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

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Abstract

Food waste reduction has been recognised as one of the top priorities under the recent European Union's Circular Economy Package and contributes to achieving the United Nations' Sustainable Development Goals (SDG 12.3). Circular Economy (CE) aims to retain the maximum value of the products and materials for a longer time in a closed-loop manner, thereby decoupling natural resource usage and economic growth. While food loss and waste (FLW) prevention and management are well-studied in literature, its researches in the CE landscape are fairly new. Through a systematic literature review, this study aims to create a taxonomy for synthesising the key aspects of FLW under the CE. A collection of 297 papers from Scopus and Web of Science was reviewed and analysed using keyword co-occurrence network analysis and structural analysis, which provides the foundation for the construction of the framework. Keyword co-occurrence network analysis allows the identification of three emerging research themes: impact assessment, biorefinery and nutrient recycling. Structural content analysis reveals the types of research methodologies, types of FLW streams, FLW prevention and management practices with associated opportunities and challenges, and the sustainability impact assessment (SIA) indicators that have been addressed in the literature. Based on these analyses, the taxonomy is proposed and future research directions are drawn along six elements: FLW supply and quantification, practices and technological aspects, logistics and supply chain management, market demand, SIA, and policy and legislation. With insights into the CE concept and FLW prevention and management, the taxonomy contributes to helping key stakeholders, including industry practitioners to grasp new business opportunities, politicians to set support strategy and strategic development plan, consumers to raise awareness and be actively involved in CE, researchers to identify novel research themes, and the society to recognise other benefits of bio-waste-based bioeconomy.

Highlights

- The proposed taxonomy is original because it takes a holistic approach and combines two areas, circular economy and food loss and waste.
- Six principles of circular economy integrated in 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

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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 billion tonnes of CO_2 equivalent) of total greenhouse gas (GHG) emission (FAO, 2014). Halving the amount of FLW contributes to reducing GHG emission from food-sourced by about 20-30% (Bajželj *et al.*, 2014). While about 10.7% of the world population (nearly 815 million) is undernourished (FAO, 2018) and 9.6 billion people need to be adequately fed by 2050 (United Nations, 2017), wasting foods represents a contemporary economic, environmental, social and ethical challenge at a global scale, which requires urgent political attentions to combat this global issue (FAO, 2013; Searchinger *et al.*, 2019; Teigiserova *et al.*, 2020). One of novel efforts to prevent and manage 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 put forward a series of actions to promote more sustainable production and consumption behaviours and patterns in EU food system, e.g. food donation and the 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 in meeting the United Nations' Sustainable Development Goal (SDG 12.3) "*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 its momentum in the CE-related academic discourse with exponential growth in the 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 number of extant literature that deal with the FLW in the CE. Appendix 1 presents a summary of such studies, providing authors' name, year of publications, 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 captured 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 differences between the first two topics lie 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 on a specific topic area, dominantly on technological feasibility in a fragmented manner. Since the 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 triple R's 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 bioprocess for the authentic transformation of 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. These narrative method of synthesising previous studies is criticised to be 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 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). This extensive review has three-fold objectives: *(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 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. 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 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[2] 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 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 FAO's conceptual framework excludes not only inedible parts of foods but also the edible foods that destined to an economically productive non-food use, such as animal feeds or industrial use. FUSIONS (2014), on the other hand, does not distinguish loss and waste and involve edible parts of foods in its proposed definition. FUSIONS (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

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

highlighted the difference between *food surplus* and *food waste*. Although food surplus is still a part of FSC and fits for human consumption, it would have ended 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 among 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 reduce 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 resource embedded in each product".

The CE concept cannot be traced back to any particular authors or dates, rather considered as the synthesis of various school of thoughts, 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 the 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 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 promote the use of wastes of one person to be resources of others, as well as minimise resource leakage (Pauli, 2010). 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 is used for lower value energy and composting production. Stimulated by biomimicry, 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 fall out 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 to the environment. Inspired by industrial ecology, the CE supports the establishment of industrial symbiosis which involves the mutually beneficial exchanges of materials, energy, water, and wastes among parties with geographic proximity to design out waste concept (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 the FLW prevention and management following six below principles:

(i) Circling longer principle: To keep foods longer in use by extending their shelf-life and re-distributing surplus foods to human consumption, which contributes to lower 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[3], rather than converting the entire food waste products into low-value energy generation (inspired by the blue economy)

(iii) Regenerative principle: To re-introduce the biological nutrients back to 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 recycle 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 exchanges of FLW as resources at local scale and regional scale (inspired by industrial ecology)

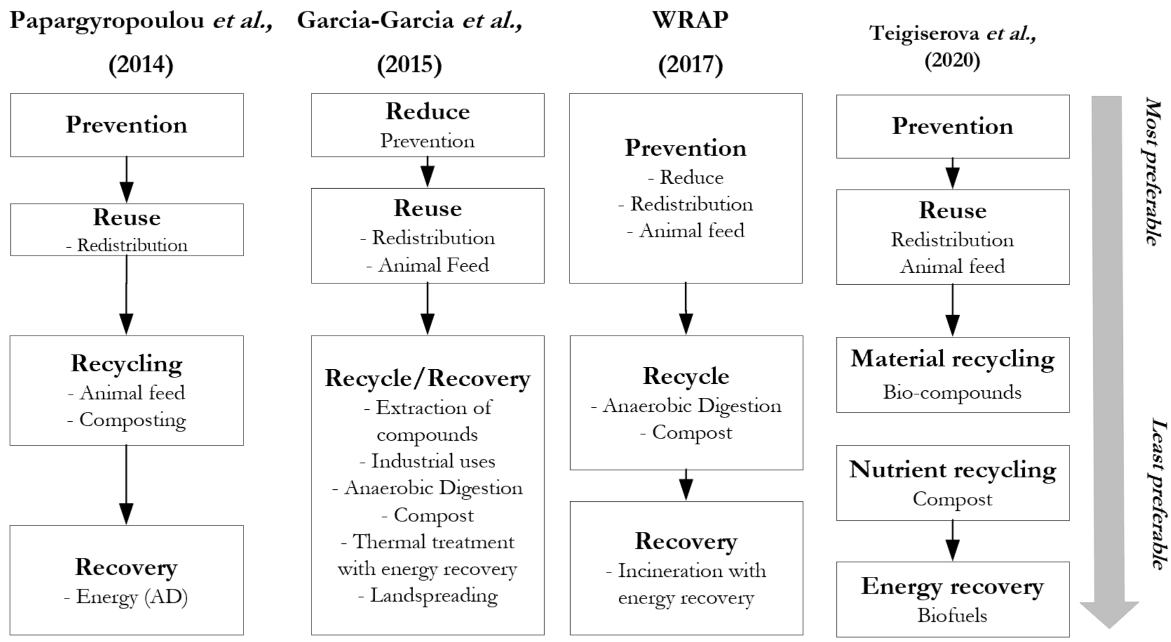


Figure 1: Food waste prevention and management options – Terminology review

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

These underlying principles fundamentally transform FLW prevention and management under the CE landscape beyond the food waste hierarchy. Waste hierarchy that was built upon the European Waste Framework Directive (WFD) dated back in 1975 and the current version in 2008, 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. Though the hierarchy encourages the circling longer (prevention and reuse) and regenerative principle (recycle and recovery) of the CE, it disregards other principles, particularly cascading principle where economic value is taken into consideration. In addition, the generic terminologies used in waste hierarchy open to

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

different interpretations by users, especially when applied to a specific industry, such as food sector (Teigiserova *et al.*, 2020), leading to the 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 the redistribution to people in form of donations or food sharing while recycle and recovery aim at converting FLW into a range of value-added products, following biomass value pyramid. However, we are aware that few studies might include animal feed conversion option in reuse (Garcia-Garcia *et al.*, 2015; Teigiserova *et al.*, 2020). Meanwhile, 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), though distinguishing reuse from prevention, listed donation as the prevention initiatives. 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 three resource management loops, 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 this paper's scope.

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 and 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. Initial screening is carried out to observe the distribution of 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 in 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 streams	- 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 have been considered as 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 merge of two databases is beneficial to increase the likelihood of capturing 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 in Scopus and 1011 papers from WoS is obtained.

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
   - Excluding 357 papers in Scopus and 103 papers in WoS
   - Including: 919 Scopus and 908 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 paper 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 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 only if they are linked to the FLW discourse, such as the output products (bioplastics) or its 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 its relevance with the research objectives.
   - Irrelevant papers: 78 papers
   - Total full-text papers retained for review: 287 papers.

(v) All references in the papers in our sample in the step (iv) were checked. This led to an additional of 21 papers, out of which 10 were found relevant and added to the sample.
   - 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, the studies in this area were scarcely carried out. 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 construction 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 the interests in the FLW and the CE has begun to take off in academia (Figure 2).

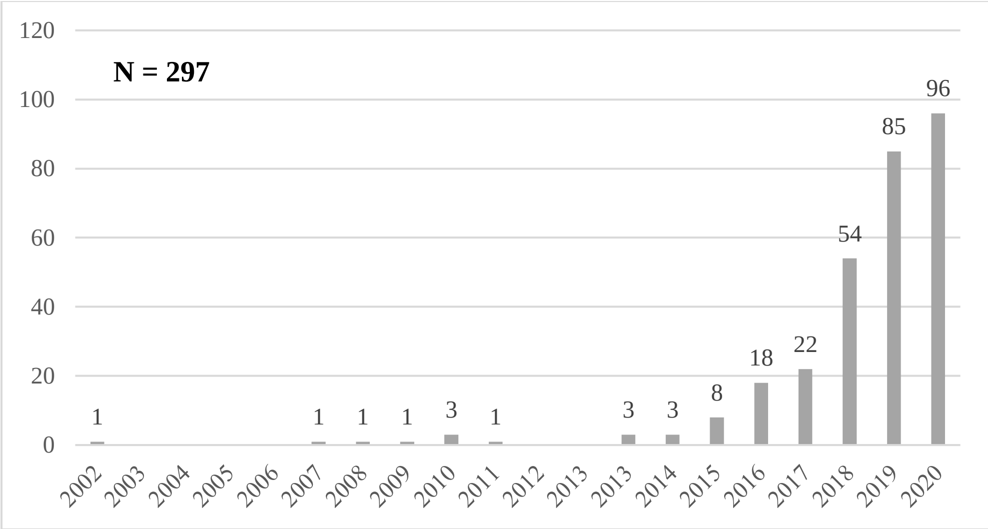


Figure 2: Research evolution on the topic of FLW management in the circular economy

In term of targeted journals (Figure 3), 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 FLW topic under the CE landscape can be linked to multiple research fields, the scope of the review papers fits well with the scope of these journals, which epitomises the biotechnological advances and sustainability paradigm.

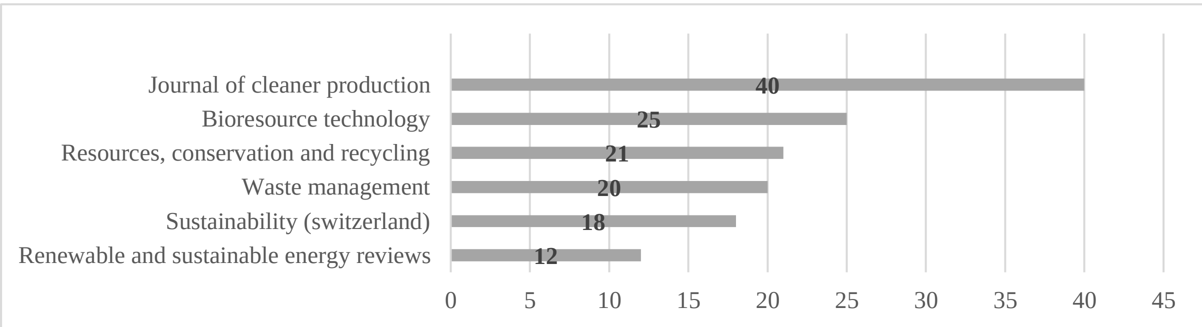
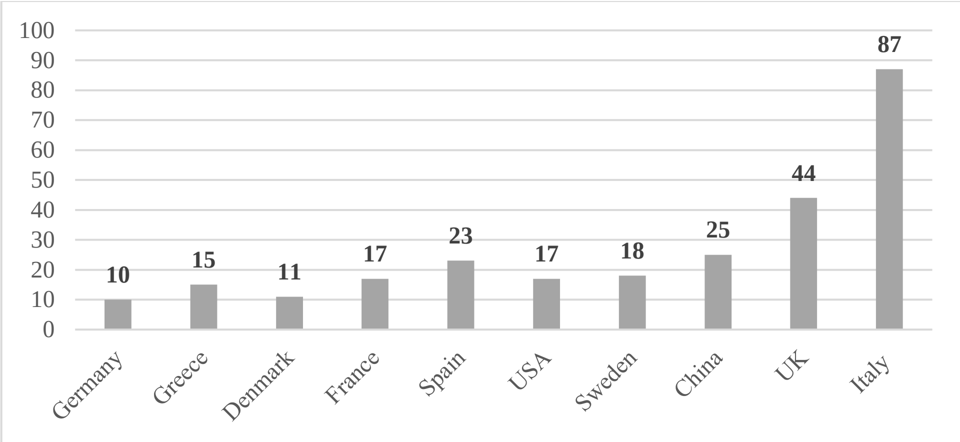
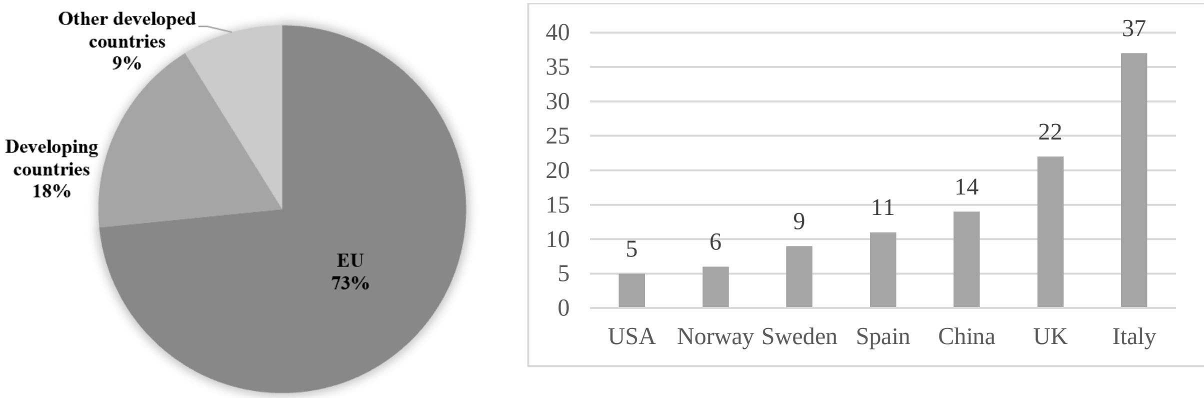


Figure 3: The number of articles per Journal (Journals with more than ten publications)

In term of geographical distribution, the majority of the articles are linked to the 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 are carried out in the EU, notably in Italy and the UK. 9% of these studies are linked to the 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 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 determines the relatedness of the keywords, which implies that the larger the number of articles in which two terms are both found, the stronger the relationship between the terms. 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).

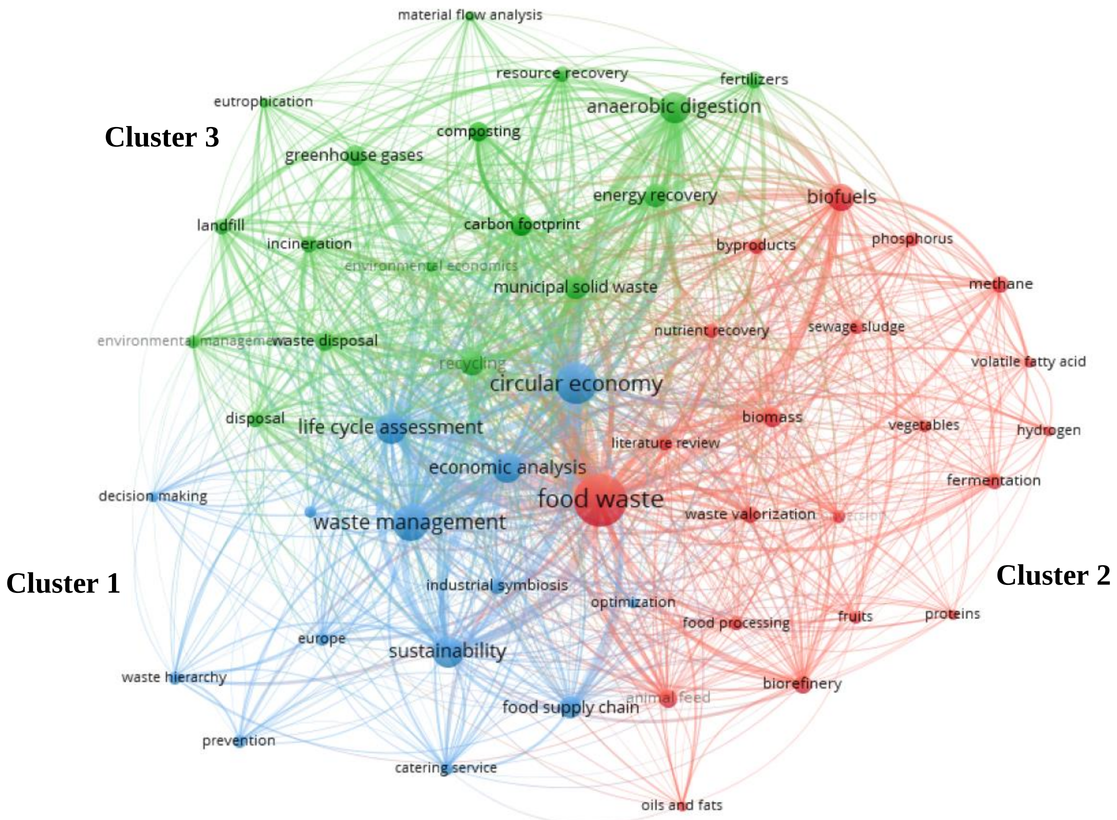


Figure 5: Keyword co-occurrence analysis

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 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 FSC. Resource exchanges at local scale following industrial symbiosis principle are increasingly emphasised as the interface between circular economy and sustainability (Imbert, 2017).

This relationship has been quantitatively measured using LCA and economic analysis tools, as revealed 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 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 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 sparks growing interests in utilising FLWs as alternative feedstocks over the last few years (Venkata Mohan *et al.*, 2016). However, the technology remains novel, which necessitates further investigation in 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 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 at small scales in any geographical locations (Ingrao *et al.*, 2018) that make it fit well to the industrial symbiosis and regenerative principle of the CE. It is estimated that if all bread wastes in the UK is fed into AD plants, it could generate roughly 10% (198 GWh) of the total energy used in bread sector each year (Veldhuis *et al.*, 2019). Comparing 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 plant 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 contributes 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). Take Italy, for instance. Italy accepts the use of digestate from agro-feedstock but bans those from organic Municipal Solid Waste (MSW). Moreover, the statistical analysis study of Beggio *et al.* (2019) established 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 in 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 are fallen into five types (i) experiment, (ii) modelling, (iii) literature review, (iv) theoretical and conceptual framework (v) survey; in which the first three methods are the most popular (Figure 6).

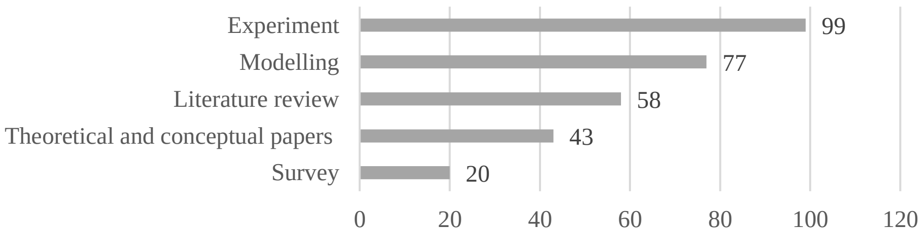


Figure 6: Type of research methods employed

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 techno-economic feasibility and environmental impact of different FLW prevention and management options and quantify the flow of the FLW stream. Novel MFA-LCA and agent-based approach to improving nutrient cycle management in agricultural system is proposed in Fernandez-Mena *et al.* (2016). Literature review papers (58 papers) comes third with the focus on seven topics that have presented in the introduction and 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 collection and recycling of MSW (Woon and Lo, 2016).

Finally, survey is the least employed method (20 papers) with the main aim 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 airlines' employees (Sambo and Hlengwa, 2018) and of restaurant's owners (Lang *et al.*, 2020).

5.2. The FLW stream

FLW streams in 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 fits 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 review sample is accorded to heterogeneous and homogeneous flows, whereas a much lesser extent is paid to the surplus.

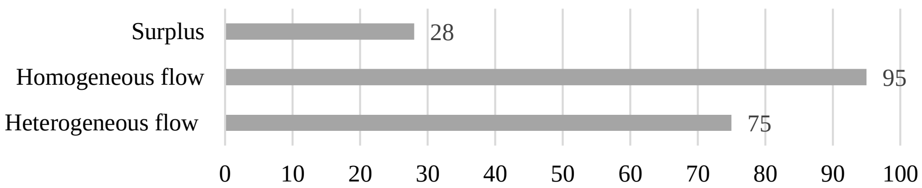


Figure 7: Types of FLW streams

Food surplus mainly occurs at the retail and consumption stages of the FSC but can arise from manufacturing and agricultural stages due to overproduction (Papargyropoulou *et al.*, 2014; Garrone *et al.*, 2016). Homogeneous flow is normally generated in the food processing stage and agricultural activities (agro-residues) (Banerjee *et al.*, 2018; Egelyng *et al.*, 2018) but it can also occur in the catering service in the case of spent coffee grounds (SCG) (Kourmentza *et al.*, 2018) or used cooking oils in the restaurants (Carmona-Cabello *et al.*, 2019). This waste stream has high compositional homogeneity and can occur at large quantities in specific locations (Cristóbal, Caldeira, *et al.*, 2018), offering abundant and low-cost resources. However, underlying challenge with this waste stream comes from seasonality and regional patterns (Gontard *et al.*, 2018), which might pose risks for year-around operation of the single-feedstock plant (Banerjee *et al.*, 2018). Conversely, the heterogeneous waste stream often stems from supermarket and household (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, should be prioritised for energy conversion and composting over incineration and landfill. Compared to homogeneous flow, this waste stream is difficult to quantify potential scale and composition (Rathore *et al.*, 2016). Also, 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 presented the preferences in literature across various FLW prevention and management options. Recycling and recovery attract wider research attention comparing to prevention and reuse, which is aligned with the finding in KCN in Section 4.

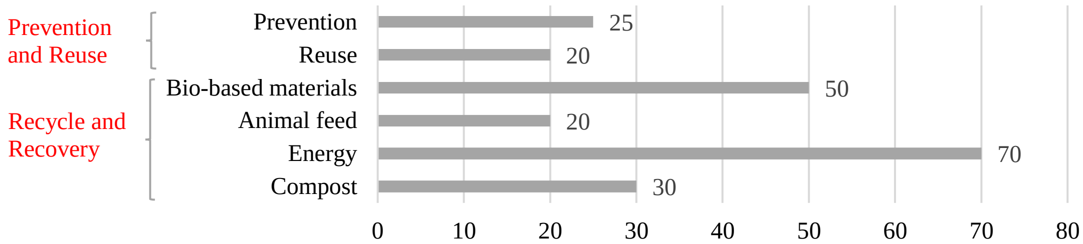


Figure 8: Types of FLW prevention and management options

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 review sample investigates the effectiveness of waste policy and prevention program 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 lower household food waste generation, e.g. by standardising data labelling, printing food storage tips in carrier bags, or revising promotion campaign for perishable foods (Vilariño *et al.*, 2017; Teigiserova *et al.*, 2020). Similarly, processing firms can reduce food wastes by remanufacturing or sale 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 a growing research recognition with a diversity of sharing models, e.g. harvest sharing, meal sharing and leftover sharing (Zurek, 2016) and numerous 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). Review sample has 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. shared plats and campus apartment in Italy (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 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, the uncertainty in the estimation of surplus availability (Facchini *et al.*, 2018), low participation interests due to incurred time and efforts 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 heats. 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 in 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 largest attention in the literature, followed by compost production. The literature is limited on the production of animal feeds. Main feedstock for bio-based material extraction and animal feeds are agro-residues, by-products from processing (e.g. fruit pulp) and vegetable/fruits 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 not merely influenced by technological feasibility (Genovese *et al.*, 2017) but also impacted by supply, market, logistics, policy and 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 to 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 term 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 insect 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 customers' acceptance (Rumpold and Langen, 2020) hinder the waste-to-feed proliferation. - **Policy:** regulations on animal feed productions 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 transports, 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 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 interests from fertiliser producers (Chojnacka *et al.*, 2020) and no pressure to change in the fertilisers (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 of 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, interests are dominantly given to environmental impact or economic feasibility assessment or a combination of both. The social assessment is scarcely addressed, which 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 summarised a list of commonly used indicators in the review sample. It is noted that there is a lack of clear guideline on the use of criteria/indicators/metrics in 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 has adopted this set.

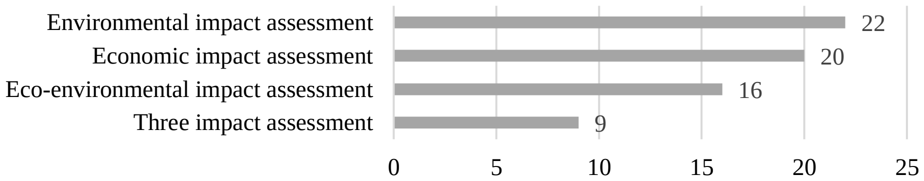


Figure 9: Types of sustainability impact assessments

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 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 adopted 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 energy balance of seven waste management system. 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 following economic indicators: treatment cost, profitability index, NPV, IRR, payback period. These indicators are assessed using some tools, such as Break-Even Point (BEP) analysis (in Ferella *et al.*, 2019), Levelized Cost of Energy (LCOE) to compute NPV (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 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 common methodological approach nor 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 indicator 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, the potential job creation and feedstock remuneration premium, whereas Sgarbossa and Russo (2017) measured energy self-sufficiency indicator (ESS), profitability indicator (PI), employment possibility indicator. Vaneeckhaute *et al.* (2018) utilized 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 elements of FLW management under the CE framework. Methodological analysis indicated the important role of the FLW streams quantification and statistical assessment. Three types of waste streams – 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 on the detailed and extensive analysis, we propose a novel way of classifying main research streams in the FLW management under the CE into six areas: (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 synthesis and classification of extant literature aim to push further evolution in this ever-increasing research agenda (Table 5).

Table 5: Research agenda basing on the taxonomy framework.

	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 the relationship between FLW minimisation and food packaging, especially for biodegradable packaging. - Examine 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 model 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's performance considering FLW reduction. - Quantitatively assess the operational management issues, logistics, supply contract, operational risks, revenue models of various food sharing models	- Focus on smart collection and transportation system. - Shift to the decentralised, small and medium-scaled biorefineries.
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-based products.

		- Explore the influence of market factor (market saturation and market power) for FLW-based bioproducts. - Analyse health and safety aspects of novel biowaste-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 context. - Assess the entire waste hierarchy including the prevention and reuse options. - Assess the benefits and impacts of the production of the 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 the cross-country comparison on the influences of policy setting on FLW prevention and prevention's directions is desirable	

6.1. FLW supply and quantification

The reliable quantification of potential FLW stream is the first and crucial step to support 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 potentials 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 pattern (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 streams (Corrado *et al.*, 2017; Teigiserova *et al.*, 2019). There is a pressing need to improve availability, reliability and level of details 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, a harmonised methodology for FLW quantification is in urgent need. 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 the 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 of their influences on 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, prolong 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 potentials, the following research agendas are proposed:

- There is a call for further investigation in 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 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 future researchers to conduct performance comparison studies for all three types of food sharing models.

6.2.2. Recycle and recovery

When surplus turns to wastes, 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 the 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 review sample (Section 5.1) suggests 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 more matured technology with high TRL and have been increasingly deployed in practice. However, operational AD plants using FLW substrate prevalently adopt mono-process for biogas production, which results in the underutilisation of resources associated (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 the logistics activities and extensive supply chain networks, which drives the shift towards more sustainable production and consumption model – a short FSC where foods are produced and consumed locally (Kiss *et al.*, 2019). As tackling FLW issue cannot be achieved by the voluntary action of a single actor, the commitment of the entire FSC actors that 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 performances 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 network 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 pursuit following research avenues:

- Further innovations in smart collection and transportation system: Several innovative collection systems are proposed and evaluated in 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 the 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 at bigger size can optimise the economy of scale, its environmental benefits cannot be offset environmental impacts 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 from the cropland of maize (Muradin *et al.*, 2018). An interesting argument put forward by Teigiserova *et al.* (2019) indicates that for 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 distance and long value chain lead to the reduction in the feedstock quality and high transport emission. 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 that 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 heats are 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 derive 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' interests (Woon and Lo, 2016; Borrello *et al.*, 2017; Genovese *et al.*, 2017; Chojnacka *et al.*, 2019; Mak *et al.*, 2020). Thus, we called for more studies on two following research avenues:

- To further investigate customers' perception and interests towards FLW-based products. When the market price of bio-based products is found to be higher than the fossil-based alternatives such as for 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 the bio-based products strongly links to global supply and demand of both bio- and fossil-based products (Teigiserova *et al.*, 2019). Undoubtedly, the more expensive the products become the higher 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 fertiliser's demand always exceeds supply, fertiliser producers who possess strong market power are less likely, without explicit support regime, to alter its hundred-year fossil-based production technology (Chojnacka *et al.*, 2020).
- The health and safety analysis entails further attention to enhance the understandings 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 detailed economic, environmental, and social assessment. Meanwhile, there is a growing interest in the adoption of life cycling approach to aid such 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 among environmentally-friendly goal, economic returns, and social benefits in the future FLW prevention and management researches. This need is also underscored in a number of papers (e.g. Zabaniotou, 2018; Omolayo *et al.*, 2021). Much attention is given to the environmental and economic assessments, while the inclusions of social aspects are 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 the SIA indicators to be tailored for specific target-product, e.g. creation of biogas-specific technical standards for biogas-derived energy (Ingrao *et al.*, 2018). Besides, 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 context 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 the highest levels of the waste hierarchy – prevention and reuse – 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 context-laden characteristics of FLW issues, the waste hierarchy should only be seen as a rough generalisation (Eriksson and Spångberg, 2017). The donation might not always 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 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 similar environmental burdens with 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 the equal interests (Facchini *et al.*, 2018). In couple with 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 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 awareness and behaviours of the FSC's actors towards more sustainable production and consumption models via the educational program, 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 can 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 activities of FLW. 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 of 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 the 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 potentials for full-scale implementation of the valorisations 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 long-term support regime by government prevents the diffusion of innovative technological initiatives (Genovese *et al.*, 2017).

It is noted that as FLW-related policy support and legal regime vary from country to country (De Clercq *et al.*, 2017), cross-country comparison offers interesting insights and useful lessons learnt. For instance, Teigiserova *et al.* (2020) underlined the variations in the food surplus reuse strategies of the EU's 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 put more efforts on prevention by raising awareness campaign while French laws focus mostly on the role of supermarkets. De Clercq *et al.* (2017) who compared 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 China to adopt consumption-linked subsidy scheme 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 factors: (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 academic agenda are currently on second and fifth factors: FLW prevention practices and conversion technologies and LCA-based SIA, more considerations need be given to the remaining factors.

We believe that the study offers fruitful suggestions for the scholars at the crossroad of two domains, the CE and FLW management. First, our taxonomy urges the comprehensive approaches towards an integrated FLW prevention and management framework for gaining the overall benefits, beyond technological feasibility. Extensive research agendas 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 beyond the waste hierarchy. Although this study is primarily oriented towards an academic audience, its implications for policymakers and decision-makers are underpinned. 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 the 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 elements of the taxonomy simultaneously. Policymakers play an instrumental role in keeping these options open to the 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 searching restriction into two databases – Scopus and Web of Science – which might exclude relevant papers that have not been listed in one of these databases. We, however, believe that the rigour of entire SLR process that covers and reflects 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 yields a significant number of papers without constraining 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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