energy and recycle nutrient-rich digestates back to soils (Zabaniotou and Kamaterou, 2019; Battista *et al.*, 2020). Additionally, AD can be deployed on a small scale in any geographical location (Ingrao *et al.*, 2018), which makes it fit well in the industrial symbiosis and regenerative principle of the CE. It is estimated that if all bread waste in the UK was fed into AD plants, it could generate roughly 10% (198 GWh) of the total energy used in the bread sector each year (Veldhuis *et al.*, 2019). Compared to incineration and landfill, AD is proven to be an efficient and eco-friendly (GHG saving) waste treatment option (Capson-Tojo *et al.*, 2016).

Traditionally, revenue from AD plants comes merely from biogas or heat/electricity yield while digestate is classified as "waste". Following the regenerative principle of CE, digestate should be utilised as bio-fertilisers and contribute to return nutrients (particular P and N) to the biosphere (Beggio *et al.*, 2019) to improve soil fertility and promote the growth of maize (Chen *et al.*, 2017). Unfortunately, not all countries recognise the legal status of this bio-fertiliser stream (Fuldauer *et al.*, 2018). Looking at Italy, for instance, the use of digestates from agro-feedstock is accepted but those from organic Municipal Solid Waste (MSW) are banned. Moreover, the statistical analysis study of Beggio *et al.* (2019) established that there is no statistically significant difference between digestate generated from agro-feedstock and organic MSW. There is a call for re-legislation to support the commercialisation of AD-effluent (Fuldauer *et al.*, 2018).

5. Structural dimension analysis

In this section, four structural dimensions were statistically and analytically evaluated to reveal the main research streams in the topic of FLW prevention and management under the CE perspective. These dimensions are chosen based on two relevant papers in the CE topic (Kirchherr *et al.*, 2017; Merli *et al.*, 2018) and one paper in the FLW management topic (Paes *et al.*, 2019). Within this highly fragmented research area, the reliance on the existing way of analysing literature offers a useful guideline for our analysis.

5.1. Research methods

The methods of review sample fall into five types (i) experiment, (ii) modelling, (iii) literature review, (iv) theoretical and conceptual framework (v) survey; the first three types of which are the most popular (Figure 6).

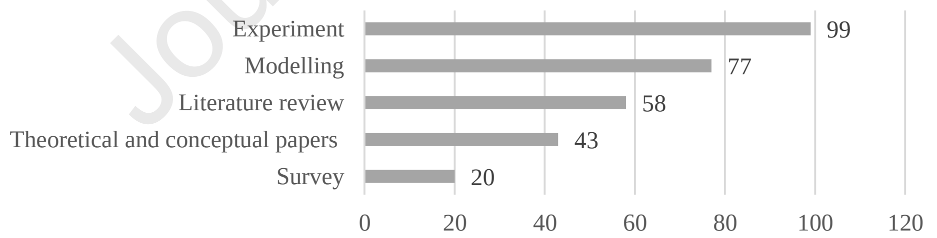


Figure 6: Type of research methods employed

The highest number of papers (99) used lab-scale or pilot studies to demonstrate the feasibility of technological innovations to valorise FLWs or enhance the efficiency of current processes (Bosco *et al.*, 2017; Esteban-Gutiérrez *et al.*, 2018; Grillo *et al.*, 2019; Atasoy *et al.*, 2020; Weber *et al.*, 2020), or demonstrate the feasibility of self-sustaining FSC model (Stoknes *et al.*, 2016). Positive results from experiments pave the way for the upscaling potentials, driving the transition towards the CE. The experimental method is followed by modelling. Common modelling tools include LCA-based methods (36), material flow analysis (MFA) (17), economic analysis (e.g. Life Cycle Costing (LCC)) (5), optimisation (15) and simulation (4). The main purposes of modelling papers are to assess the techno-economic feasibility and environmental impact of different FLW prevention and management options and quantify the flow of the FLW stream. A novel MFA-LCA and agent-based approach to improving nutrient cycle management in agricultural systems is proposed in Fernandez-Mena *et al.*

(2016). Literature review papers (58 papers) come third with the focus on seven topics that have been presented in the introduction and are condensed in Appendix 1.

A theoretical and conceptual method is adopted in 43 papers. These studies mainly aim at sustainable consumption models to prevent and redistribute food waste generation (Mylan *et al.*, 2016; Hebrok and Heidenstrøm, 2019). Several behaviour theories are employed: frame analysis for food donations (Tikka, 2019), the theory of change (ToC) for food sharing (Michelini *et al.*, 2020), prospect's theory for customers' perception of biowaste products (Russo *et al.*, 2019), convention theory for retailer's role in tackling FLW (Swaffield *et al.*, 2018). Some conceptual frameworks are proposed: the six-step framework for nutrient stock and flow accounting (van der Wiel *et al.*, 2020), a seven-step framework for integrated LCA-LCC methodology (De Menna *et al.*, 2020), a framework for MSW collection and recycling (Woon and Lo, 2016).

Finally, the survey is the least employed method (20 papers) with the main aim being to investigate *(i)* perception of end-users towards biowaste-based products (Danso *et al.*, 2017; Aschemann-Witzel, Ares, *et al.*, 2019; McCarthy *et al.*, 2019; Russo *et al.*, 2019; Coderoni and Perito, 2020) *(ii)* consumers' willingness to participate in the CE program (Borrello *et al.*, 2017; Russo *et al.*, 2019; Borrello *et al.*, 2020); *(iii)* effectiveness of FLW collection policies and sorting behaviours (Miliute-Plepiene and Plepys, 2015; Liikanen *et al.*, 2016; Andersson and Stage, 2018); *(iv)* prevention attitude and behaviours of households (Jereme *et al.*, 2018; Todorova *et al.*, 2018; e.g. Fogarassy *et al.*, 2020), of airline employees (Sambo and Hlengwa, 2018) and of restaurant owners (Lang *et al.*, 2020).

5.2. The FLW stream

FLW flows in the review sample are grouped into three types: *(i)* surplus *(ii)* homogeneous flow *(iii)* heterogeneous flow; the last two FLW types attract the largest attention (Figure 7). Surplus food represents the edible food that is fit for human consumption, while the last two groups remain either natural inedibility or inedibility due to degradation (Teigiserova *et al.*, 2020). This classification comes from the differences in desirable prevention and management strategies for each stream. Studies on food surplus are associated with prevention and reuse options while homogeneous FLW flow is commonly linked to valorisation for high-value compounds (Oldfield *et al.*, 2016; Corrado and Sala, 2018; Teigiserova *et al.*, 2019). Heterogeneous flow is most suitable for energy and nutritional recovery, i.e. via AD and composting. In addition, this classification contributes to overcoming the ongoing debates in interpreting inedible versus edible or unavoidable versus avoidable in extant literature (Slorach *et al.*, 2019b). Relatively equal consideration in the review sample is accorded to heterogeneous and homogeneous flows, whereas a much lesser extent is paid to the surplus.

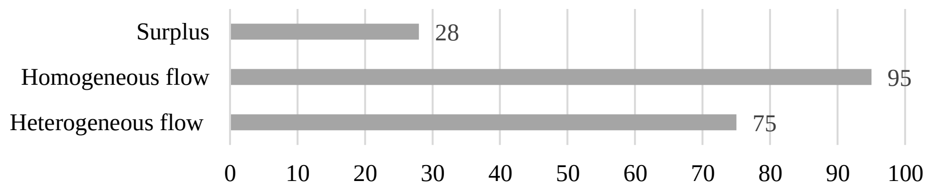


Figure 7: Types of FLW flows

Food surplus mainly occurs at the retail and consumption stages of the FSC but can arise at manufacturing and agricultural stages due to overproduction (Papargyropoulou *et al.*, 2014; Garrone *et al.*, 2016). Homogeneous flow normally occurs at the food processing stage and agricultural activities (agro-residues) (Banerjee *et al.*, 2018; Egelyng *et al.*, 2018) but it can also be generated in the catering services, such as in the case of spent coffee grounds (SCG) (Kourmentza *et al.*, 2018) or used cooking oils in restaurants (Carmona-Cabello *et al.*, 2019). This waste stream is discharged in large quantities with high compositional homogeneity at specific locations (Cristóbal, Caldeira, *et al.*, 2018), offering abundant and low-cost resources. However, the underlying challenge with this waste stream comes from seasonality and regional patterns (Gontard *et al.*, 2018), which might pose risks for the year-round operation of the single-feedstock plant (Banerjee *et al.*, 2018). Conversely, the heterogeneous waste stream often stems from supermarkets and households (Ng *et al.*, 2019) and catering services including restaurants, hotels, hospitals and schools (Strazza *et al.*, 2015; Nizami *et al.*, 2017), which might not be suitable for valorisation due to composition complexity, and should be prioritised for energy conversion and composting over incineration and landfill. Compared to homogeneous flow, this waste stream is difficult to quantify in terms of potential scale and composition (Rathore *et al.*, 2016). In addition, it encounters logistical challenges from the collection and transportation process in geographically dispersed supply sources (Kokossis and Koutinas, 2012).

5.3. FLW prevention and management options

Figure 8 shows the preferences in literature across various FLW prevention and management options. Recycling and recovery attract wider research attention compared to prevention and reuse, which is aligned with the finding in KCN in Section 4.

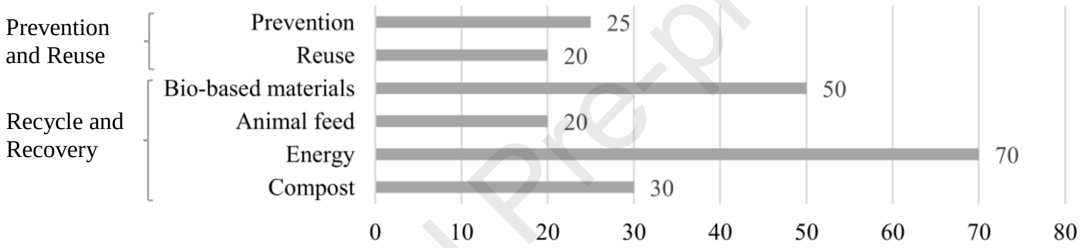


Figure 8: Types of FLW prevention and management options

5.3.1. Prevention and Reuse

As noted in Section 5.2, prevention and reuse are only associated with surplus flow management. Prevention in the review sample mainly targets consumption stages, but other parts of the supply chain are also discussed. At the household level, FLW generation is primarily derived from sociopsychological and cultural factors such as social norms, perception, education level, individual preferences (Todorova *et al.*, 2018; Aschemann-Witzel, Ares, *et al.*, 2019). Thus, a number of papers examined how these factors drive FLW generation (e.g. in Mylan *et al.*, 2016; Hebrok and Heidenstrøm, 2019; Lehtokunnas *et al.*, 2020). Generic prevention practices that target more sustainable consumption are proposed, including enhancing food literacy and knowledge in cooking and planned purchases (Vilariño *et al.*, 2017; Hebrok and Heidenstrøm, 2019), acceptance of sub-optimal foods, and food safety perception (Aschemann-Witzel, Ares, *et al.*, 2019). A small body of literature in the review sample investigates the effectiveness of waste policy and prevention programs in shifting consumers' behaviour, such as sorting policy, awareness campaign, home composting promotion, leftover consumptions (e.g. in Miliute-Plepiene and Plepys, 2015; Andersson and Stage, 2018; Johansson and Corvellec, 2018; Zorpas *et al.*, 2018). From upstream of the FSC to retailers, prevention can be attained by better logistics and more efficient management tools by, for instance, adequate storage, cold chain management for perishable items, spoilage prevention packaging, smaller plates at different prices (Vilariño *et al.*, 2017). In addition, it is suggested that prevention efforts are prioritised for more resource-intensive products, such as red meat and dairy products (Teigiserova *et al.*, 2020). Retailers and restaurants can contribute to lowering household food waste generation, e.g. by standardising data labelling, printing food storage tips on carrier bags, or revising promotion campaigns for perishable foods (Vilariño *et al.*, 2017; Teigiserova *et al.*, 2020). Similarly, processing firms can reduce food wastes by remanufacturing or selling with promotion and discount (Garrone *et al.*, 2016). Some studies quantitatively assess the impacts of prevention in comparison with FLW management methods, such as reuse, AD, compost and incineration (Albizzati *et al.*, 2019; Brancoli *et al.*, 2020). The most extensive list is found in Cristóbal, Castellani, *et al.* (2018) who evaluated twelve prevention measures, seven reuse and three recycling-recovery practices. The results of these studies supported prevention and reuse as the most favourable options in term of environmental performance.

Reuse has gained growing research recognition with a diversity of sharing models, e.g. harvest sharing, meal sharing and leftover sharing (Zurek, 2016) and numerous other sharing initiatives (Facchini *et al.*, 2018). Although reuse might not automatically translate to FLW reduction (Morone *et al.*, 2018), it enhances social welfare, reduces food poverty, and alleviates hunger (Zhu *et al.*, 2018). Based on an analysis of 52 food-sharing platforms, Michelini *et al.* (2020) proposed a novel way to divide reuse into: Sharing for charity, Sharing for the communities, Sharing for money (Michelini *et al.*, 2020). The review sample paid equal attention to all three types:

- Sharing for money, also known as pseudo sharing, is primarily in form of Business to Consumer (B2C) allowing retailers and catering outlets to post unsold foods on social media so consumers can buy. However, it can also be in Business to Business (B2B) form, e.g. where collectors gather food left-overs from retailers and make value out of them (Choi *et al.*, 2019)
- Sharing for charity is in B2B and Customer to Business (C2B) forms where food is collected from all sorts of donors and redistributed to food banks at local and national scale e.g. food aid activities in Finland (Tikka, 2019) or donation of retailers (Lee and Tongarlak, 2017)
- Sharing for community, also known as Peer to Peer (P2P) sharing, is when food is shared amongst consumers, e.g. food sharing in the campus environment (Lazell, 2016; Morone *et al.*, 2018). P2P has become increasingly popular in practice thanks to the web-based platform and mobile apps (Harvey *et al.*, 2020; Makov *et al.*, 2020). P2P users are commonly found to be in the group with lower income yet higher education level (Makov *et al.*, 2020).

However, the outreach of reuse might encounter the following challenges: market fragmentation, traceability and responsibility of food donors, strict safety and hygiene norms (Zurek, 2016; Sarti *et al.*, 2017; Tikka, 2019), lack of coherent efforts, uncertainty in the estimation of surplus availability (Facchini *et al.*, 2018), low participation interests due to time and effort incurred and psychological barriers (Makov *et al.*, 2020).

5.3.2. Recycle and recovery

A plethora of options are identified to extract and retain the value from bio-waste, but they are normally grouped into three technological pathways: thermochemical, physiochemical and biochemical processes (Nizami *et al.*, 2017). The thermochemical process such as pyrolysis or gasification is used to turn biogas into fuels, electricity, and heat. Physiochemical (like transesterification) converts bio-waste into fuels and bio-products. Biochemical (like AD or fermentation) aims to turn bio-waste into energy and fertilisers. These technological options have been thoroughly reviewed in the literature (Appendix 1). Examples are manifold: valorisation option in Mirabella *et al.* (2014); Teigiserova *et al.* (2019), AD in Capson-Tojo *et al.* (2016); biorefinery models in Venkata Mohan *et al.* (2016); pyrolysis in Elkhalifa *et al.* (2019). The output of the technological options for processing bio-waste can be grouped into four categories: (i) bio-based materials, (ii) animal feed, (iii) energy, and (iv) compost.

As presented in Figure 8, the conversion of bio-waste to energy and bio-based materials received the widest attention in the literature, followed by compost production. The literature is limited on the production of animal feeds. The main feedstock for bio-based material extraction and animal feeds are agro-residues, by-products from processing (e.g. fruit pulp) and vegetable/fruit wastes, which are homogeneous in nature. Conversely, the main feedstock for energy conversion is from heterogenous organic MSW flow such as household or restaurant wastes. Although the CE encourages a cascading use of multiple products across various industries via valorisation or bio-refinery, the highest interest remains on food-to-energy conversion, which could be partly attributed to the policy supports (e.g. subsidies) for energy recovery in diverting organic waste from landfill (Berbel and Posadillo, 2018).

The opportunities and challenges associated with each type of output category, are synthesised and summarised in Table 3. These are not merely influenced by technological feasibility (Genovese *et al.*, 2017) but also impacted by supply, market, logistics, policy, quantification issues. The first column in Table 3 lists the four output categories. The table also lists the main articles in the literature, the technological options together with the opportunities and challenges associated with each category.

Table 3: Opportunities and challenges of food waste management outputs

Categories	Illustrative articles	Technological options	Opportunities	Challenges
Bio-based materials (e.g. functional foods, supplements, enzymes, colourants, bioplastics)	Mirabella *et al.* (2014); Vardanega *et al.* (2015); Banerjee *et al.* (2018); Castro-Muñoz *et al.* (2018); Kourmentza *et al.* (2018); Zuin and Ramin (2018); Barreira *et al.* (2019); Contreras *et al.* (2019); Teigiserova *et al.* (2019); Zabaniotou and Kamaterou (2019); Ioannidou *et al.* (2020); Madeddu *et al.* (2020); Ng *et al.* (2020)	Supercritical technology Membrane separation Green chemistry Solvent extraction Enzyme extraction Electro-based extraction (e.g. ultrasounds, microwaves)	- **Supply:** the large-scale, concentrated, and low-cost supply of FLW feedstock (Kourmentza *et al.*, 2018; Barreira *et al.*, 2019) - **Market**: customers' shift towards natural-based products (Shogren *et al.*, 2019; Teigiserova *et al.*, 2020)	- **Technology:** Low technological readiness level (TRL), mainly at lab-scale (Banerjee *et al.*, 2018; Zabaniotou and Kamaterou, 2019), entails high R&D cost (Ng *et al.*, 2020) and high investment uncertainty (Cristóbal, Caldeira, *et al.*, 2018). - **Quantification:** low reliability in estimating material potentials in terms of quantity and quality (Mirabella *et al.*, 2014) - **Logistics:** high logistics cost involved in the collection (Ng *et al.*, 2020) and storage for quality preservation (Banerjee *et al.*, 2018) - **Market:** the understanding of nutrient and economic value for the nutraceutical products is fairly limited while excessive modification of food could cause potential risk to consumers' heath (Mirabella *et al.*, 2014)
Animal feed (insect meal, feed ingredients)	Stiles *et al.* (2018); zu Ermgassen *et al.* (2018); Girotto and Cossu (2019); Tedesco *et al.* (2019); Barbi *et al.* (2020); Gasco *et al.* (2020); Pinotti *et al.* (2020); Zarantoniello *et al.* (2020)	Invertebrate biorefinery Microalgae	- **Market:** the ever-rising feed cost drives the search for nutrient-rich insects as a cheaper alternative (Conti *et al.*, 2019)	- **Technology:** Microalgae cultivation is at early stage (Stiles *et al.*, 2018). - **Market:** safety concerns (Conti *et al.*, 2019) and low customer acceptance (Rumpold and Langen, 2020) hinder the waste-to-feed proliferation. - **Policy:** regulations on animal feed production are more stringent in some countries, particularly in EU (Girotto and Cossu, 2019)
Energy (biogas, biodiesels, biochar, liquid, gas, fuels, heat and electricity)	Fuldauer *et al.* (2018); Ingrao *et al.* (2018); Vaneeckhaute *et al.* (2018); Antoniou *et al.* (2019); Barampouti *et al.* (2019); Caruso *et al.* (2019); Elkhalifa *et al.* (2019); Loizia *et al.* (2019); Chandrasekhar *et al.* (2020); Weber *et al.* (2020)	AD Pyrolysis Gasification Fermentation Combined heat and power	- **Technology:** energy-conversion technology has high TRL (Chang *et al.*, 2011) - **Logistics:** the introduction of innovative FLW transport, i.e. smart recycle bin (Yeo *et al.*, 2019), under-the-sink FLW disposal connecting to the sewer system (Cecchi and Cavinato, 2019), pipeline transmission (Muradin *et al.*, 2018)	- **Technology:** further R&D into optimal feedstock, and optimal process design and conditions is needed to cope with the low-yield issue and maximise output of targeted products (Elkhalifa *et al.*, 2019) - **Supply**: supply locations are geographically dispersed (Kokossis and Koutinas, 2012); FLW feedstock bears regional and seasonal traits (Caruso *et al.*, 2019); source segregation is required (Cecchi and Cavinato, 2019).
Compost	Peng and Pivato (2017); Chojnacka *et al.* (2019); Bruni *et al.* (2020); Chojnacka *et al.* (2020)	Digestates from AD Composting Vermicomposti ng	- **Logistics**: a growing interest in decentralised composting (e.g. community, home composting) (Bruni *et al.*, 2020) - **Market:** the demand for fertilisers always exceeds supply (Chojnacka *et al.*, 2020); consumer preferences towards foods produced from the upcycled and eco-friendly materials enhance the intrinsic value of digestate used as recycled fertilisers/ compost (Guilayn *et al.*, 2020)	- **Technology**: this technology has a small production scale compared to fossil-based fertiliser production (Chojnacka *et al.*, 2020), encounters difficulty in planning and use, causes unpleasant odour for neighbourhood (Case *et al.*, 2017); there is limited knowledge regarding vermicomposting (Choudhary and Suri, 2018). - **Logistics:** high collection and handling costs (Sakarika *et al.*, 2019) - **Policy:** the legal status of digestate that varies in different countries hinders its use (Stiles *et al.*, 2018; Beggio *et al.*, 2019; Chojnacka *et al.*, 2020); and no specific quality control and criteria available for using digestates as fertilisers (Guilayn *et al.*, 2020). - **Market:** lack of interest from fertiliser producers (Chojnacka *et al.*, 2020) and no pressure to change in the fertiliser (phosphorus) industry

				(Guilayn *et al.*, 2020).

5.4. Sustainability impact assessment

The transition of FLW prevention and management towards the CE calls for consistent approaches for the proper triple-bottom-line assessment of current impacts and future scenarios. Figure 9 encapsulates the distribution of studies conducting at least one pillar of sustainability impact assessment (SIA). In general, attention is given predominantly to environmental impact or economic feasibility assessment or a combination of both. The social assessment is scarcely addressed, and this is attributed to the absence of reliable data and consistent assessment metrics (Sgarbossa and Russo, 2017; Cristóbal, Castellani, *et al.*, 2018). Sgarbossa and Russo (2017) further argued that the promotion of FLW circular practices positively contributed to social sustainability. Table 4 summarises a list of commonly used indicators in the review sample. It is noted that there is a lack of a clear guideline on the use of criteria/indicators/metrics in the literature (Belaud *et al.*, 2019). Zabaniotou (2018) recommended borrowing a list of 24 biorefinery sustainability indicators for SIA given FLW is utilised as feedstock in biorefinery. Unfortunately, none of the papers in the review sample adopted this set.

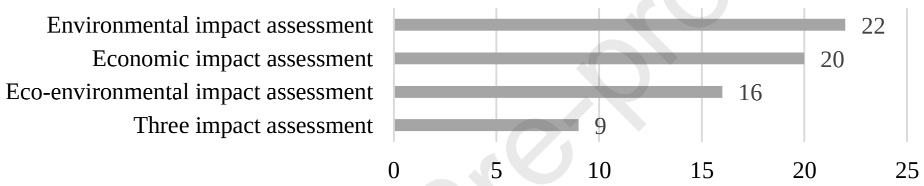


Figure 9: Types of sustainability impact assessments

Table 4: Sustainability impact assessment main indicators and metrics

Sustainability pillars	Commonly used indicators	Illustrative references
1. Environmental	A full or subset of 19 ReCiPe mid-point impact categories.	Laso et al. (2016); Oldfield et al. (2016); Santagata et al. (2017); Cobo et al. (2018); Muradin et al. (2018); Slorach et al. (2019b; 2019a); Schmidt Rivera et al. (2020); Slorach et al. (2020)
	GHG saving only	Eriksson et al. (2015); Marrucci et al. (2020); Scherhaufer et al. (2020)
	Resource use (energy and water)	Strazza et al. (2015); Edwards et al. (2017); Eriksson and Spångberg (2017); Laso, Margallo, García-Herrero, et al. (2018); Hoehn et al. (2019); Piezer et al. (2019); Yeo et al. (2019); de Sadeleer et al. (2020)
2. Economic	Cost indicators (e.g. CAPEX, OPEX)	Bolzonella et al. (2018); Esteban-Gutiérrez et al. (2018); Abad et al. (2019); Sakarika et al. (2019); Chen et al. (2021)
	Revenue indicators; Profitability index	Demichelis et al. (2018); Fuldauer et al. (2018); Stiles et al. (2018); Papirio et al. (2020)
	Investment indicators: IRR, NPV, payback periods, CRoI	Zabaniotou et al. (2015); Cristóbal, Caldeira, et al. (2018); Fuldauer et al. (2018); Ferella et al. (2019); Montoro et al. (2019); Hoo et al. (2020); Matrapazi and Zabaniotou (2020); Weber et al. (2020)
3. Social	Job creation	Chang et al. (2011); Sgarbossa and Russo (2017); Santos and Magrini (2018)
	Health and safety from the use of organic-based products	Alfaro and Miller (2014); de la Caba et al. (2019); Shogren et al. (2019)

Note: CAPEX: Capital expenditure; OPEX: Operational Expenditure; NPV: Net Present Value;
CRoI: Carbon Return on Investment

5.4.1. Environmental impact assessment

A large body of literature in the review sample (36 papers) employed LCA to conduct environmental impact assessment. LCA is a standardised methodology in ISO standards (ISO, 2006a; 2006b) and the International Reference Life Cycle Data System (ILCD) handbook (Chomkhamsri *et al.*, 2011) to evaluate potential environmental impacts and resources used throughout a product's life cycle. LCA can be used on its own or combined with other quantitative tools, e.g. mathematical modelling (Cobo *et al.*, 2018; Cristóbal, Castellani, *et al.*, 2018), or agent-based modelling (Fernandez-Mena *et al.*, 2016). LCA is also modified into Life Cycle Protein Assessment (LCPA) to calculate protein content in the FSC (Laso, Margallo, Serrano, *et al.*, 2018). A variety of LCA methodologies in FLW management is reviewed in De Menna *et al.* (2020); (Omolayo *et al.*, 2021).

Different impact categories have been used with the support of LCA software like SimaPro and Gabi. Several studies in the review sample – e.g. Laso *et al.* (2016); Santagata *et al.* (2017); Slorach *et al.* (2019a; 2019b); Schmidt Rivera *et al.* (2020); Slorach *et al.* (2020) – use all or almost all of 19 impact categories in ReCiPe mid-point methodology. The remaining only adopt several impact categories such as global warming potential (GWP), Eutrophication Potential (EP), Acidification potential (AP) (Laso, Margallo, Serrano, *et al.*, 2018) and fossil resource depletion potential (FRDP) (Vaneeckhaute *et al.*, 2018). Several papers merely address the carbon footprint (GHG savings/emissions) of different waste treatment options (six redistribution and treatment options in Eriksson *et al.* (2015), five valorisation and recycling options in Scherhaufer *et al.* (2020), composting and AD in a supermarket Marrucci *et al.* (2020)). Although justification is provided for the selection of a subset of indicators (Sgarbossa and Russo, 2017), variations in the selections might challenge the cross-comparison or mislead the interpretation of the results.

Resource usage indicators, including energy and water, are also measured in several studies using a life cycle approach. Edwards *et al.* (2017), for instance, evaluated the energy balance of seven waste management systems. Further, Hoehn *et al.* (2019) proposed Energy Return on Investment– Circular economy index (EROIce) to quantify the amount of energy recovered from FLW among three options, AD, incineration and landfill with energy recovery. Laso, Margallo, García-Herrero, *et al.* (2018) combined four indicators: water, energy consumption, GWP, and nutritional content indicators to consider three treatment options (i) animal feed (ii) incineration (iii) landfilling with energy recovery.

5.4.2. Economic impact assessment

To evaluate economic impacts, the review sample employed the following economic indicators: treatment cost, profitability index, NPV, IRR, payback period. These indicators are assessed using tools, such as Break-Even Point (BEP) analysis (in Ferella *et al.*, 2019), Levelized Cost of Energy (LCOE) (in Muradin *et al.*, 2018; Hoo *et al.*, 2020), and LCC (in Sakai *et al.*, 2017; De Menna *et al.*, 2018; Slorach *et al.*, 2019a). LCC adopts the life cycling thinking to calculate the cost of a product and service over its life span and is standardised for specific product categories like petroleum (ISO, 2008). Compared to LCA, the LCC studies for FLW management and valorisation routes is still in its infancy with neither a common methodological approach nor an effective and transparent categorisation of costs (De Menna *et al.*, 2018). In addition, it is desirable to combine LCC with other indicators, such as revenues, profit, value-added, to reflect larger economic impacts.

5.4.3. Eco-environmental impact assessment

A combined economic and efficiency assessment is also common. For example, Albizzati *et al.* (2019) compare environmental and economic impacts of four options for surplus management at a supermarket: donation, animal feeds, AD and incineration. Muradin *et al.* (2018) combined LCA and

LCOE indicators to evaluate the environmental and economic effectiveness of the waste-to-energy process. An integrated LCC and LCA framework for FLW prevention and management was proposed in De Menna *et al.* (2020), but only Slorach *et al.* (2019a) carried out the LCA-LCC assessment for four options: AD, in-vessel composting, incineration, and landfill.

5.4.4. Three impact assessment (environmental + economic + social)

A handful of studies in the review sample addressed three impacts simultaneously and the adopted indicators are dissimilar. For instance, Santos and Magrini (2018) employed waste emission reduction, GHG savings, potential job creation and feedstock remuneration premium, whereas Sgarbossa and Russo (2017) measured the energy self-sufficiency indicator (ESS), profitability indicator (PI), employment possibility indicator. Vaneeckhaute *et al.* (2018) utilised two economic indicators (NPV and IRR), four environment indicators (GWP, EP, AP, FRDP), and a stakeholders' perception inquiry as a social impact factor.

6. Discussion: a synthesis of research streams and research agenda

The findings from KCN analysis in Section 4 suggested that impact assessment, biorefinery and nutrient recycling are three underlying research lines in extant literature. This is supported by a significant number of articles found on these topics from the structural dimension analysis (Section 5). However, the fine-grained analysis in Section 5 also gave rise to other critical factors of FLW management under the CE framework. Methodological analysis indicated the important role of the FLW flows quantification and statistical assessment. Three types of FLW flows – surplus, homogeneity and heterogeneity – follow different prevention and management pathways, but they encounter challenges arising from the following sources: technologies, supply, quantification, logistics, market factors, policy. Grounded in the detailed and extensive analysis, we propose a novel way of classifying the literature in FLW management under the CE into six research streams: (i) FLW stream supply and quantification, (ii) practices and technological aspects, (iii) logistics and supply chain management, (vi) market demand, (v) SIA, (vi) policy and legislation. This novel classification aims to push further evolution in this ever-increasing research agenda (Table 5).

Table 5: Research agenda basing on the taxonomy framework.

Research streams	FLW prevention and reuse	FLW valorisation
Supply and Quantification	- Improve availability, reliability, and level of detail in the FLW generation data. - Develop a consistent methodological framework to quantify the scale of food surplus, loss and waste; and apply the methodology to specific supply chains. - Investigate the chemical composition of FLW resources	
Practices and technological aspects	- Examine impacts of innovative food packaging, especially for biodegradable packaging, on FLW minimisation. - Investigate the enablers and determinants for the engagement in three food sharing models, particularly for P2P. - Quantitatively evaluate the performance and associated benefits of three sharing models.	- Assess the upscaling technological feasibility of FLW-based biorefinery models with a focus on optimal process design using computational tools, such as modelling and simulation. - Optimise the process design to produce multiple high-value outputs and enhance yields at the scale that maximises the economic feasibility.
Logistics and supply chain management	- Examine short FSC performance considering FLW reduction. - Quantitatively assess the operational management issues, including logistics, supply contract, operational risks, revenue models of various food sharing	- Focus on smart collection and transportation systems of FLW. - Shift to decentralised, small and medium-scaled biorefineries.

	models	
Market demand	- Derive a reliable estimation of financial value from surplus foods circulated by three food sharing models.	- Focus on end-users' perception and attitudes towards the use of FLW-derived products. - Explore the influence of market factors (market saturation and market power) for FLW-based bioproducts. - Analyse the nutritional value and safety aspects of novel FLW-based products.
SIA	- Develop a harmonised SIA indicator set for three dimensions of sustainability. - Conduct spatial and temporal LCA studies in different areas and socio-economic contexts. - Assess the entire waste hierarchy including the prevention and reuse options. - Assess the benefits and impacts of the production of FLW-based products versus fossil-based counterparts and FLW-based products versus first-generation biomass-based alternatives	
Policy and legislation	- Examine the effectiveness of the incentives policy on FLW prevention and reuse and management options. - Solve the conflicting and unharmonised policies and regulations that could hinder the promotion of circular FLW prevention and management practices. - Conduct a cross-country comparison on the influences of policy setting on FLW prevention and prevention's directions.	

6.1. FLW supply and quantification

The reliable quantification of potential FLW flows is the first and crucial step in supporting the formation of effective FLW interventions and policies in all three flows of FLW (Corrado and Sala, 2018; Hamelin *et al.*, 2019). This helps to monitor the progress of FLW reduction over time (Garrone *et al.*, 2016), estimate the potentials of re-distribution activities (Facchini *et al.*, 2018), and identify the important waste stream with respect to mass in order to evaluate its potential for different treatment options (Imbert, 2017; Metson *et al.*, 2018). This also offers a solution to overcome the scattered and unstable supply issue of FLW, especially the residues that bear regional and seasonal patterns (Caruso *et al.*, 2019; Gaglio *et al.*, 2019), and alleviate the risk of year-round operation, i.e. by combining multi-seasonal feedstocks (Vardanega *et al.*, 2015; Banerjee *et al.*, 2018). Unfortunately, the unavailability of FLW data and high variability in accounting methods hinder the reliable quantification of FLW flows (Corrado *et al.*, 2017; Teigiserova *et al.*, 2019). There is a pressing need to improve availability, reliability and level of detail in the data on the volume of food loss, waste and surplus generation (Corrado and Sala, 2018; Cristóbal, Caldeira, *et al.*, 2018; Facchini *et al.*, 2018). A useful recommendation for enhancing the FLW generation data at the household level is based on consumers' diaries, weighting, and source separation (Teigiserova *et al.*, 2020). Similarly, although some FLW accounting methods, such as MFA (Metson *et al.*, 2018; Amicarelli *et al.*, 2020; Stephan *et al.*, 2020) or geo-localized methodology (Hamelin *et al.*, 2019) have been applied, FLW quantification is in urgent need of a harmonised methodology. Further, as FLW occurs at all stages of FSC, future work should be conducted at the supply chain level – such as the case of pasta in Principato *et al.* (2019) – to quickly locate the hotspots of FLW generation along the supply chain and allocate efforts to tackle the problems.

In addition to FLW accounting, it is significant to grasp insights into the chemical composition and energy content of different FLW types (Nizami *et al.*, 2017; Barreira *et al.*, 2019) because they influence the choice of optimal technologies for bio-based production. However, the knowledge of FLW chemical composition and energy content is fairly limited (Banerjee *et al.*, 2018), which opens up an avenue for future studies to explore.

6.2. Practices and technological aspects of FLW prevention and management

6.2.1. Prevention and reuse

As analysed in Section 5.3.1., prevention practices vary across the supply chain. Household FLW reduction mainly aims at shifting behaviours, whereas the upper parts of the FSC focus primarily on better logistics and more efficient management. There is an increasing interest in exploring the impact of food packaging on FLW minimisation (Kakadellis and Harris, 2020), which paves the way for further research, such as the role of innovative sustainable food packaging solutions in preserving food quality, prolonging food shelf-life, and reducing FLW level (i.e. Guillard *et al.*, 2018) or the accounting method for packaging-related FLW (i.e. Pauer *et al.*, 2019; Wohner *et al.*, 2020). The promotion of biodegradable packaging in FSC, which is in line with the pure circle principle of the CE, is also a topic of great interest in this angle.

As for reuse specified in Section 5.3.1, the existence of all three sharing models – sharing for money, sharing for charity, and sharing for community – is evident in both practice and academics. To unlock their full potential, the following research agendas are proposed:

- There is a call for further investigation into the enablers and determinants of the users' engagement in all three food sharing models (Michelini *et al.*, 2020), particularly P2P – a pure sharing model where donor-recipient reciprocity and balance are rare (Harvey *et al.*, 2020). Examples of enablers include the perception and socioeconomic status of online sharing donors, volunteers, and recipients. Stigma from recipients of food, e.g. feeling embarrassment or indebtedness, or fear might challenge the collection of data for this type of research. In addition, the scope of these studies should target various FSC actors from farmers, processors, retailers, restaurants and household to non-profit organisations (Zhu *et al.*, 2018).
- The quantitative examinations of the performance and associated benefits of different sharing models are desirable. Although Choi *et al.* (2019) evaluated the impacts of a sharing for money platform, authors recommend that future researchers conduct performance comparison studies for all three types of food sharing models.

6.2.2. Recycle and recovery

When surplus turns to waste, appropriate FLW recycle and recovery are necessary to retain the FLW value, which is aligned with the regenerative and cascading principle of CE. As we have been in a petroleum-based society for many years, biorefinery that integrates multiple processes needs to be promoted at an industrial scale to effectively compete and replace the fossil-fuel industry (Vardanega *et al.*, 2015). However, a significant number of experiments and technological review papers in the review sample (Section 5.1) suggest that FLW-based biorefinery technologies are mainly at conceptual design, laboratory-scale, or pilot-scale level. The technical viability and economic feasibility assessments for the upscale potentials of these integrated processes are urgently needed (Caldeira *et al.*, 2020). These assessments can be aided by computational tools, such as process modelling and simulation (Vardanega *et al.*, 2015).

Section 4 revealed biorefinery and AD-based technologies as two dominant research lines in the review sample. Biorefinery is linked to the valorisation of the homogeneous stream to generate higher-end products, such as bioactive compounds and animal feed using insect rearing. AD, on the other hand, is associated with energy and compost generation using the heterogeneous FLW feedstock. Compared to the biorefinery, AD is a mature technology with high TRL and has been increasingly deployed in practice. However, operational AD plants using FLW substrate prevalently adopt mono-processes for biogas production, which results in the underutilisation of associated resources (Lytras *et al.*, 2020). Recent research interests have been extended to allow the production of multiple high-value products along with biogas. Examples of desirable outputs include biomethane, biohydrogen, lactic acid, succinic acid, volatile fatty acids, bioelectricity – technological details are available in the review papers of Lytras *et al.* (2020) and Dahiya *et al.* (2018). The technological feasibility and financial feasibility of a sequential production of lactic acid and biogas from FLW were confirmed in Barampouti *et al.* (2019). Further, Section 5.3.2 signalled the issue of low yield and small capacity as the limitations of the current waste conversion technologies, not only for unproven technologies like bio-material extractions but also for the proven technologies like AD. As such, the investigation into optimising process design to produce multiple high-value output products and enhance yields at commercial scale level to maximise the economic feasibility continues to be the promising research avenue for future studies.

6.3. Logistics and supply chain management

Logistics and supply chain management are essential parts of FLW prevention and management (Barampouti *et al.*, 2019; Weber *et al.*, 2020). A significant portion of FLW, particularly for perishable items, is attributed to logistics activities and extensive supply chain networks, which drives the shift towards a more sustainable production and consumption model – a short FSC where foods are produced and consumed locally (Kiss *et al.*, 2019). As tackling the FLW issue cannot be achieved by the voluntary action of a single actor, the commitment of all actors in the entire FSC, which might involve rethinking the supply chain model to minimise FLW, such as via promoting short FSC, is essential (Muriana, 2017). Thus, we suggested a new research line devoted to the unveiling of the performance of short FSC compared to the traditional counterpart taking FLW into consideration. As for reuse, a quantitative examination of various supply chain management issues, including logistics, supply contract, operational risks, revenue models (Choi *et al.*, 2019), is advocated to determine the critical factors underpinning the success of each sharing model (Michelini *et al.*, 2018). For instance, Choi *et al.* (2019) established logistics cost as the significant factor justifying the benefits of the food sharing models.

An effective recycle and recovery of FLW entails the establishment of extensive logistics networks and supply chain management – from the collection, transportation to the production process before launching the output products to the market (Barampouti *et al.*, 2019). When collection and transportation stages are responsible for significant environmental impacts, addressing logistics issues associated with these stages, such as the geographic location of plants, inbound and outbound transport types and distances, is a crucial point that has been emphasised in many papers in review samples (e.g. Nizami *et al.*, 2017; Carillo *et al.*, 2018; Muradin *et al.*, 2018; Vaneeckhaute *et al.*, 2018; Slorach *et al.*, 2019b). Future studies could fruitfully pursue the following research avenues:

- Further innovations in smart collection and transportation systems: Several innovative collection systems are proposed and evaluated in the literature: the use of *under-the-sink FLW disposal* connected to a sewer system; pipelines for FLW transport instead of trucks (Muradin *et al.*, 2018); the use of bio-diesel for truck transportation (Santagata *et al.*, 2017); pre-composter for FLW mass and volume reduction at the collection point (Sakarika *et al.*, 2019); drying process to reduce moisture content allowing longer storage and lower transportation cost (Barreira *et al.*, 2019). More studies in this direction are expected to lower the environmental and cost impacts associated with collection and transportation.
- The shift to decentralised plants*:* there is a growing interest in decentralised FLW conversion technologies in the review sample, e.g. smart bin fermentation system (Yeo *et al.*, 2019). Although fewer plants of bigger size can optimise the economy of scale, its environmental benefits cannot offset the environmental impact deriving from longer transport distance. Take AD

plant, for instance; it was proven that the plant can only create a favourable environmental impact when located within 20km of the maize cropland (Muradin *et al.*, 2018). An interesting argument put forward by Teigiserova *et al.* (2019) indicates that for a FLW-based biorefinery plant, the economy of scope that relies on cascading production is independent of scale, which is beneficial to small and medium scale, short-chain biorefineries. Besides, large biorefinery plants with long transport distances and a long value chain lead to a reduction in the feedstock quality and high transport emissions. The rapid deterioration nature of FLW implies a further loss in nutrient contents. Smaller plants, on the other hand, reduce the associated transport cost, and alleviate the pressures on the required infrastructure for sorting, storage, and transportation (Mak *et al.*, 2020) while intensifying the production process to increase value-added (Banerjee *et al.*, 2018; Barampouti *et al.*, 2019). This trend also incentivises the closed-loop model, which is aligned with the industrial symbiosis principle of the CE; for instance, a decentralised biogas plant is located in the vicinity of an agri-food processing plant, from which the FLW feedstock is supplied to the biogas plant via transmission pipelines while the generated heat is fed back to the processing plant or its farms (Muradin *et al.*, 2018).

6.4. Market demand for food surplus and bio-based products

This factor is not applicable to prevention but crucial for other options. For reuse, special attention should be paid to deriving a reliable approximation for the financial value of food surplus circulated in three sharing models, thereby reflecting better the real value brought about by these sharing operations (Richards and Hamilton, 2018; Harvey *et al.*, 2020). For recycle and recovery, technological feasibility and continuous supply assurance are not the only constraints for commercial success. The market factor should be taken into consideration to expand and diversify market outlets of bio-based products and attract investors' interest (Woon and Lo, 2016; Borrello *et al.*, 2017; Genovese *et al.*, 2017; Chojnacka *et al.*, 2019; Mak *et al.*, 2020). Thus, we call for more studies on two following research avenues:

- To further investigate customers' perception and interest towards FLW-based products. When the market price of bio-based products is found to be higher than the fossil-based alternatives such as in cases of bioplastics (in Shogren *et al.*, 2019; Teigiserova *et al.*, 2019) and biofertilizers (in Chojnacka *et al.*, 2020), drivers for purchasing bio-based products stem directly from attitude and indirectly from green self-identity. Thus, insights into consumers' attitudes and how those attitudes might be influenced provide useful information to producers and consumers beyond the basic idea of how FLW can potentially be recovered for reuse (Russo *et al.*, 2019).
- To explore the generic market condition factors, i.e. market saturation and market power, of the output products. This is because the market price of bio-based products is strongly linked to the global supply and demand of both bio- and fossil-based products (Teigiserova *et al.*, 2019). Undoubtedly, the more expensive the products become the higher the incentives to tap into the cheaper alternatives, e.g. low-cost food waste resources. Moreover, such incentives also depend on market power. Take the fertiliser market as a salient example. As demand for fertiliser always exceeds supply, fertiliser producers who possess strong market power are less likely, without an explicit support regime, to alter their hundred-year fossil-based production technology (Chojnacka *et al.*, 2020).
- The nutritional value and safety analysis entail further attention to enhance the understanding of end-users about the potential benefits and impacts (Longhurst *et al.*, 2019; Teigiserova *et al.*, 2019). This should be supported by scientific evidence, especially for nutraceutical products where their effectiveness might not be clear.

6.5. Sustainability impact assessment

Section 5.4 revealed that the selection of optimal FLW prevention and management options requires a detailed economic, environmental, and social assessment. Meanwhile, there is a growing interest in the adoption of a life cycling approach to aid such a decision (Ingrao *et al.*, 2018; Laso, García-Herrero, *et al.*, 2018; Omolayo *et al.*, 2021) because it fosters the development of a coherent modelling and a systematic analytical framework of FLW prevention and management (De Menna *et al.*, 2018). Four future research avenues are identified in this section:

- We call for the development of a list of friendly integrated sustainability impact indicators allowing a balance between environmentally-friendly goals, economic returns, and social benefits in future FLW prevention and management research. This need is also underscored in a number of papers (e.g. Zabaniotou, 2018; Omolayo *et al.*, 2021). Much attention is given to environmental and economic assessments, while the inclusion of social aspects is rare and mainly constrained to job creation (Ubando *et al.*, 2020), which demands further consideration. A list of social indicators proposed by Kooduvalli *et al.* (2019); Ioannidou *et al.* (2020) can be employed. Additionally, an integrated LCA, LCC and social life assessment (s-LCA) for triple-bottom-line assessment opens up interesting research avenues for future studies (Imbert, 2017; Mak *et al.*, 2020). Further, we recommend that SIA indicators are tailored for specific target products, e.g. creation of biogas-specific technical standards for biogas-derived energy (Ingrao *et al.*, 2018). Moreover, the incorporation of a nutritional value in SIA also leaves a promising avenue of research in the future (i.e. in Ingrao *et al.*, 2018; Laso, Margallo, Serrano, *et al.*, 2018).
- Since laws and policies regarding FLW vary across spatial context and best practices are influenced by seasons and locations, there is a need for developing spatial and temporal SIA studies in different areas and socio-economic contexts at different periods to enhance data transparency, facilitate cross-comparison and support spatially and temporally targeted FLW polices (Omolayo *et al.*, 2021).
- A dearth of studies incorporates prevention and reuse (the top priorities in the waste hierarchy) in SIA. This is partly attributed to the methodical difficulties in acquiring reliable data concerning FLW prevention actions (Cristóbal, Castellani, *et al.*, 2018). Due to the context-laden characteristics of FLW issues, the waste hierarchy should only be seen as a rough generalisation (Eriksson and Spångberg, 2017). Donation might not always be as strictly environmentally efficient as AD or incineration (Eriksson et al., 2015). An SIA applicable to all levels of the waste hierarchy is desirable to inform decision-making, and in the long term, promote the design of sustainable and cost-efficient interventions and more resource-efficient FSC (Cristóbal, Castellani, *et al.*, 2018). Further, it is unlikely that a single option in the waste hierarchy is sufficient to tackle the FLW problem. For instance, although reuse is favourable, food hygiene or biosecurity decreases the likelihood of reuse for the entire FLW stream; thus, a flexible combination of prevention, reuse, recycling and recovery tailored for the local infrastructure is highly recommended (Eriksson and Spångberg, 2017).
- Similarly, SIA should also be carried out to assess the comparative impacts of the production of the FLW-based products versus fossil-based counterparts (Ioannidou *et al.*, 2020); and of FLW-based products versus first-generation biomass-based alternatives (Mak *et al.*, 2020). This is to avoid the suboptimal designs of FLW-based biorefineries with almost the same environmental burdens as the petrochemical systems (Zabaniotou and Kamaterou, 2019).

6.6. Policy and legislation

Policy and legislation are widely acclaimed for their instrumental role in shaping national FLW prevention and management directions. For instance, the UK policies incentivise FLW prevention and conversion to energy and compost, while surplus food redistribution has not gained equal interest (Facchini *et al.*, 2018). Combined with the highly fragmented and independent redistribution efforts, the outreach of food redistribution initiatives in the UK is therefore limited. The provision of government incentives is important to develop a larger and coherent redistribution system at all stages of the FSC (Facchini *et al.*, 2018) and to make the best use of sharing models for the entire FSC (Choi, 2020). For prevention, the government can shift the FSC actors' awareness and behaviour towards more sustainable production and consumption models via educational programs, FLW monitoring and FLW separation policy at the household level. Although the effectiveness of these campaigns has been analysed in several studies (Jereme *et al.*, 2018; Johansson and Corvellec, 2018; Aschemann-Witzel, Giménez, *et al.*, 2019), these studies are confined to a specific context-setting. Similar studies could be replicated in different countries to support policymaking progress. The organisation and efficiency of short FSC can also be fundamentally affected by governmental support or regulatory policies (Kiss *et al.*, 2019).

For reuse and recycle, policy and legislation can progress and hinder these FLW activities. As a driver, law and regulations influence the development of specific FLW management routes via penalty and reward instruments, such as subsidy, tax relief, biofuel obligation or disposal fee (Liu *et al.*, 2018; Zabaniotou, 2018; Ferella *et al.*, 2019). A ban on surplus disposal at supermarkets, such as in France, promotes donations efforts (Lee and Tongarlak, 2017; Richards and Hamilton, 2018; Harvey *et al.*, 2020). In addition, strong legislative support can educate consumers to recognise the benefits of bio-based product consumption which increases public acceptance and induces behavioural change. This contributes to ensuring the market demand for FLW-based products. Conversely, conflicting and unharmonised policies might constrain engagement in FLW management. The unclear legal status of digestate, as analysed in Section 4.3, is a stark example. Besides, legal restrictions might eliminate the potential for full-scale implementation of the valorisation options (Quina *et al.*, 2017), such as the EU stringent regulation on the reuse of foods as animal feeds and bans on the use of animal by-products as feeds (zu Ermgassen *et al.*, 2018). Thus, re-legislation should be considered to help farmers to cut cost, save land use and environmental impacts. Further, a lack of a long-term support regime by the government prevents the diffusion of innovative technological initiatives (Genovese *et al.*, 2017).

It is noted that as FLW-related policy support and legal regimes vary from country to country (De Clercq *et al.*, 2017), cross-country comparison offers interesting insights and useful lessons to be learnt. For instance, Teigiserova *et al.* (2020) underlined the variations in the food surplus reuse strategies of the EU member countries: Italy encourages food donation in the whole FSC; Denmark, Belgium, France only target the retail level; Germany, Portugal, and Hungary stimulate food donation via tax deduction. Giordano *et al.* (2020) compared Italian and French laws regarding FLW hierarchy and uncovered that Italian law puts more effort into prevention by raising awareness campaigns while French laws focus mostly on the actions of supermarkets. De Clercq *et al.* (2017), who compared the legal framework of seven countries for FLW-based AD technology, associated the rapid proliferation of AD plants in China with its centralised policy setting, and recommended that China adopt consumption-linked subsidy schemes as in Germany and Sweden to tie the payments to the amount of biogas consumed rather than the amount produced to avoid biogas being dumped at low price. The paper also underlined the role of the policies in the UK and France in incentivising the production of multiple outputs – such as electricity, heat, and bio-fertiliser – from AD plants in order to ensure revenue stability for plant operators.

7. Conclusion and limitations

7.1. Conclusion

In this study, a novel taxonomy is proposed to synthesise and classify the exhaustive and highly fragmented FLW literature under the CE landscape into six streams of research: (i) FLW sourcing and quantification, (ii) practices and technological aspects, (iii) logistics and supply chain management (iv) market factor (v) sustainability impact assessment (vi) policy and legislation. The taxonomy allows us to accentuate current research lines and paves the way for future research directions (Table 5). While the spotlights in the academic agenda are currently on the second and fifth factors: FLW prevention practices and conversion technologies and LCA-based SIA, more consideration needs to be given to the remaining factors.

We believe that this study offers fruitful suggestions for scholars at the crossroads of two domains, the CE and FLW management. First, our taxonomy urges comprehensive approaches towards an integrated FLW prevention and management framework for gaining the overall benefits, beyond technological feasibility. Extensive research agendas can direct future researchers towards the achievement of such a holistic approach while avoiding stagnant and saturated research areas. Second, a thorough discussion of how the CE principles are translated into FLW prevention and management offers an insight into the underlying features of the FLW under the CE that goes beyond the waste hierarchy. Although this study is primarily oriented towards an academic audience, it has clear implications for policymakers and decision-makers. The taxonomy offers a useful guideline for managers and policymakers in structuring their strategies and actions for effective FLW prevention and management at both national and supply chain levels. Managers are encouraged to quantify FLW-related problems and explore a range of potential options to tackle them. These options should be quantitatively assessed to apprehend possible trade-offs considering six research streams in the taxonomy framework simultaneously. Policymakers play an instrumental role in keeping these options open to managers via effective incentive schemes. Meanwhile, conflicts and ambiguity in laws and regulations should be solved on the basis of scientific evidence.

7.2. Limitations

Finally, it is important to point out certain limitations of the paper. The first limitation comes from our search restriction to two databases – Scopus and Web of Science – which might exclude relevant papers that have not been listed in one of these databases. However, we believe that the rigour of the entire SLR process, which covers and reflects the extensive body of knowledge, offers a fairly comprehensive and systematic picture of the research topic, and thus, the credibility of research results is ensured. In addition, the breadth of the study may come at the cost of the depth of the analysis. We have used a reasonable mix of keywords on two large topics – FLW and CE – that yield a significant number of papers without constraint to a particular research domain. Although relevant references are provided in each section to guide future researchers and alleviate the depth limitation, we call for more collaborative research among researchers from diversified fields, such as supply chain management and operation management, to deepen the understanding of the role of each factor in our framework.

Appendix 1

Literature review papers on FLW under the CE

Area of focus	Size	References	Size	Stages of FSC			FLW prevention and management options						Evaluation Criteria				
				FH	PM	RC	Pre-vention	Reuse	Feed	Chemi-cal	Energy	Compost	Tech	Econ	Env	Scio	Poli
FLW conversion technologies	1	Mirabella *et al.* (2014)	111		x					x			x				
	2	Capson-Tojo *et al.* (2016)	N/S			x					x		x	x	x		
	3	Kaur *et al.* (2018)	N/S	x	x	x				x			x				
	4	de la Caba *et al.* (2019)	10		x					x			x	x	x	x	x
	5	Barreira *et al.* (2019)	N/S		x					x			x				
	6	Castro-Muñoz *et al.* (2018)	N/S		x					x			x	x	x		
	7	Caruso *et al.* (2019)	N/S	x							x		x				
	8	Macura *et al.* (2019)	N/S	x								x					
	9	Elkhalifa *et al.* (2019)	N/S	x	x	x					x	x	x	x	x		
	10	Ferrazzi *et al.* (2019)	31			x			x				x				
	11	Gasco *et al.* (2020)	N/S		x	x			x								x
	12	Kim *et al.* (2020)	N/S	x	x	x					x	x	x				
	13	Ricciardi *et al.* (2020)	200	x						x			x				
	14	Ng *et al.* (2020)	N/S	x	x					x	x	x	x				
	15	Chandrasekhar *et al.* (2020)	N/S	x	x	x					x		x				
	16	Casallas-Ojeda *et al.* (2020)	N/S			x					x	x	x				
	17	Awasthi *et al.* (2020)	N/S			x						x	x				x
	18	Chojnacka *et al.* (2019)	N/S	x		x						x	x				
	19	Peng and Pivato (2017)	N/S			x						x	x				
	20	Bruni *et al.* (2020)	N/S			x						x	x				x

	21	Pinotti *et al.* (2020)	N/S	x					x				x				
	22	Maschmeyer *et al.* (2020)	N/S	x	x				x	x			x				
	23	Negri *et al.* (2020)	N/S			x					x		x	x			x
	24	Guilayn *et al.* (2020)	N/S			x					x		x				
Biorefinery model	25	Venkata Mohan *et al.* (2016)	N/S	x	x	x				x	x		x				
	26	Nizami *et al.* (2017)	N/S	x	x	x							x	x	x	x	x
	27	Maina *et al.* (2017)	N/S	x	x	x				x	x	x	x				
	28	Berbel and Posadillo (2018)	N/S		x				x	x	x	x	x				
	29	Banerjee *et al.* (2018)	N/S		x					x			x				
	30	Dahiya *et al.* (2018)	N/S		x	x				x	x	x	x				
	31	Jin *et al.* (2018)	N/S	x	x					x	x		x	x	x	x	x
	32	Zabaniotou and Kamaterou (2019)	93		x					x	x		x	x	x		x
	33	Contreras *et al.* (2019)	N/S	x	x					x	x		x				
	34	Morone *et al.* (2019)	28	x	x	x	x	x	x	x	x	x					
	35	Battista *et al.* (2020)	N/S							x	x	x	x				
	36	Lytras *et al.* (2020)	N/S			x				x	x	x	x				
	37	Madeddu *et al.* (2020)	N/S	x	x					x			x				
	38	Ubando *et al.* (2020)	N/S		x	x				x	x	x	x				
	39	Wainaina *et al.* (2020)	N/S			x					x		x	x	x		
	40	Barampouti *et al.* (2019)	N/S			x				x	x		x	x			
	41	Ioannidou *et al.* (2020)	N/S		x					x			x	x			
	42	Dattatraya Saratale *et al.* (2020)	N/S		x					x	x		x				
LCA methods for FLW prevention	43	Ingrao *et al.* (2018)	20			x					x		x		x		
	44	De Menna *et al.* (2018)	27	x	x	x							x	x			

and management routes	45	Vieira and Matheus (2019)	25			x					x	x	x		x		
	46	Kakadellis and Harris (2020)	19			x				x			x		x		
	47	Omolayo *et al.* (2021)	22	x	x	x	x	x	x	x	x	x			x		
Methods of quantifying the FLW flows	48	Corrado and Sala (2018)	10	x	x	x											
	49	Facchini *et al.* (2018)	N/S			x		x									
	50	van der Wiel *et al.* (2020)	N/S			x	x										
FLW-related policies	51	De Clercq *et al.* (2017)	N/S	x	x	x	x				x		x	x	x		x
	52	Mak *et al.* (2020)	N/S														
The FLW hierarchy framework	53	Vilariño *et al.* (2017)	N/S	x	x	x							x	x	x	x	x
	54	Kyriakopoulos *et al.* (2019)	N/S	x	x	x							x	x	x	x	x
	55	Paes *et al.* (2019)	33			x					x	x	x	x	x	x	x
	56	Teigiserova *et al.* (2020)	N/S	x	x	x	x	x	x	x	x	x					
FLW prevention behaviours	57	Hebrok and Boks (2017)	112			x	x										x
	58	Schanes *et al.* (2018)	60			x	x										x
This paper			297	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Note: FH: Farming & Harvesting; PM: Processing and Manufacturing; RC: Retail and consumption.

N/S: Not specified the number of articles under review.

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