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The Sustainable Use of Food Waste in the Circular Food Supply Chain – A Systematic Review and Analysis of the Scientific Deficiencies

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THE SUSTAINABLE USE OF FOOD WASTE IN THE CIRCULAR FOOD SUPPLY CHAIN – A SYSTEMATIC REVIEW AND PROSPECT OF THE SCIENTIFIC DEFICIENCIES

Abstract

A systematic literature review was conducted on studies related to sustainable food waste in the circular economy. Specific databases were searched for academic studies from 2015 to 2019, 23 studies were identified and analysed for year, page length, journal, methodology, theories and experimental findings. The aggregated findings suggested that the most significant gap is that a variety of techniques and approaches have been taken, but that there has been insufficient focus on any of them. In addition, a small number of publications work in this field, and the slow emergence of the employment demonstrates the huge untapped potential. In some studies, a common theme was sustainable food waste from local agriculture, such as chestnut shells, citrus fruit and olive waste. A variety of technologies were identified, many used in bio refineries but these are emerging technologies and some studies merely tested ideas on a small scale. Hence, substantially more research and a greater collaboration between various stakeholders in sustainable food waste is required. The main motivators for the initiative was found to be replacement of fossil fuels by biofuels and diminishing the issue of global food security.

Keywords

- Agri-Food
- Food Waste
- Biorefinery
- Food Supply Chain
- Sustainable

Introduction

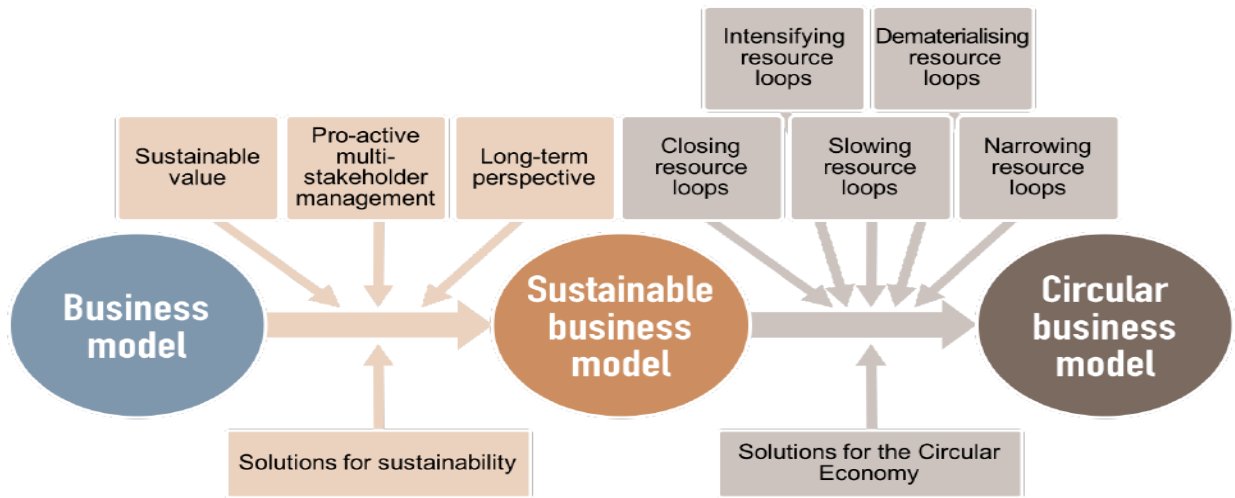
The circular economy is a business model concept that is based on generating sustainable development by means of creating value and delivery. Circular supply chain management (CSCM) is a relatively new and unexplored notion, which has the purpose of configuring and coordinating the supply chain so that as much waste as possible is eliminated (Geissdoerfer, Morioka, Carvalho & Evans, 2018). In order to accomplish this objective, various resource loops in the supply chain are managed in a variety of ways. Goal is to minimize not only food waste but also emission, resource input and energy leakage overall. Minimization shall therefore be accomplished by the following resource loops (Bocken, de Pauw, Bakker & van der Grinten, 2016; Geissdoerfer et al., 2018):

- Closing resource loops
- Slowing resource loops
- Narrowing resource loops
- Dematerialising resource loops
- Intensifying resource loops

Closing resource loops refers to recycling the materials used, while slowing resource loops alludes to repairing and maintaining products to create a second lifetime cycle. By reducing the material use in a product the resource loop may be narrowed whereas dematerialising can be accomplished by substituting a product with a software solution as well as a service solution, if accessible. Intensifying resource loops refers to increasing the use of a product by improving the availability of a product

The difference between CSCM, the standard sustainable business model and traditional models is illustrated in figure 1.

Figure 1 Comparison of Business and Supply Chain Models



Source: Geissdoerfer et al. (2018, p. 718)

The research is important because the extent of food waste globally is very high - according to Lundqvist, de Fraiture & Molden (2008), an estimated 50% of all food grown is lost or wasted before it reaches the customer. The need to substantially reduce this proportion of food wastage is vital as malnutrition is evident in many parts of the world (Parfitt, Barthel & Macnaughton, 2010). In addition one third of all food purchased by consumers in rich countries is wasted, estimated at between 95 and 115 kilograms (kg) per person compared with between 6 and 11 kg in poor nations, for very different reasons (Parfitt, Barthel & Macnaughton, 2010). Crop failure, poor farming, process and packaging methods are the major reasons for waste in underdeveloped countries, whereas buying more food than is necessary leads to waste in developed nations (UNRIC, 2019). Generating sustainability in the food supply chain is vital to minimising this waste, and CSCM aims to eliminate it and furthermore to process the waste created in the most effective way. Thereby sustainability is decisive to not only benefit in present age but also future generations – by environmental resilience as well as social inclusiveness and economic performance (Bocken, de Pauw, Bakker & van der Grinten, 2016; Geissdoerfer et al., 2018).

Study Objectives and Methodology

The prime objective of this research is to review the existing published literature regarding the use of sustainable food waste in the food supply chain and therefore, to determine the focus as well as the major gaps in current research.

Therefore, its objectives is to:

- Identify studies which focus on the sustainable processing of food waste in a circular supply chain
- Focus the search on the years 2005 to 2018, later modified to 2015 to 2019 due to relevance
- Employ studies located in specified databases
- Critically evaluate the studies identified
- Evaluate and aggregate the findings of all the relevant, high quality studies to establish the literature gaps. (Tranfield, Denyer & Smart, 2003; Baumeister & Leary, 1997)

This research employs a pluralist approach because it integrates the objective and subjective philosophies, in order to obtain objective facts and subjective opinions which are provided by researchers whose studies are included in the review (Saunders, Lewis & Thornhill, 2015). Therefore, the research philosophy is pragmatism (Collis & Hussey, 2014) and the research strategy is documentary and archival research, which is enabled by the scope of the internet to provide extensive research facilities, including robust academic papers (Saunders et al., 2015), which build the focus of this review. Furthermore, a mixed methods approach is taken to the systematic review so that quantitative and qualitative data can be reported (Creswell & Creswell, 2014). The quantitative data relates to the number of studies resulting from the online search, and the number of those selected as having direct relevance to meeting the objectives of the review, whereas the qualitative data is derived from the findings documented by the researchers, regarding sustainable food waste processing in the circular supply chain. Secondary data was employed in the review and accessed from Science Direct Scopus, SpringerLink, EconLit and EIS databases, though Saunders et al. (2015) advises that the search results will not find all the existing literature. In addition, Tranfield et al. (2003) suggests that other relevant sources, such as conference

proceedings that are available on the internet, should be identified, so that Google Scholar was conducted as a further searching tool.

The online search was based on Boolean logic, with the purpose of narrowing the search as much as possible, so that the search terms agri-food, food waste, biorefinery, food supply chain and sustainable were linked as a search string by AND, specifically: Agri-Food AND Food Waste AND Biorefinery AND Food Supply Chain AND Sustainable (Saunders et al., 2015; Tranfield et al., 2003).

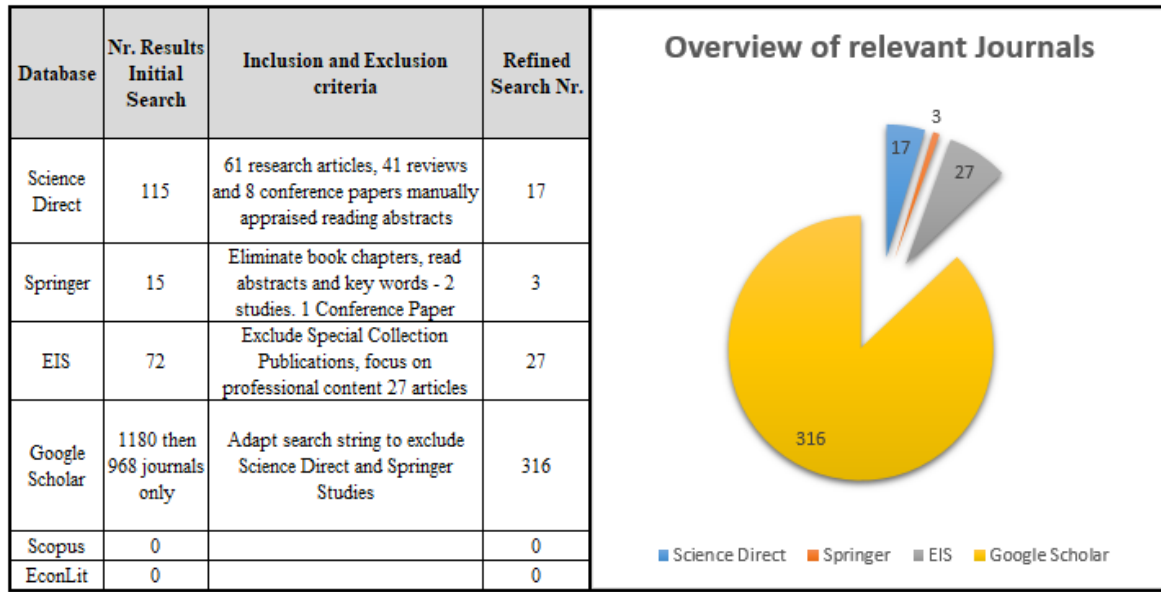
Once the initial search was completed, all the citations gathered were reviewed and the relevant studies were selected, so as to conduct a detailed appraisal of the text. At each stage, the studies included and excluded in the review are documented and reasons for the respective decision was provided. In relation to the studies included in the review, initially a summary is made of the country in which the study was based, the year it was published, the identity of the authors as well as the keywords and page length were summarised.

Due to the awareness that own bias may prevent a neutral choice of literature included and of its interpretation, two methods that would minimise bias were therefore adopted. The first was to check the interpretation made against the original text regularly to ensure it aligned with the author's intended meaning as recommended by Creswell (2013) and secondly to adopt the bracketing technique suggested by Tufford and Newman (2011). The research using the bracketing technique attempts to separate own thoughts from those of the writer and to focus fully on what has been documented so as to eliminate own bias.

Review

The search produced excessive numbers of articles, and reducing the number of subject area subsets, generally revealed no articles of particular relevance to this study. EconLit produced zero results, and extracting relevant studies from EIS was difficult as well and reports were the only relevant papers identified. The quantitative search results and identification of relevant sources are summarised in figure 2.

Figure 2 Summary of the Research



Source: Own figure

In searches on Science Direct, Springer and EIS it was necessary to select specialized subject criteria in order to narrow the search initially, so that the search string “Agri-Food AND Food Waste AND Biorefinery AND Food Supply Chain AND Sustainable” was not affected by irrelevant journals. The final numbers selected from each database were further refined as their contents were analysed and the findings aggregated. Since the original number of studies was beyond the scope of this systematic review, the number to be included was reduced to 23, firstly by eliminating the EIS studies, which were of government rather than academic derivation, and to limit the years of the review from 2015 to 2019 due to relevance and higher actuality. This action is also justified on the basis that no Science Direct studies before this period could be acknowledged as significant in academic interest in this subject. In the initial search only one relevant study was found before 2015 amongst the databases employed in the search. The findings of the systematic review are summarised in figure 3 and 4.

Figure 3 Summary of Research Articles until 2016

Author Year	Abbreviated Title	Nr of Pages	Journal	Geographical Location	Approach	Key Points
Scoma, A. 2016 (2014)	High impact biowastes from South European agro-industries	15	Critical Review in Biotechnologies,	Italy	Quantitative Empirical Approach	Biorefineries employing biowaste from agriculture, such as grape, olive, sugar beet, tomato all organic leftovers. Valorisation. Production of sustainable alternatives to fossil fuels.
El-Mekawy, A. 2015	Food and agricultural wastes as substrates for bio-electrochemical system	13	SD: Food Research International	Egypt, Belgium, Australia, UK, India	Quantitative Empirical Approach	Review and appraisal of bioelectrical systems technology for bioenergy generation for food and agriculture waste water.
Campos-Vega, R. 2015	Spent coffee grounds: A review on current research	13	SD: Trends in Food Science & Technology	Canada, Mexico	Mixed Methodology	Evidence for the need for efficient techniques for the valorisation of spent coffee grounds, fruit and bean processing, containing large amounts of organic compounds.
Vardanega, R. 2015	Adding value to agri-food residues - supercritical technology	11	SD: The Journal of Supercritical Fluids	Brazil	Quantitative Empirical Approach	Conversion of waste from agricultural processing and industry to produce bioenergy for sustainability, reduction of fossil fuel emissions. Supercritical fluid extraction technology use.
Parajuli, R. 2015	Biorefining in the prevailing energy and materials crisis	20	SD: Renewable and Sustainable Energy Reviews	Denmark	Quantitative Empirical Approach	Discussion and assessment of sustainability principles associated with biorefinery techniques. Efficiency of biorefinery dependent on biomass selected, which relates to 40% to 60% operating cost
Giroto, F. 2015	Food waste generation and industrial uses: A review	10	SD: Waste Management,	Italy	Literature Review	New research focuses on recovering the nutrients in waste food, and carbon fixation by means of composting, whilst lowest in hierarchy are incineration and landfilling.
Ashardi M 2016	Pre-treatment and extraction techniques - waste throughout the agri-food chain	45	Royal Society of Chemistry :Green Chemistry	Sweden, UK, Portugal, Italy, Croatia, Argentina, Spain, Turkey, Serbia	Quantitative Empirical Approach	Food bio waste valorisation for sustainable chemicals, to recover added value compounds
Goldberg, A. 2016	Energy-efficient biomass processing with pulsed electric fields	22	Springer: Biotechnology for Biofuels	Tel Aviv, Israel, France, Germany Lituania, Italy Slovenia	Quantitative Empirical Approach	Sustainable development from biomass including food waste by means of energy efficient technologies, biorefineries using pulsed electric fields.
Anwar, J. 2016	Challenges in the valorisation of chitinous biomass	6	SD: Current Opinion in Green and Sustainable Chemistry	South Africa	Literature Review	Food waste as a huge source of chitin and chitosan could be subjected to valorisation in a biorefinery to generate compounds such as lactic, succinic and citric acids and biopolymers.
Oldfield, T.L. 2016	An environmental analysis of options for utilising waste food and food residue	10	SD: Journal of Environmental Management	Ireland	Quantitative Empirical Approach	Food waste is circular bio-economy in Ireland, case study of four possible actions, minimisation, incineration, anaerobic digestion and composting; their eutrophication (EP), acidification (AP) and global warming potential (GWP) using 3 processing
Zhang, C. 2016	Improving yield and composition of protein concentrates from green tea residue	10	SD: Food and Bioproducts Processing	The Netherlands	Quantitative Empirical Approach	Concept of developing biorefinery technology for unused biomass from the agri-food supply chain as a crucial factor for sustainable global food security, rather than increasing crop yield.

Europe
America
Asia
Africa
International

Quantitative mathematical modelling
Quantitative Empirical Approach
Review
Case Study
Mixed

Source: Own figure

Figure 4 Summary of Research Articles from 2016

Author Year	Abbreviated Title	Nr of Pages	Journal	Geographical Location		Key Points
Goucher, L. 2017	The Environmental Impact of Fertilizer - wheat-to-bread supply chain	16	Nature Plants	UK	Quantitative Empirical Approach	Analysis of complete supply chain for a loaf of bread - unsustainable fertilisers found to create inefficiencies
Cohen, M. 2017	Biomolecules from olive pruning waste in Sierra Mágina	10	SD: Journal of Environmental Management	Franace	Quantitative Empirical Approach	Biorefinery concept substitution of fossil fuel resources by converting pruning waste from olive trees by pyrolysis producing a pathogen free fertiliser.
Rajwinder Singh, S 2018	Evaluating Partnerships in Sustainability Orientated Food Supply Chain	18	Energies	Italy and India	Quantitative Empirical Approach	Focus is on investigating food supply chain performance to assess food supply chain sustainability.
Zuin, V.G. 2018	Green and Sustainable Separation of Natural Products from Agro Industrial Waste	54	SpringerTopics in Current Chemistry	UK (Brazil)	Quantitative Empirical Approach	Sustainable extraction of natural products from agro-industrial waste, biomass, biorefinery, green chemical extraction. Global food security.
Guillard, V. 2018	The Next Generation of Sustainable Food Packaging - Circular Economy Context	13	Frontiers in Nutrition	Italy and France	Quantitative mathematical modelling	Agro food waste converted to biodegradable food packaging
Morales, A. 2018	Optimization of alkaline pre-treatment of chestnut shells following a bio refinery approach	11	SD: Industrial Crops and Products	Spain	Quantitative Empirical Approach	Biorefinery to convert chestnut shells into bioethanol and lignin, a significant energy source.
Kaur, G. 2018	Recent Trends in Green and Sustainable Chemistry & Waste Valorisation	10	SD: Current Opinion in Green and Sustainable Chemistry	Hong Kong	Literature Review, studies conference papers and case study	Includes case study of biorefinery in which food waste is converted to fructose as a high value added product and an example of circular economy.
Perez, M. 2018	Life cycle environmental impacts of substituting food wastes for traditional anaerobic digestion feedstocks	16	SD: Journal of Cleaner Production	UK	Quantitative Empirical Approach	Studies the lifecycle environmental impact of food waste treatment - UK policies on resource management, circular economy and climate change and ban on landfilling of food waste. Offers three environmentally friendly actions
Ong, K. 2018	Trends in food waste valorisation: Case study South and Southeast Asia. Bioresource Technology	13	SD: Bioresource Technology	Hong Kong	Quantitative Empirical Approach	Food waste in Asia generated from agricultural processes, transportation, storage and human consumption, food security issues, environmental protection and energy efficiency driving food valorisation (FV)
Ali Rajaeifar, M. 2019	A review on beet sugar industry - waste-to-energy strategy for power supply	20	SD: Renewable and Sustainable Energy Reviews	Iran	Quantitative Empirical Approach	Review of sugar beet production globally, an electricity intensive process, and testing the potential for using sugar beet waste to produce renewable bioelectricity.
Garcia-Garcia, G. 2019	Opportunities for waste valorisation in the food industry	18	SD: Journal of Cleaner Production	UK	quantitative case study approach	Production lines analysed for food waste in 4 UK businesses, food waste categorised, quantified and patterns of waste generation and current waste management practices are identified
Morone, P. 2019	Food waste: Challenges and opportunities for bio-economy	7	SD: Journal of Cleaner Production. Virtual Special Issue (VSI)	Italy, Greece, Estonia, UK, Sweden	Review of studies in VSI	Emphasises the need for greater collaboration between social and physical scientists, economists, IT and software engineers and designers.
Yu, I. 2019	Supercritical Carbon Dioxide Extraction of Value-Added Products -from Food Waste	9	American Chemical Society Sustainable Chem. Eng	Hong Kong, UK, France, Thailand, South Korea	Quantitative Empirical Approach	Valorisation of corn, taro, lettuce, and bean sprout using sequential supercritical CO ₂ extraction and thermochemical conversion

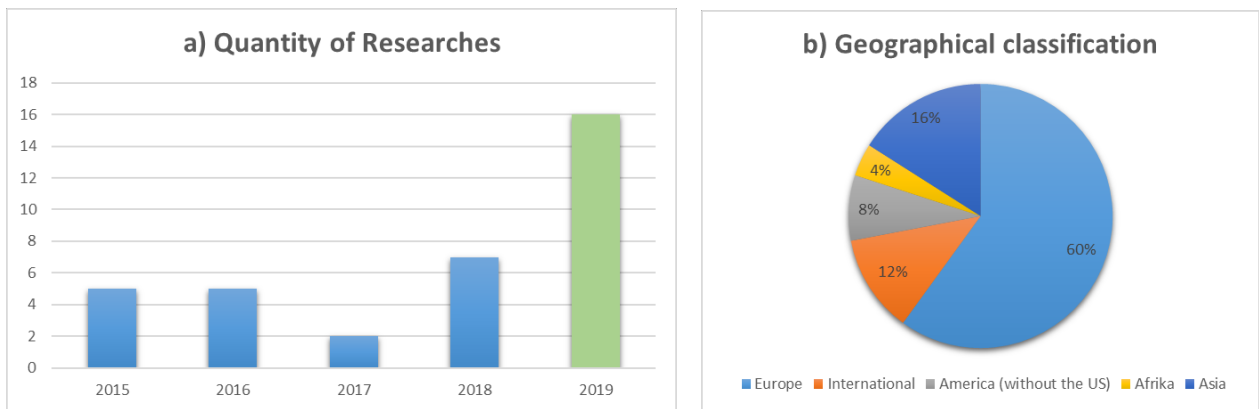
Europe
America
Asia
Africa
International

Quantitative mathematical modelling
Quantitative Empirical Approach
Review
Case Study
Mixed

Source: Own figure

The major findings from this review were that Science Direct Journals are the most active in sustainable use of food waste in the circular economy, and that academic interest has been increasing since 2015. Four studies out of 23 identified were produced by in the first quarter of 2019, which indicates a massive growth of researches compared to earlier years extrapolating the numbers for 2019, as shown in figure 5a).

Figure 5 quantification and geographical classification



Source: Own figures

There are groups of researchers in the specified locations, who generate research into this field regularly, which may lead to bias since similar methods and approaches may be used. Geographically, European countries, particularly Italy and UK, and Hong Kong/China dominate the research, with Brazil and Argentina representing South America as shown in figure 5b). Iran also shows interest, whereas there is a distinct absence of studies from the United States, suggesting it is lagging behind in considering the environmental and social impact of sustainable food waste processing in terms of circular economy principles.

The majority of the studies are quantitatively focussed with substantial details of scientific methods and data regarding conversion rates of food waste to value added products, 20 studies in total, one a systematic literature review, another a short review for a VSI and the last of 23 appeared to have mixed methodology. The majority are 15 to 20 pages in length,

with only two studies, both concerning green chemistry being extensive, 45 and 54 pages respectively.

The motivations for generating sustainable food waste in the food supply chain are environmentally and socially driven, five papers give significant emphasis to replacement of fossil fuel sources by biofuels produced from food waste, another to health improvement and two to sustainable global food security.

Techniques include minimising waste by encouraging consumers to buy less food or for retailers and consumers to donate edible food waste, bio refineries are mentioned specifically in nine studies and associated with a range of technologies. Valorisation is mentioned six times and others include bioelectrical systems, supercritical fluid extraction as well as incorporating carbon fixation by composting, pulsed electrical fields and pyrolysis. Three studies produce a hierarchy of techniques for handling food waste, for instance Giroto, Alibardi and Cossu (2015) suggest an order of:

1. techniques for recovering the nutrients in waste food
2. carbon fixation by means of composting
3. incineration and landfilling

The identification evaluation of supply chain partners' activities in means to improve efficiency is an addition technique suggested in two studies. In further two studies the legal policies associated with sustainable practice are supplementary discussed.

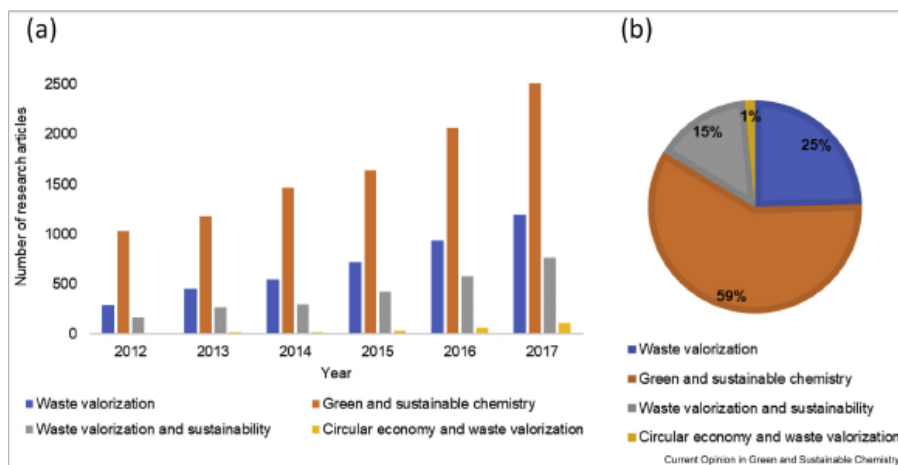
The products from sustainable food waste are most often energy by creation of biofuel products but one study produces a pathogen free fertiliser (Cohen et al., 2017), another sustainable biodegradable packaging (Guillard et al., 2018) and the Iran based study bioelectricity (Ali Rajaeifar, 2019). A different approach was taken by Zhang et al. (2016) who suggested that sustainable food waste techniques were an alternative to improving crop yield in the context of global food security.

Types of food waste are often agricultural waste and the waste subject matter generally relates to key industries in the countries in which the researchers operate; for instance, in Dublin it is general food waste (Oldfield, White & Holden, 2016), in Italy olive, grape and tomatoes (Scoma et al., 2016), in Brazil sugar cane, corn and grape (Vardanega, Prado, & Meireles, 2015) and potatoes, peas and grain in the UK (Garcia-Garcia, Stone & Rahimifard, 2019).

Most studies emphasise that the techniques are emerging rather than mainstream, which is reinforced by the small number of studies that resulted from the search, and Morone et al. (2019) suggests this situation could be improved considerably by greater collaborations between social and physical scientists, IT and software experts and economists. The circular economy is inferred in many studies and emphasised in three, and in all cases the focus is on coordinating the supply chain to diminish or eliminate waste in the sense of Geissdoerfer et al. (2018).

The systematic literature review conducted by Kaur et al. (2018) is of particular interest regarding the relationship of green chemistry to sustainable green chemistry associated with sustainable food waste as a circular economy concept (figure 6), because it states that green chemistry is aligned to sustainable principles, but unless it is employed in the context of sustainable technologies in the circular economy it cannot be included in that category. This is reinforced by the outcomes of the systematic review of studies accessed from the Science Direct database from 2102 to 2017, figure 2, which demonstrates a large rise in green and sustainable chemistry, in standard and sustainable waste valorisation, but relative slower gains in the interest in circular economy and waste valorisation techniques. These findings tend to reinforce the findings of this review, that although the number of studies on sustainable use of food waste in the circular economy food supply chain is increasing, it is still of very minor interest and the focus of a few scientists globally.

Figure 6 Comparison of studies on green chemistry, valorisation and circular economy



Source: Kaur et al., (2018, p. 35)

Conclusion

This Systematic Literature Review has met its objectives by identifying 23 studies in specified journals that emphasised sustainable processing of food waste in a circular supply chain, over the amended period of 2015 to 2019. The studies were analysed for year, page length, journal, methodology, theories and experimental findings. The findings were then aggregated into table 2 and discussed with the result that specific trends were common to groups of studies. The most significant gap, also identified by Morone et al. (2019), is that a variety of techniques and approaches have been taken but insufficient focus on any of them is given. Comparing the various approaches bio refineries appear to be the only common ground. The small number of scientists working in this field, who stress the slow emergence of the employment of technologies to create a sustainable food waste supply chain, also demonstrates the huge untapped potential. The major agricultural waste within each nation’s economy tends to differ, but a common trend is the focus on better utilising nationally produced food waste to improve the social and ecological environment for citizens. The issue remains in the early stages of resolution, and requires more research into identifying how each supply chain partner’s activities can be more effectively coordinated, as well as the major types of locally produced food waste that will optimise outcomes for energy, packaging, fertilisers and many, as yet, unknown added value products.

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Eidesstattliche Erklärung

Ich erkläre hiermit an Eides statt, dass ich die vorliegende Arbeit selbständig verfasst und dabei keine anderen als die angegebenen Hilfsmittel benutzt habe. Sämtliche Stellen der Arbeit, die im Wortlaut oder dem Sinn nach Publikationen oder Vorträgen anderer Autoren entnommen sind, habe ich als solche kenntlich gemacht. Die Arbeit wurde bisher weder gesamt noch in Teilen einer anderen Prüfungsbehörde vorgelegt.

Ort, Datum

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