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Review

Energy Systems in the Food Supply Chain and in the Food Loss and Waste Valorization Processes: A Systematic Review

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Abstract: The intensity in energy consumption due to food production systems represents a major issue in a context of natural resources depletion and an increasing worldwide population. In this framework, at least a third of global food production is being lost or wasted. Moreover, about 38% of the energy embedded in total food production is being lost. Consequently, the assessment of energy consumption in food systems, and in food loss and waste valorization systems, is an increasing trend in recent years. In this line, this work presents a systematic review, selecting 74 articles from a search of 16,930 papers regarding the key words "energy assessment food". The aim was to determine the current and historical trends in this field of research. Results pointed to a worldwide acceleration in trends since 2014, standing out in China and other Asian countries. Concerning the topics of the publications, energy consumption in the food sector is a research field which has existed since 1979. Moreover, the study of energy valorization systems using food loss and waste is an increasing trend since 2010. Additionally, publications focused on the water–energy–food nexus appeared firstly in 2014 and have grown exponentially. Moreover, life cycle assessment highlights as the most widespread methodology used.

Keywords: energy assessment; food systems; food loss and waste; water–energy–food nexus; anaerobic digestion

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1. Introduction

If the impacts along the whole life cycle are considered, the food supply chain (FSC) appears as one of the most polluting daily activities [1]. It is due to different reasons, among which stands out, the highly mechanized agricultural production and its use of agrochemical products, the long transportation distance for distributing food, the overpacked food, and the increase in processed foods consumption, highlighting the so-called fourth and fifth range products, which are ready to be eaten and sold frozen [2]. These factors have entailed an increase in the energy consumption throughout the entire supply chain, transforming it from a net producer of energy to a net consumer of energy [3]. Consequently, over time, according to different works, such as Cuellar and Webber in 2010 [4], Lin et al. in 2011 [5], and Vittuari et al. in 2016 [6], the energy inputs began to be higher than the energy outputs, and today the FSC requires 10–15 kJ of fossil fuel to produce 1 kJ of food. Therefore, the energy intensity of modern food systems represents a major issue in a current framework of decreasing limited resources, and growing population [7].

On the other hand, more than a third of the worldwide produced food is being lost or wasted, representing about 38% of the energy embedded in its production [8]. In this line, food loss and waste (FLW) have central consequences on the energy balance of the FSC, which leads to environmental impacts: natural resources are grind down, biodiversity and habitats are lost, soil and water are degraded, and climate change is aggravated through the emission of greenhouse gas (GHG) [5].

In this entire context, the assessment of the energy systems along the whole FSC is being an increasing field of research with different approaches and scopes. Among them, the emerging framework of the water–energy–food nexus stands out. It is considered by any authors as a promising field for guiding policy development and governance structures in a world that is facing climate change, population growth, and inequality in terms of access to resources [9]. In this line, the main reasons behind the increasingly acceptance of the nexus concept are linked with the problem of water scarcity and pollution, the high levels of energy consumption, which are associated with enormous levels of GHG emissions, and the need to achieve food security [10]. Additionally, the management of FLW with energy recovery, following different possible paths, such as incineration or anaerobic digestion (AD), is another important trend of research which is standing out in recent years. More concretely, in Hoehn et al. [11] it was highlighted as a potential path for contributing to improve the energy inefficiencies of the FSC, reducing the net energy consumption. This work presents a systematic review, by selecting works concerning the different approaches in the research field of energy systems in the food supply chain and in the FLW management. With this purpose, different aspects have been assessed: the specific topic of each paper, the country of publication, the publication year, the number of citations, the scope of the assessment, and if all food is considered or only concrete fractions. Moreover, as life cycle assessment (LCA) is a highly used methodology in the field of research, it has been used to analyze the number of publications using that methodology. The objective was to determine current and historical trends in this field of research, with the initial hypothesis of a relatively recent origin of the first publications, with an exponential growth trend in the last decade. The results of this systematic review aim to serve as a reference guide when it comes to visualizing the state of the art in this field of research.

2. Material and Methods

2.1. Literature Search Strategy, Inclusion Criteria, and Analysis of Study Findings

In order to develop the review protocol, the Preferred Reporting Items for Systematic review and meta-analysis protocols (PRIMA-P) guideline was used as a reference [12]. For searching the publications in the field of study, this review has used Scopus as the database for the development of the review, based in the reviewing methodology presented in other publications in the literature, such as Fernández–Ríos et al. [13]. In order to do a complete follow-up of all the publications registered around the analyzed topic, a first round of searching, using the keywords "energy assessment food" was carried out on 14 October 2021, as shown in Figure 1. The keywords were selected considering the search spectrum broad enough so that most, or perhaps all, of the scientific publications to date could fall within the scope of the search. Through it, from the 16,930 documents found in Scopus, 411 documents where firstly preselected, in which the keywords were coinciding with topics related to energy systems of food production, FLW management or nexus publications which included the energy pillar and were linked to the food system. The 411 preselected papers were used for the assessment of the geographic distribution, and the time evolution. It was done a first general assessment of the three different fields of research analyzed in this study: (i) energy assessment in the food sector (Group 1), (ii) energy recovery from FLW (Group 2), and (iii) water–energy–food nexus publications related or close to the food sector (Group 3). Secondly, from the 411 papers preselected, a second filter was implemented by selecting those articles with 40 or more cites, reducing the number of works to the 74 articles with the highest impact in the scientific community. This element has been considered in this study as a valid filter of the high interest of those publications in the scientific community, as it is the most evolved criterion for measuring of a scientist or group or nation [14]. On the other hand, articles that focused on analysis only of energy crops were excluded. The exceptions were water–energy–food nexus papers linked to energy from biomass, as they were considered to be directly or indirectly linked to energy and food systems. Moreover, those works focused on the nutritional energy of food or FLW, were excluded, as well as articles on AD of general waste or of solid waste. Additionally, some of the publications included in Group 1 or Group 2 could potentially be considered related to Group 3, but since they did not use the novel Nexus concept, they were not linked to it.

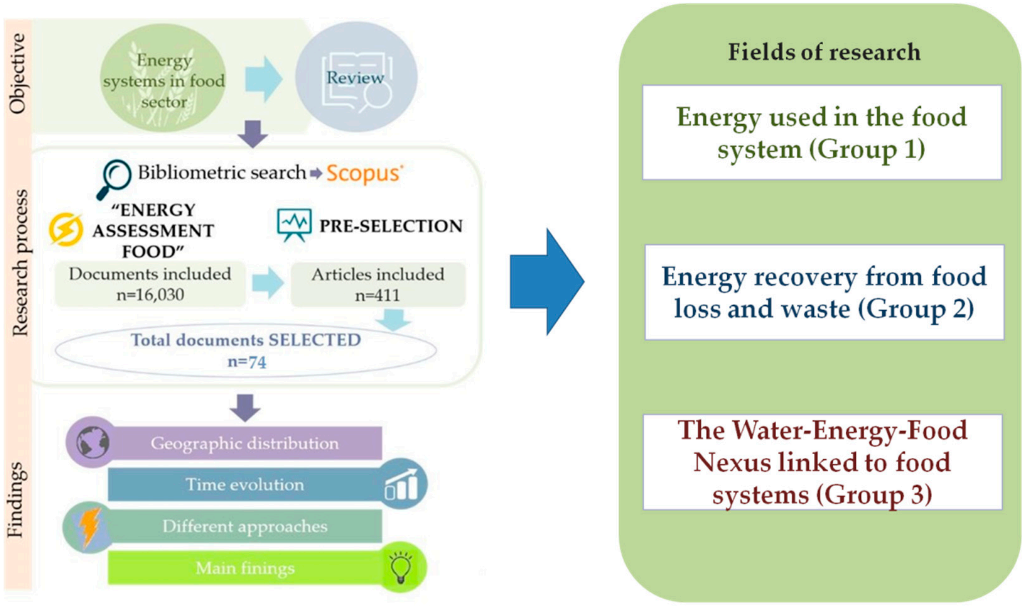

Figure 1. The methodology implemented for the selection of the papers assessed throughout this study. The three fields of research detected in the 74 selected papers regarding energy assessments in the food sector are highlighted.

As represented in Figure 1, once the 74 papers were selected, they were classified and assessed relating the three topics of research. All works were described, as well as classified depending on the year of publication, the scope of the study, the fact of considering all food or only concrete fractions, and, as LCA was detected to be the highest used methodology, they were also classified in terms of (i) using LCA or (ii) not using LCA.

2.2. Limitations of the Study

There are different methodological gaps which have to be highlighted. Firstly, this review only used the Scopus database, even though several good databases are available such as EBSCO, Web of Science, ProQuest, ScienceDirect, etc. However, it was assumed that the result would not vary considerably since almost 19,000 articles were taken into account in the first filter in this search. Moreover, the consideration of the number of cites as a filter between the pre-selection and the selection round, although it is a reference measure of quality within the scientific community, using the citation criteria may follow few major issues such as citations in lower reputed journals, self-citation, high visibility and advertisement of a paper, equal credit in case of multiple authors [14]. Additionally, given that the search was carried out in October 2021, and the publication of the article has been delayed a few months, other potentially impactful publications that could have been included in the review could be left out. In any case, the fact of putting the barrier of 40 publications also helps to limit this effect in the short term.

Finally, the selected keywords of searching were a subjective decision. In this line, other potentially related terms of the field of study were not included, which could have increased the spectrum of publications found, such as "energy feeding" or "primary energy nutrition".

3. Results of the Preliminary Paper Selection

3.1. Mapping of the Publications in the Field of Research

The 411 preselected publications have been used for this assessment. As presented in Figure 2, the papers were developed in 54 different countries. The USA (58 publications), China (46 publications), Italy (46 publications), and the United Kingdom (41 publications) where the countries with higher number of publications. It is noteworthy that in the case of China, as well as in other Asian countries on a smaller scale, the publications in the assessed field of research are popping up in recent years. In the case of China, despite being the second country with more publications, the first work dates back to 2012, whereas the first paper carried out in the United States was published in 1973. More concretely, from 46 publications, 38 of them were published since 2018 in China. Other Asian countries with similar trends since 2018 are Singapore (7 of 7 papers counted), Malaysia (6 of 7 papers counted), South Korea (2 of 3 papers counted), and Thailand (4 of 5 papers counted). At the other extreme, in the USA only 28 of 48 publications detected are due to the period 2018 and 2021. A similar behavior was found in Australia (1 of 6 papers counted) or Sweden (6 of 12 papers counted). If the complete continents are assessed, Europe represents 45.5% of total publications, Asia 30.4%, North America 15.8%, South America 5.1%, Africa 1.7%, and Oceania 1.5%.

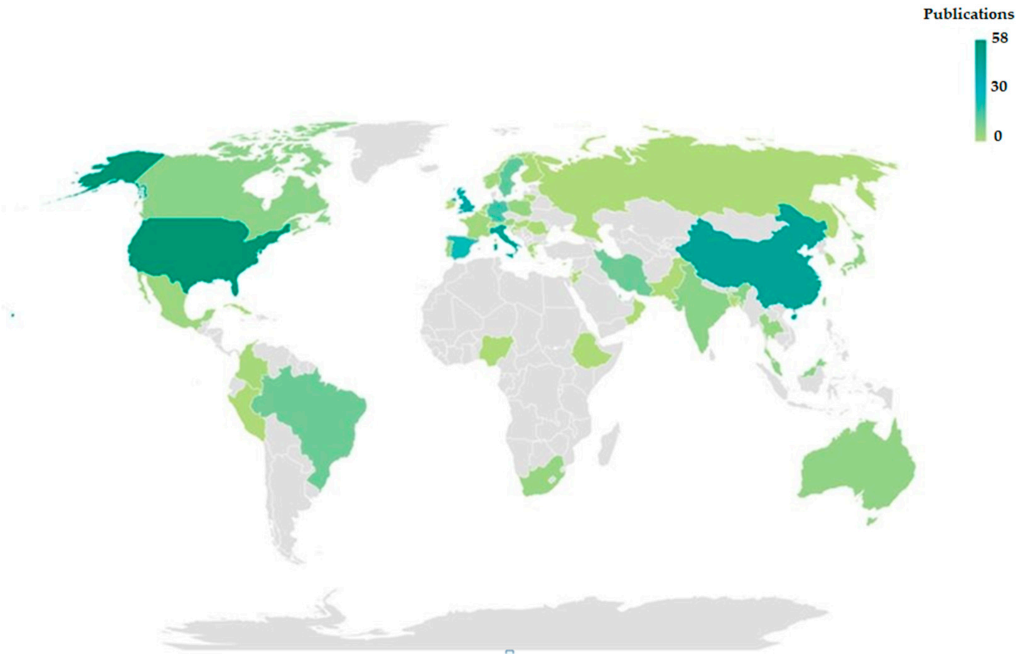

Figure 2. Geographical distribution of the publications included in the review, considering the preselected 411 publications between 1979 and 2021.

3.2. Time Evolution of the Publications

This section also considers the 411 preselected articles. According to them, until 2014, Group 1 was clearly the most dominated topic of articles. The articles included in the topic of Group 2 have been increasingly published in the last years, and especially since 2011. Before that date, only one article in 1996, and two more in 1979, were found. It is interesting to note that despite the possibility of using AD systems as an option for energy recovery from FLW being an issue that in recent years has emerged as a novelty, there was already a publication in the USA in 1979 surrounding this field. It highlighted AD as technically capable of converting agricultural feedstocks into a stabilized sludge and biogas without the labor intensiveness of the Asian systems or the cost and technical sophistication of western sewage treatment plants. The study considered that the use of animal wastes for both cooperative and single farm systems had greater potential than other residues such as food plant wastes and cellulosic feedstocks from both a technical and economic perspective [15]. Finally, publications focused on the field of Group 3 are currently in an exponential emergency process. Nevertheless, it is a field of study whose first references are from 2014, with no previous precedents detected.

Concerning the total number of works from the 411 preselected articles, Group 1 represents 29.0% (119 publications), Group 2 works are the 45.0% (185 publications), and Group 3 represents the 26.0% (107 publications). On the other hand, in relation only to the works selected based on their number of citations (64), those of Group 1 account 32.8% of the papers (21 publications), Group 2 represents 53.1% (34 publications), and Group 3 accounts only 14.1% (9 publications). An overview is presented in Figure 3.

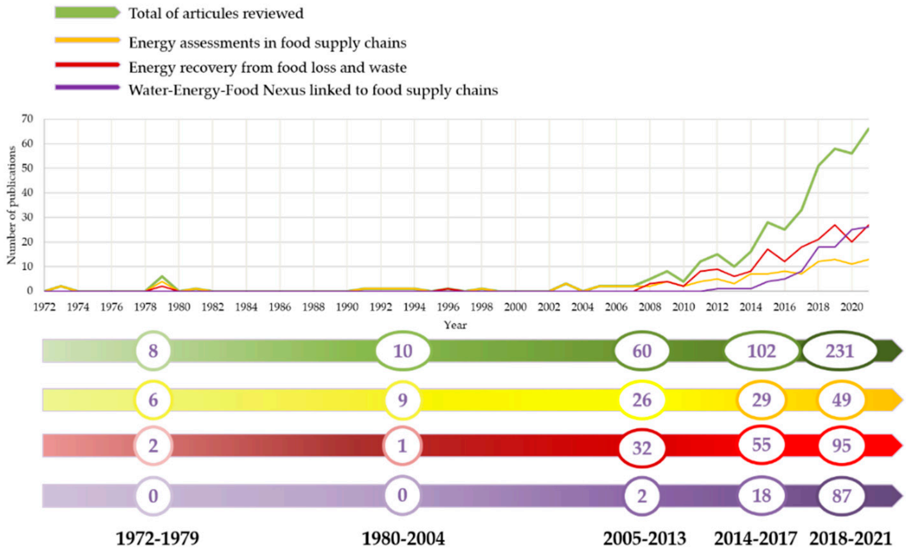

Figure 3. Temporary distribution of the 411 publications preselected in the review. Reports were excluded from the figure. In green the total articles reviewed. In yellow are the articles focusing on energy assessments in the food sector (Group 1). In red are the articles focusing on energy recovery from food loss and waste (Group 2). In purple are the articles focusing on the water–energy–food nexus linked to food systems (Group 3).

4. Results of the High-Cited Papers

4.1. Energy in the Food System

As presented in Table 1, the majority of the publications have a global approach (8), follow by national (6) and international approaches. Concerning the methodology, LCA is present in only 6 of the publications. Regarding the food assessment, the majority are related to specific fractions (12), in comparison with those considering food in general (11).

Highly cited publications of Group 1 were found since many decades, being the first study found developed by Slesser in 1973 [16]. It focused on the assessment of food production, both agricultural and industrial processes, in energy terms for 131 food producing systems. The methodology developed was presented to be especially applicable to the less developed countries. Later, in 1992, Giampietro [17] developed an energy analysis of the agricultural ecosystem management, using a set of parameters derived from energy analysis, for examining the ecological aspects of agricultural management. More than a decade later, in 2004, Kim and Dale [18] estimated the energy and global warming impacts regarding the production of corn, soybeans, alfalfa, and switchgrass. Moreover, they assessed the impacts of these crops' transportation to a central crop processing facility, which was called "biorefinery". For that objective, data from eight different States of the United States were used. Results indicated that each crop has different functions, and are thereby allocated the environmental burdens to the different functions delivered by the assessed crops is needed for directly comparing one crop to another. Moreover, Schlicht and Fleissner [19] presented an assessment of regional energy turnover and a comparison with the global produced food, considering the ecology of scale. The recorded data of fruit juices and of lamb meat suggested a strong relation of the specific energy turnover and the business size. Consequently, they concluded by emphasizing that it was not important the rationality of the business. Just the efficiency and logistics of the production and the operations determined the specific energy turnover. In 2006, Piringer and Steinberg [20] presented an assessment of the energy use linked to the United States produced wheat production. Lakshmi et al. [21] developed an energy assessment concerning the energy consumption in microwave cooking of rice, and presented a comparison with other domestic appliances. Hermes et al. [22] created a simplified model to assess the energy performance of household refrigerators and freezers via a steady-state simulation. Moreover, Mushtag et al. [23] developed an assessment of the complex energy, water and economics dynamics concerning a selection of countries with highest rice production worldwide.

Table 1. The 23 selected works, concerning the so-called Group 1 and relating the different scopes, methodologies and food assessments.

Publication Year	Paper Reference	Scope					Methodology	Food Assessment
		Global	International	National	Regional	Local		
1973	Slesser [16]	x					Energy subsidy	General
1992	Giampietro [17]	x					Energy analysis	General
2004	Kim and Dale [18]					x	LCA	Corn/soybean/alfalfa
2005	Schlich and Fleissner [19]		x				LCA	General
2006	Piringer and Steinberg [20]				x		Input/output model	Wheat production
2007	Lakshmi et al. [21]				x		Experiments	Rice cooking
2008	Hernes et al. [22]	x					Model	General
2009	Mushtaq et al. [23]				x		Energy balance	Rice cultivation
2010	Sogut [24]				x		Energy/exergy	Tomato paste
2011	Cellura et al. [25]	x					LCA	General
2012	Bogdanski [26]	x					Review	General
	Tuomisto et al. [27]	x					LCA	General
2013	Evans et al. [28]			x			Energy audits	General
2014	Sarauskis et al. [29]			x			Energy/cost/CO_2	Maize
	Pairotti et al. [30]			x			LCA	General
	Blanke and Burdich [31]			x			Energy balance	Apple fruit
	Popp et al. [32]			x			Meta-analysis	General
	Daccache et al. [33]			x			Water/CO_2	Mediterranean crops
2015	Taner and Sivrioglu [34]				x		Energy/exergy	Sugar
2016	De Nicola et al. [35]	x					Time series	8 food commodities
2017	Eriksson and Spångberg [36]			x			Energy use/CO_2	Fresh fruit and vegetables
2019	Nabavi–Pelesaraei et al. [37]				x		LCA	Rice milling

In 2010, Sogut et al. [24] presented an energetic and exergetic performance evaluation of a tomato paste production. They concluded by explaining that the brix ratio increased in each effect as a result of the evaporation of water, from 8.6% to 29%, the brix ratio being one of the most important parameters for the determining the thermodynamic properties of tomato paste. In 2011, Cellura et al. [25] developed a paper concerning the energy and environmental impacts of Italian households' consumption, with an input–output approach. It was suggested the importance of including emissions arising both from energy and non-energy sources, in the assessment of environmental impacts to obtain reliable simulations. Bogdanski [26] highlighted in 2012 that increasing evidence shows that diverse and integrated farming systems and landscapes that are based on agroecological farming practices are sustainable paths towards climate-smart agriculture. This is a fact of high importance, especially in the currently times, which are characterized by a steadily growing world population and increasing resource competition. In the same year, Toumisto et al. [27] carried out a comparison of energy and greenhouse gas (GHG) balances and biodiversity impacts of different farming systems by using LCA accompanied by an assessment of alternative land uses. In 2014, Evans et al. [28] presented a paper focused on an assessment of the methods to reduce the energy consumption of food cold stores. Moreover, Sarauskis et al. [29] studied the energy balance, costs, and CO_2 emissions of tillage technologies in maize cultivation. Pairotti et al. [30] assessed the energy consumption and the GHG emission of the Mediterranean diet, developing a systematic assessment using a hybrid LCA-IO method. Blanke and Burdich [31] carried out an energy balance for locally grown versus imported apples. They found that the primary energy requirement of regional produced and stored several months on-site, partially compensated for the larger energy required for importing fresh fruit from overseas. Popp et al. [32] assessed the effects of bioenergy expansion related to food, energy, and environment. Daccache et al. [33] developed an assessment of the water and energy footprint of irrigated agriculture in the Mediterranean region. In 2015, Taner and Sivrioglu [34] assessed and optimized the energy and exergy of a model sugar factory in Turkey. After it, De Nicola et al. [35] carried out a work where, by using monthly data between 1970 and 2013, an assessment of the extent co-movement among the nominal price returns of 11 major energy, agricultural, and food commodities was provided. In 2017, Eriksson and Spångberg [36] assessed the carbon footprint and energy use of different FLW management options for fresh fruit and vegetables from supermarkets. Finally, in 2019, Nabavi–Pelesaraei et al. [37] carried out a study aiming to provide an overview of the energy use, economic costs and environmental impacts in the production of white rice in milling factories of Guilan province, in Iran.

4.2. Energy Recovery from Food Loss and Waste

As presented in Table 2, the majority of the publications concerning the Group 2 have a national approach (13), followed by international (12) approaches. Concerning the methodology, LCA is present in the majority of the publications (17). Regarding the food assessment, the majority are related to food in general (27) considering food in general (8).

The first highly cited study in Group 2 was found in 2009, when Gerbens–Leenes et al. [38] presented a quantitative assessment and consequences of an increasing share of bioenergy in energy supply. The objective was to determine the water footprint of the energy from biomass. Since 2011, the level of publications in the field of Group 2 clearly increased. In that year, Cooper and Leifert [39] presented an LCA of GHG from organic and conventional food production systems, with and without bioenergy options. Banks et al. [40] presented an assessment of the energetic and environmental benefits of co-digestion of FLW and cattle slurry. Ramzan et al. [41] simulated a hybrid biomass gasification using Aspen plus, developing a comparative performance analysis for food, municipal solid, and poultry waste. Shie et al. [42] presented an energy LCA of rice straw bioenergy derived from potential gasification technologies. The main motivation for the research was the fact that rice straw is being considered as a source for potential biofuel in Taiwan. Kimming et al. [43] presented a comparative LCA concerning the use of small-scale heat and power plants with biomass from agriculture. They highlighted the potential of using biomass from farmland as a renewable fuel for rural areas, through the investment in those small-scale plants. However, it was also questioned if biomass-based energy generation is a good environmental choice regarding the GHG emissions impacts, as well as wondering on the negative consequences of using of agricultural land for other objectives than food production. Moreover, Banks et al. [44] presented a mass and energy balance on AD of source-segregated domestic food waste. In 2012, Hall and Howe [45] assessed the energy from the food processing industry, which is a major energy user. It identified AD as an opportunity to go some way to achieving energy security in a sustainable manner. Bernstad and la Cour Jansen [46] assessed the separate collection of household food waste for AD, developing a comparison of different techniques from a systems perspective. Zubarayeva et al. [47] developed a spatially explicit assessment of local biomass availability for distributed biogas production via AD, using the Mediterranean case study. The study focused on the development of the approach on the assessment of biogas potentials to provide a support for decision-makers and bioenergy industry at a local scale. In 2013, Rajagopal et al. [48] presented a sustainable agri-food industrial wastewater treatment using a high-rate AD process. This review article compiled the various advances made since 2008 in sustainable high-rate AD technologies with emphasis on their performance enhancement when treating agri-food industrial wastewater. Kim et al. [49] developed in 2013 an evaluation of different FLW disposal options in terms of global warming and energy recovery concerning South Korea. AD was highlighted as the best option, following by co-digestion and fryer incineration (per 1 tonne of FLW).

Table 2. The 30 selected works, concerning the so-called Group 2 and relating the different scopes, methodologies and food assessments.

Publication Year	Paper Reference	Scope					Methodology	Food Assessment
		Global	International	National	Regional	Local		
2009	Gerbens–Leenes et al. [38]	x					Water footprint	General
2011	Cooper and Leifert [39]			x			LCA	General
	Banks et al. [40]					x	Data/modelling	Dairy cattle slurry
	Ramzan et al. [41]	x					ASPEN Plus	General
	Shie et al. [42]				x		LCA	
	Kimming et al. [43]			x			LCA	General
	Banks et al. [44]	x					Experimental plant	General
2012	Hall and Howe [45]				x		LCA	General
	Bernstad and la Cour Jansen [46]			x			LCA	General
	Zubaryeva et al. [47]			x			Multicriteria Analysis	General
2013	Rajagopal et al. [48]	x					Review	General
	Kim et al. [49]					x	LCA	General
	Ebner et al. [50]	x					LCA	General
	Vandermeersch et al. [51]				x		LCA	General
	Hamelin et al. [52]				x		LCA	Six co-substrates
2015	Angelondi and Smith [53]			x			Data/Interviews	General
	Styles et al. [54]					x	LCA	General
	Xu et al. [55]				x		LCA	General
	Bacenetti et al. [56]				x		LCA	Tomato purée products
	Jin et al. [57]				x		LCA	General
	Tonini et al. [58]	x					LCA	General
2016	Voelklein et al. [59]				x		Experimental lab	General
2017	Lijó et al. [60]			x			LCA	General
2018	Wapas et al. [61]					x	Experimental setup	General
	Ingrao et al. [62]		x				Review	General
	Xiao et al. [63]				x		Experimental setup	General
	Chinnici et al. [64]			x			Estimations	General
2019	Slorach et al. [65]				x		LCA	General
	Ali Rajaeifar et al. [66]	x					LCA	Beet sugar industry
	Zabaniotou and Kamaterou [67]	x					Review	Coffee grounds

In 2014, Ebner et al. [50] presented an assessment on GHG impacts of a novel process for converting FLW to ethanol and co-products. Waste-to-ethanol conversion was highlighted as a promising technology to provide renewable transportation fuel while mitigating feedstock risks and land use conflicts. Moreover, Vandermeersch et al. [51] carried out an environmental sustainability assessment of different FLW valorization options, analyzing the study case of a company of the retail sector in Belgium through exergy analysis, exergetic LCA, and a traditional LCA. Additionally, Hamelin et al. [52] assessed the environmental consequences of different carbon alternatives for increased manure-based biogas. In 2015, Angelonidi and Smith [53] presented a comparison of wet and dry AD processes for the treatment of municipal solid waste and FLW. Styles et al. [54] carried out a consequential LCA of biogas, biofuel and biomass energy options within an arable crop rotation. Xu et al. [55] presented an LCA of FLW-based biogas generation. Bacenetti et al. [56] focused a study on mitigation strategies in the agri-food sector, concerning the AD of tomato puree by-products, using an Italian case study. Jin et al. [57] developed an LCA of energy consumption and environmental impact of an integrated FLW-based biogas plant. Tonini et al. [58] assessed the environmental implications of the use of agri-industrial residues for biorefineries, aiming to implement a deterministic model for indirect land-use changes. In 2016, Voelklein et al. [59] presented an assessment of increasing loading ratio in two-stage digestion of FLW, which involved a first stage hydrolysis reactor followed by a second stage methanogenic reactor. In 2017, Lijó et al. [60] assessed the environmental effect of substituting energy crops for FLW as feedstock for biogas production. Thereby, two real biogas plants were assessed and compared from a life cycle perspective. In 2018, Waqas et al. [61] focused a study on the optimization of FLW compost with the use of biochar. In 2018 Ingrao et al. [62] analyzed the FLW recovery into energy in a circular economy perspective. The goal was to develop a comprehensive review of aspects related to plant operation and environmental assessment. They highlighted that FLW has great potentials to be recovered, through a set of technologies such as AD, into high-value energy, fuel, and natural nutrients. Xiao et al. [63] analyzed the energy balance of a temperature-phased AD of FLW. Moreover, Chinnici et al. [64] presented an assessment of the potential energy supply and biomethane from the AD of agri-food feedstocks in Sicily. In 2019, Slorach et al. [65] developed a study focused on the environmental sustainability of AD of household food waste in the UK. Ali Rajaeifar et al. [66] presented a review on beet sugar industry with a focus on implementation of waste-to-energy strategy for power supply. Finally, Zabaniotou and Makaterou [67] developed a critical review of the potentialities and perspectives of using coffee grounds for biorefinery. An approach of FLW valorization, advocating circular bioeconomy, was included.

4.3. The Water–Energy–Food Nexus in Food Supply Chain

In this section, all those works that directly or indirectly relate the WEF nexus with food systems have been considered. In this case, the works related to bioenergy with food or potential food, including a nexus approach, have been included. As presented in Table 3, the majority of the publications related to Group 3 have a global approach (10). Concerning the methodology, LCA is present in only eight of the publications. Regarding the food assessment, the majority are related to food in general (20), being only two publications found focusing on specific fractions.

The WEF nexus concept applied to the food sector, began to be exponentially present in highly cited works since 2012, when Hermann et al. [68] developed a study focused on climate, land, energy, and water (CLEW) interactions in Burkina Faso. In 2013, Ringler et al. [69] assessed the nexus across water, energy, land, and food (WELF). All it in the context of water, land, and energy as resources which are all crucial contributors to food security, and the sustainable development goals (SDG), representing a globally significant test for the implementation of the nexus thinking. In 2015 Jeswani et al. [70] carried out a work focused on the environmental sustainability issues in the WEF nexus concerning breakfast cereals and snacks, considering different impact categories and stages of the FSC. By using the water footprint and LCA methods, Pacetti et al. [71] presented a study case of biogas production from energy crops with a water-energy nexus approach, considering the importance of the water, energy and food elements. In 2016, Keairns et al. [72] claimed the need to consider new frameworks and tools when developing nexus analyses, such as those integrating societal and technical dimensions. Yang et al. [73] analyzed the future nexus of the Brahmaputra River Basin, considering the climate, energy, water, and food trajectories. De Laurentiis et al. [74] presented a review with the focus on overcoming food security challenges within an energy-water-food nexus (EWFN) approach. It suggested that most of the publications were focused on the assessment of the resource efficiency and environmental impact regarding food production, whilst fewer assessed the environmental performance of diets and the potential environmental savings of the reduction of FLW generation. Moreover, Al-Saidi and Elagib [75] developed a review towards understanding the integrative approach of the water–energy–food nexus. In 2017, Miller–Robbie et al. [76] presented an assessment regarding wastewater treatment and its potential for being reused in urban agriculture, assessing thereby, the food–energy–water–health nexus in Hyderabad, India. Giupponi and Gain [77] integrated a spatial assessment of the WEF dimensions of the SDG. Al-Ansari [78] integrated GHG control technologies within the energy, water, and food nexus to achieve sustainability in food production systems. Moreover, Ramaswami et al. [79] focused on an urban systems framework to assess the trans-boundary FEW nexus, implemented in Delhi, India. In 2018, Karabulut et al. [80] presented a proposal for integration of the ecosystem–water–food–land–energy (EWFLE) nexus concept into LCA. Salmoral and Yan [81] developed an LCA on virtual water and embodied energy in food consumption in the Tamar catchment, in the UK, with a WEF nexus approach. Moreover, a systematic review of the methods for assessing the WEF nexus was presented [82]. De Amorim et al. [83] assessed the interactions between food, water, and energy security with a nexus approach and in the context of global risks. Different state-of-the art reviews were provided in 2018: on the one hand focusing of the climate risks and opportunities of implementing a WEF nexus approach [84]. On the other hand, concerning the concepts, research questions and methodologies in the field of water–energy–food [85]. Additionally, Nie et al. [86] combined data analytics and mixed-integer nonlinear modeling and optimization methods establishing the interdependencies and potentially competing interests among the FEW elements in the system. Finally, in 2019 Simpson and Jewitt focused a review on the development of the WEF nexus as a framework for achieving resource security. Moreover, Pastor et al. [87] assessed the global nexus of food–trade–water sustaining environmental flows by 2050. The publication was linked to the aim of meeting the SDG.

Table 3. The 21 selected works, concerning the so-called Group 3 and relating the different scopes, methodologies, and food assessments.

Publication Year	Paper Reference	Scope					Methodology	Food Assessment
		Global	International	National	Regional	Local		
2012	Hermann et al. [68]			x			Review	General
2013	Ringler et al. [69]	x					Review	General
2015	Jeswani et al. [70]			x			LCA	Cereals/snacks
	Pacetti et al. [71]			x			LCA	Maize/sorghum/wheat
2016	Keairns et al. [72]	x					LCA	General
	Yang et al. [73]			x			Water system model	General
	De Laurentiis et al. [74]	x					LCA	General
2017	Al-Saidi and Elagib [75]	x					Review	General
	Miller–Robbie et al. [76]			x			LCA	General
	Giupponi and Gain [77]			x			Indicator-based approach	General
	Al-Ansari et al. [78]				x		LCA	General
	Ramaswami et al. [79]			x			Environmental footprint	General
2018	Karabulut et al. [80]	x					LCA	General
	Salmoral and Yan [81]			x			LCA	General
	De Amorim et al. [82]	x					WEF Global Risks Report	General
	Albrecht et al. [83]	x					Review	General
	Nhamo et al. [84]				x		Review	General
	Zhang et al. [85]	x					Review	General
2019	Nie et al. [86]				x		Multi-objective optimization	General
	Pastor et al. [87]	x					GBM Model	General
	Simpson and Jewitt [9]	x					Review	General

4.4. Life Cycle Assessment as a Methodological Approach

Given its wide presence in the literature in this field as a methodology, in this work LCA was specifically analyzed compared to other types of methodologies, and it is noteworthy it is widely used in all publications related to energy assessments in food systems, especially highlighting those related to FLW valorization options. More concretely, related the publications included in Group 1, 6 of 22 of them used LCA, at global (2), international (1), national (1), regional (1) and local (1) levels. Moreover, 4 of 6 publications had a general approach in terms of food or FLW categories considered. On the other hand, concerning the studies included in Group 2, it was accounted that 17 of the 30 selected publications followed the LCA methodology, with a global (3), regional (9), or local (5) approach. Of all them, 14 of 17 accounted for all food items, for national, regional, and local approaches. Finally, Group 3 included 8 of 20 publications using LCA with a global (3), national (1), regional (3), or local (1) approach. Regarding the fractions of food assessed, 6 o 8 publications presented a general approach. However, despite the wide use of LCA in the field of research, there was no clear trend of evolution over time in terms of an increase in its use towards standardize it as a reference methodology compared to other methodologies.

5. Findings of the Study and Conclusions

As main conclusions of the conduced review, it has been confirmed that the field of "energy assessment in food systems" is a growing trend, especially in relation to FLW valorization systems and the WEF Nexus. The number of publications in this field has been accelerated considerably since 2014, and became especially clear since 2018. Likewise, the countries that are developing more scientific papers are the USA, China, Italy, and the UK. Nevertheless, it is noteworthy that in the case of China, as well as in other Asian countries on a smaller scale, these publications are popping up in recent years. If the complete continents are assessed, Europe represents 45.5% of total publications, Asia 30.4%, North America 15.8%, South America 5.1%, Africa 1.7%, and Oceania 1.5%.

Concerning the 74 high-cited papers selected for the assessment, energy in food systems represented 21 (32.8%) publications, energy recovery from FLW 34 publications (53.1%), and WEF nexus only 9 (14.1%) publications. Similar trends were found if the preselected 411 papers are compared. It should be noted that of the three groups of publications detected, the WEF nexus analysis is a very recent trend (2014) with exponential growth in recent years, although some previous publications with similar approaches could potentially have been included in Groups 1 and 2, by not using the nexus concept. Those related to FLW valorization systems, although they have increased a lot in recent years, have a longer trend. In this line, a study without citations was found in 1979 that already raised the use of AD systems for agricultural systems and raised the influence of the incorporation of FLW to these systems. Different publications assessing FLW management highlighted that biomass produced on farmland is a renewable fuel that can prove suitable for small-scale combined heat and power plants in rural areas. On the other hand, publications related to energy assessments in the food system have remained present over the years. Finally, LCA was specifically analyzed, highlighting as the most important methodology used in the field, but without a clear trend of evolution towards a standardization as a reference method compared to other ones.

One of the main contributions of this study is that an extensive historical review has been carried out, focusing on the publications with the greatest impact in terms of citations, but also including a previous analysis of all the literature found in general (almost 19,000 publications). As a general conclusion, on the one hand, a clear general interest in the scientific community in recent years in these fields of study has been highlighted, in which new concepts such as the Nexus emerge, and new fields of study such as the recovery of energy with unavoidable FLW. In a context of increasingly evident limitation of natural resources, and rise in environmental, social, and economic costs of energy production, interrelated with a highly globalized food supply chain, research in this field of study will most likely continue to grow in the coming years at rates as great or more than in recent years. On the other hand, sometimes it is important to look back in order to realize that there are questions and fields of study that began much earlier than is thought. It has been seen in the case of the analysis of energy systems and also of FLW management alternatives such as AD. This point must be taken into account, as sometimes emerging fields of study can be nurtured by lines of research from the past. The results obtained through this systematic review aim to be useful as a reference guide when it comes to visualizing the state of the art in this field of research, as a tool for progress towards more sustainable energy food systems.

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Abbreviations

AD	Anaerobic Digestion
FLW	Food Loss and Waste
GHG	Greenhouse Gas
LCA	Life Cycle Assessment
SDG	Sustainable Development Goals
WEF	Water–Energy–Food

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