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Review

Exploring the Global Scientific Literature on Food Waste and Loss

Selma Mokrane [1], Elvira Buonocore [1], Roberto Capone [2] and Pier Paolo Franzese [1,*]

[1] UNESCO Chair "Environment, Resources and Sustainable Development", Department of Science and Technology, Parthenope University of Naples, Isola C4, 80143 Naples, Italy
[2] International Center for Advanced Mediterranean Agronomic Studies (CIHEAM), Mediterranean Agronomic Institute of Bari, via Ceglie 9, 70010 Bari, Italy
* Correspondence: pierpaolo.franzese@uniparthenope.it

Abstract: The growing global population and modern dietary patterns are the main drivers of current unsustainable food systems, with one of the most serious consequences being the growing issue of food waste and loss (FWL). FWL is a global problem since one-third of the global food produced for human consumption is wasted or lost yearly. FWL occurs throughout the food supply chain. In this study, the scientific literature on FWL was explored. Social network analysis and bibliometrics were integrated to explore the issue of food waste in relation to environmental impact and food security. The generated network maps displayed the relationships among keywords, authors, and countries dealing with the issue of food waste, highlighting the exponential growth of the studies focusing on food waste since 2010. The results allowed for the understanding of the evolution of food waste scientific research, identifying the most important topics and research paths. In addition, the results also showed a clear research shift from an older approach to food waste, based on the downstream notion of waste, to a more modern approach, based on sustainability, food security, consumer behavior, and the circular economy, addressing the problem of food waste by preventing it with upstream actions and policies. Considering the remarkable ethical, environmental, social, and economic implications of FWL, the outcomes of this study display the need for developing interdisciplinary approaches and methodologies capable of providing a comprehensive understanding of the FWL issue.

Keywords: food waste and loss; food security; zero hunger; SDG; bibliometric network analysis

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1. Introduction

The modern world is undergoing significant changes as a result of economic development, increased purchasing power, dietary habits, and increased food production and consumption patterns. On the other hand, developing countries are affected by increased poverty, political instability, resources depletion, and food insecurity. This imbalance resulted in two major problems. First, the increased food consumption in high-income countries induced large amounts of edible food being wasted. FAO (2011) estimated that on a yearly basis, one-third of the food produced worldwide is wasted or lost throughout the food supply chain (FSC), generating several social, environmental, and economic impacts [1]. Secondly, paradoxically, food security still remains a serious problem threatening 828 million people worldwide who do not have enough access to food [2].

The topic of food waste gained much interest in the last decades, due to the various negative impacts of food waste and loss (FWL) and the rising awareness about the extent of the problem on a global level, specifically its relationship with the issues of food security and climate change. For instance, it is recognized in the UN 2030 Agenda for Sustainable Development, specifically in SDG 2–Zero Hunger—focusing on achieving food security and improved nutrition in addition to promoting sustainable agriculture—in which the target 2.1 states " ... *end hunger and ensure access by the poor people and people in vulnerable situations including infants to safe, nutritious, and sufficient food all year round*", and in SDG

12–Responsible Consumption and Production, in which the target 12.3 states " . . . *to halve per capita global Food waste by 2030 at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses"* [3]. The achievement of both SDG 2 and 12 can be enhanced by the implementation of circular economy strategies based on the reduction of food waste and sustainable consumption patterns.

A wide range of FWL definitions can be found in the scientific literature. For instance, FAO (2011) defines FWL as "the masses of food lost or wasted in the part of food chains leading to edible products going to human consumption" [1]. This definition includes only food intended for human consumption, but that ended up wasted, even if it is used later for other purposes, such as feed, composting, or other possible routes. Instead, in the FUSION report (2014) the definition of food waste, in addition to the edible food parts, also includes the inedible parts removed from the FSC to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill, or discarded to sea) excluding the part revalorized for feed or bio-based material and biochemical processing [4].

Different notions of FWL are generally used in relation to the different stages of the FSC. For instance, "food loss" is attributed to the losses occurring in the early stages of the FSC (agriculture and postharvest stages), whereas "food waste" refers to the losses in the downstream stages of the FSC (retail, household, and hospitality) [1,5,6].

A further classification of food waste is referring to avoidable, possibly avoidable, and unavoidable food waste. Avoidable food waste includes food that is edible by the major part of consumers, but ends up thrown away because it exceeded its expiration date or was not wanted anymore. Possibly avoidable food waste is food thrown away due to personal preferences, while unavoidable food waste is food unwanted by the major part of consumers (e.g., eggshells, bones, orange peels, etc.) [5,7].

Research Questions, Goal, and Novelty of the Study

The following research questions were addressed in this review:

Q1: What are the main aspects investigated by the scientific literature on FWL?

Q2: What are the main research gaps and trends in the global scientific literature on FWL?

The goal of the present study is to explore the global scientific literature on FWL focusing on its environmental and socio-economic impact. For this goal, a bibliometric network analysis was performed to generate maps based on network data, analyzing the relationships among keywords, authors, and countries linked to the research on FWL.

The novelty of the study relies on a comprehensive investigation of the FWL issue in relation to the two timely topics of "environmental impact" and "food security". Therefore, the study is aimed at providing an holistic assessment on FWL to explore the complexity of the topic and its interlinkages with sustainable development goals.

2. Food Waste and Loss along the Food Supply Chain (FSC)

The FSC is defined as a succession of actions and movements between different actors, going from farmers producing food, passing by manufacturers, then distributed to retailers to reach the final consumers (e.g., household or hospitality level). Through this process, part of the produced food is lost or wasted [4]. Currently, globalization, diet shifts, and changes in modern consumption patterns lead to different factors, including the rise in the consumer's expectations of more fresh products, the increased distances between production and consumption location areas, and the migration of people from small villages to big cities. All these trends contribute to making the FSC longer and more complex with many more entities involved in the whole supply chain. As a result, the more complex the FSC is, the larger is the amount of generated waste and related costs [8,9].

FWL can occur in different steps of the FSC (Table 1), starting from primary production with agricultural (e.g., fruits, vegetables, cereals, legumes, and pulses), fisheries and livestock production, to post-harvest stages as storage and handling [4,9]. In the primary production stage, a significant amount of food loss occurs due to several rea-

sons, including field infestations from pest and diseases or variable weather conditions causing damage to food crops and related harvest. In addition, technical factors, such as inefficiencies in the production processes, poor material and storage facilities, as well as market price fluctuations and overproduction can also lead farmers to leave their crops unharvested [1,10].

Table 1. FWL in the food supply chain.

Food Supply Chain Stages	Food Waste or Loss	Causes
Primary production (agriculture, livestock production, and fisheries)	Food loss	Pests, diseases, market fluctuating prices, variable climatic conditions, inefficient material, technical problems.
Storage and handling	Food loss	Poor storage facilities, inadequate temperatures, technical problems.
Processing, manufacturing, and packaging	Food loss	Inefficient material, logistic problems, industrial waste.
Distribution	Food loss	Increased distances, technical problems.
Retail	Food waste	Poor storage, expiry date, aesthetic standards, poor packaging.
Household	Food waste	Expiry date, over preparation, aesthetic, and food preferences.
Hospitality	Food waste	Over preparation, poor storage, large portion size, and over ordering.

Developing countries register the highest amount of food loss in the primary production stage with over 40% of the total FWL occurring in the post-harvest or processing stage. This is due to inefficient machineries and techniques to harvest and store food commodities. Nevertheless, food loss is still significant in developed countries due to overproduction, aesthetic standards, and market fluctuating prices [9,11].

Food losses can also occur in the processing, manufacturing, and packaging stages due to spilling, degradation, inefficiencies in the industrial process, management problems, quality and aesthetic standards (including customer and retail demand and expectations), as well as the inevitable fraction of waste generated by agro-industrial processes [9,10]. Moreover, losses during distribution could be mainly due to the high number of intermediaries, long distances, unsuitable cold chains, or damages during the loading and unloading of food commodities [9,10].

Starting from retail and supermarkets, the thrown away or expired commodities are referred to as "food waste". Commonly, food waste is generated due to aesthetic preferences and expectations, irregularity in the consumer demand, and unsuitable packaging or storage [6,12].

In contrast to primary and post-harvest production, the household waste is highest in developed countries with over 40% of total FWL at the retail or household level [1,9]. FAO (2011) stated that the food waste at the retail and consumer level in high income countries reached 220 Mt, which equals approximately the total food production in Sub-Saharan Africa (230 Mt) [1]. Nevertheless, household food waste per capita remains a significant issue in both high- and low-income countries. In 2019, at the global level, 61% of the total food waste (931 Mt) was attributed to the household [6,13]. Food waste occurring in the household stage could be mainly due to over purchasing, over preparation, and large portion sizes, confusion about labels and expiry dates, storage problems, and unsuitable packaging (particularly for highly perishable commodities) [7,12].

At the consumption level, we can distinguish another type of food waste generated by catering and hospitality activities (e.g., restaurants, airplanes, hotels, schools, and hospitals), significantly increasing the extent of the food waste problem. This type of waste can occur either during the preparation phase (over preparation, large portion

sizes, expired products, bad storage) or during the consumption phase (over ordering and customer leftovers) [14,15]. In 2019, at the global level, the hospitality sector represented 26% (242 Mt) of the total food waste [6], while it represented 9.4% (nearly 5 Mt, equivalent to 12 kg/capita) of the total FWL in Europe [16].

Finally, considering all stages of the FSC, more food waste is connected to perishable commodities, such as fruits and vegetables, meats, and fish, while less food waste is linked to cereals [6].

3. Impact of Food Waste and Loss

3.1. Environmental Impact of FWL

Agricultural and livestock production are among the most polluting and resource-intensive practices responsible for several ecological issues. In the last decades, food production has constantly increased to satisfy the growing food demand. In parallel, FWL followed a considerable rise, in conjunction with wasting all inputs used for the production along the FSC while generating useless emissions and other environmental impacts [11].

Several works studied the impact of FWL on the environment by exploring its water and carbon footprints, as well as its impact on other natural resources. The global carbon footprint of FWL was estimated to be around 4.4 Gt of CO_2 eq. per year, representing 8% of the total human-caused GHG emissions [17].

The environmental impacts of food chains are aggravated when food is lost or wasted. Kummu et al. (2012) stated that global FWL accounts for about 24% of the total farmland, freshwater, and fertilizer consumption used for food production [18]. In addition to these environmental costs, managing all the organic waste generated by households, food services, industrial processes, and farm sectors generates significant GHG emissions and other downstream environmental impacts due to the disposal of FWL. In fact, solid waste landfills emit large amounts of methane (CH_4) each year, a GHG emission with a 20–25-fold higher warming effect than carbon dioxide (CO_2) [19,20]. In this regard, Read et al. (2020) stated that if the USA FWL could be reduced by 50%, the USA environmental footprint would decrease by 8 to 10% [21].

It is worth mentioning that the environmental burden of FWL differs from country to country, depending on the amount of waste, the type of waste, and on which stage the FWL occurs. A life cycle assessment study performed on 15 countries by Skaf et al. (2021) highlighted that FWL in high-income countries (USA, KSA, UAE, and Canada) showed the highest environmental burden in nearly all the environmental impact categories. In particular, the FWL of the USA resulted in climate change of 172 Mt CO_2 eq., fossil depletion of 22 Mt of oil eq., and 121 billion m^3 of water depletion. These environmental costs and impacts were much higher compared to other low-income countries, such as Mexico, South Africa, Argentina, and Lebanon (see Table 2) [22].

Table 2. Annual environmental impact of food waste and loss for selected high- and middle-low-income countries (modified from [22]).

	Countries	Annual Climate Change (Mt CO_2 eq.)	Annual Fossil Depletion (Mt Oil eq.)	Annual Water Depletion (m^3)
High-income countries	USA	172	21.70	1.11×10^{10}
	Canada	16.30	2.13	1.10×10^{9}
	UAE	4.49	0.64	7.18×10^{8}
	KSA	18.40	2.62	2.95×10^{9}
Middle-low-income countries	Lebanon	0.09	0.01	1.47×10^{7}
	South Africa	0.64	0.11	5.64×10^{7}
	Argentina	3.83	0.46	3.67×10^{8}
	Mexico	12.20	1.47	1.17×10^{9}

Similarly, Europe registers a high amount of FWL and the related environmental burden. An approximate amount of 57 million tonnes of FWL was generated in 2020, resulting in annual figure of 127 kg of wasted food per person [16]. Scherhaufer et al. (2018) analyzed the contribution of FWL in Europe to global warming, resulting in 186 Mt CO_2 eq. [23]. Different stages of the FSC are characterized by different contributions to environmental costs and impacts. For instance, Scherhaufer et al. (2018) reported that environmental impact is originated, in a large portion, in the primary production stage due to the overall related emissions as well as the significant livestock emissions [23]. Nevertheless, reducing food waste in the other stages of the FSC (e.g., processing and food service) would still result in several positive outcomes. It would lower eutrophication potential in the processing sector, GHG emissions in the food service sector, and the water use in households [21].

3.2. Social Impact of FWL

FWL is a critical ethical issue considering that millions of people still do not have the opportunity to satisfy their most basic nutritional needs (828 million worldwide) [2]. Indeed, when the FWL problem is addressed in a social perspective, it is often linked to food security. Nevertheless, it is complex to identify how FWL can exacerbate the food security issue and how reducing FWL could contribute to mitigate hunger and undernourishment [6]. Abbade (2020) estimated that the global FWL could contribute in feeding 939 million adults with a daily caloric intake of 2000 kcal/day/person, as well as a daily protein intake of 50 g/day/person [24].

Moreover, FWL could have indirect social costs, as it leads to the upgradation of farming systems, hence exposing inhabitants relying on these practices to more toxic compounds (e.g., pesticides and heavy metals), while also depleting natural resources and causing energy insecurity, poverty, health problems, and rising conflicts. From another perspective, food waste could be viewed as an issue of excess food purchase and consumption, especially in higher income countries, which is currently causing serious health problems, such as being overweight and obesity, referred to in the scientific literature as metabolic waste [25,26]. Serafini and Toti (2016) estimated the excess food intake, leading to excess body fat in overweight and obese individuals, as metabolic food waste, and analyzed its environmental impact (carbon, water, and land footprint) by food category [27]. Furthermore, food waste could be perceived as nutritional waste, where each quantity of wasted food is translated as lost nutritional elements. Chen et al. (2020) evaluated the daily nutritional elements loss and the environmental impacts related to global food waste [28].

3.3. Economic Impact of Food Waste

Economic costs of FWL are not negligible, especially the costs due to waste disposal. In addition, wasting food implies wasting the economic investments needed to support the production process. At a global scale, on a yearly basis, the economic cost of FWL is roughly USD 1 trillion, which would result in an approximate value of USD 2.6 trillion if environmental and social costs were also included [29]. At the European level, the cost of FWL was calculated as EUR 130 billion per year [16]. The extent of the economic costs differs by country and by the stage in the FSC. High-income countries register higher costs of food waste during the consumption stage. For instance, in the USA, a family composed of four people generates waste worth a value of USD 1600/year, while a UK average family wastes food worth a value of about USD 890/year [28–33]. Whereas, in lower-income countries, higher economic losses due to FWL are observed during the primary production stages. Sub-Saharan Africa registers an annual grain production value of USD 27 billion, out of which USD 4 billion is attributed to post-harvest losses [6,32].

FWL is a multiscale issue with intertwined environmental, social, and economic consequences. In other words, reducing FWL may reduce environmental impacts and save resources belonging to more vulnerable and marginalized populations, whilst also saving economic costs and improving their nutrition and health [33].

4. Food Waste and Loss Research

The growing FWL issue and its serious implications fostered global research interest and provoked policy makers to explore the issue and to find alternative solutions to reduce its serious consequences. Therefore, several studies explored FWL along the FSC to assess the real extent of the problem [1,6,7,9,13,22,26,31,34–36], while others proposed unified methodologies to account for FWL [5,10,14,37]. Furthermore, other studies focused on exploring the environmental, social, and economic benefits of FWL reduction interventions [21,33]. Several studies also focused on the FWL along food supply chain stages [5,12,18,21,38]. Likewise, several projects, initiatives, and action plans were also implemented by governments and NGOs to tackle FWL, most of them in line with timely targets to reduce FWL, such as the UN Sustainable Development Goals (Goal 12 "responsible consumption and production" and Goal 2 "zero hunger") and the European Union Circular Economy Action Plan. Among these initiatives, it is worth mentioning: "The Waste & Resources Action Programme" and the "Love Food, Hate Waste initiatives" in the UK; the initiative of "last minute market", "*Fondazione Banco Alimentare Onlus*", and "Good End" projects in Italy; the National Pact Against Food Waste and the "*Association Nationale de développement des Épiceries Solidaires A.N.D.E.S*" in France; and several other initiative promoted by the Environmental Protection Agency in the USA, all aimed at reducing waste and addressing the undernourishment problem while promoting sustainable agriculture [8,38].

5. Bibliometric Network Analysis

A bibliometric network analysis was performed to explore the global scientific literature and research trends on the topic of food waste, also exploring the relationship between the environmental impact and food security issues. The application of bibliometric network analysis is an effective way to explore the global scientific trends of a particular topic and combine it with the social network, by generating comprehensive statistics and graphs built on connections between countries, authors, documents, and organizations on a given topic [39].

The VOSviewer software (1.6.16) was used in this study, allowing the generation of network maps based on bibliometric data to analyze the connections existing among different clusters of authors, keywords, countries, journals, and organizations [39].

The bibliometric data used in this analysis were derived from the Scopus database on 22 April 2022, using the keywords "Food waste" combined with the keywords "Environmental impact" and "Food security". All documents related to the selected keywords were used to perform the analysis without restricting the search to a specific time frame.

We performed the following analyses: (i) the temporal evolution of the topic in relation to the number of documents produced; (ii) the co-occurrence of keywords; (iii) the co-authorship among authors; and (iv) the co-authorship among countries. The software generates network maps based on different items (e.g., keywords, nations, and authors). The items are organized into clusters based on the relationships among them (e.g., common keywords, number of documents per source or per author, co-citations, etc.). The network maps display the different items connected through links; the greater the link, the thicker the line shown in the map, which is represented by link strength. The resolution parameter determines the number of clusters seen in the network maps. The greater the resolution, the greater the depth of detail. This value can be adjusted to display an appropriate number of clusters in the maps [39]. In the present analysis, the resolution parameter was set at 1.00.

6. Results and Discussion

6.1. Temporal Trend of Food Waste Research in Relation to "Environmental Impact" and "Food Security"

The research on the Scopus research engine was performed using the keyword "Food waste" and the following combinations: "Food waste" AND "Environmental impact", "Food waste" AND "Food security", and "Food waste" AND "Food security" AND "Environmental impact". The resulting number of documents of each keyword combination is shown in Table 3. Most of the documents (70%) were research articles, while other documents types were reviews, book chapters, surveys, and conference papers.

Table 3. Number of documents related to food waste scientific research.

Keyword Combination	"Food Waste"	"Food Waste" AND "Environmental Impact"	"Food Waste" AND "Food Security"	"Food Waste" AND "Environmental Impact" AND "Food Security"
Number of documents	14,984	1143	616	86

The first publications on the food waste issue appeared at the end of the 1990s/early 2000s, registering an exponential growth since 2011. Since then, the food waste issue has gained increasing interest from the scientific community and from policy makers. This turning point in the research on FWL could be related to the publication of the FAO report on the global quantification of FWL [1] and the report explaining the methodology adopted in the quantification [10]. These reports shed light on the extent of the problem and paved the way for further studies on the impact of FWL at different scales in various countries. Subsequently, the interest increased significantly, reaching 2701 documents in 2022 (Figure 1).

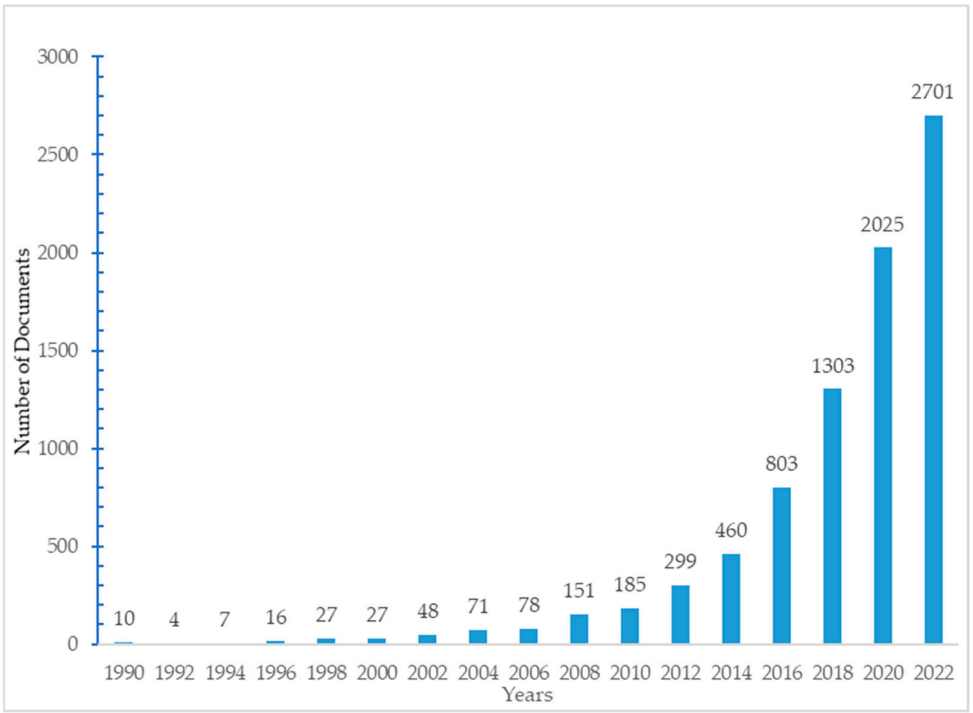


Figure 1. "Food waste" research temporal evolution.

Nevertheless, we cannot address the food waste problem as a global issue without also addressing its environmental and socio-economic impact. When viewed from a social perspective, FWL is always linked to the food security issue.

The food waste issue is largely linked to its environmental impact, and the research on this combination of keywords also followed an exponential growth in the last decade. This goes in parallel with the increasing concerns about climate change and the large environmental impacts of food chains [17].

The combination of "Food waste" and "Food security" research follows a similar trend, but with a lower number of documents, as shown in Figure 2. The surge in the research on food waste and its association with food security started from 2014 to 2015 with 29 documents and reaching 138 documents in 2022, showing that this research direction

triggered the global scientific community. In 2007–2008, during the global food price crisis [40], the topic of food availability received more attention in scientific publications and policy debates, alongside the undernourishment issue and unsustainability of current food systems, which have been identified as major challenges of this century [40–42].

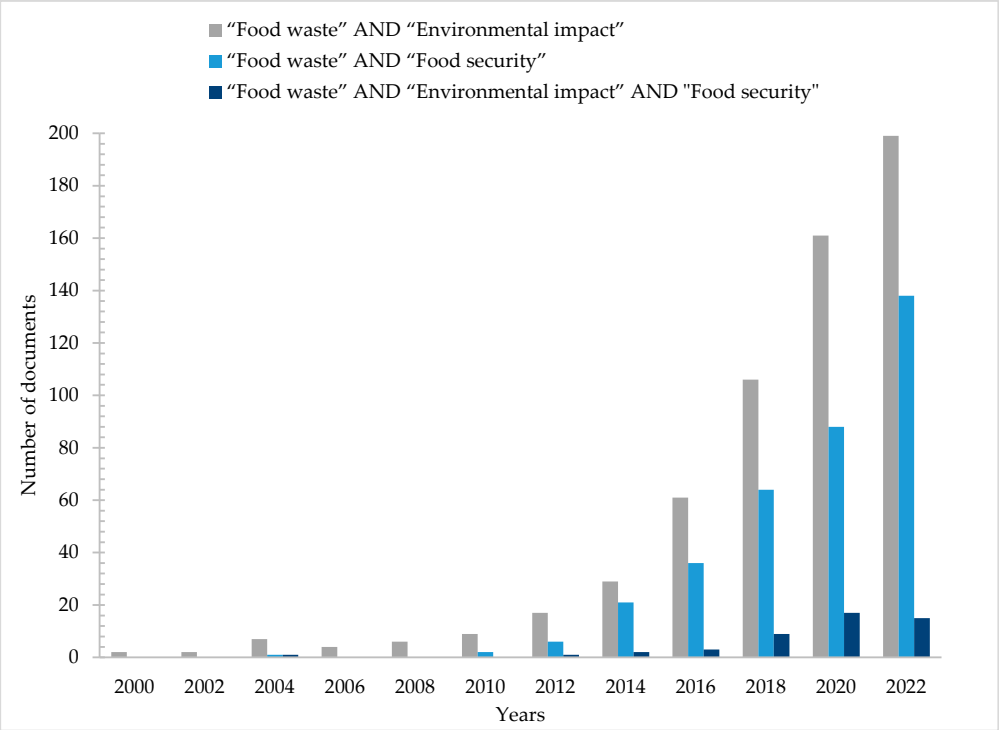


Figure 2. "Food waste", "Food security", and "Environmental impact" research temporal evolution.

Finally, the research integrating "Food waste" and both "Environmental impact" and "Food security" has a strong multicriteria perspective adopted in a smaller number of documents, still showing a temporal increase, more evident in the years 2019 and 2022, with 20 documents focusing on food security and the environmental impact of food waste in 2021 (Figure 2).

Nevertheless, many initiatives and organizations aim to reduce FWL to reduce both environmental and socio-economic impacts.

6.2. Co-Occurrence Keywords Network

The co-occurrence keywords network analysis answered the research question Q1. In particular, the three combinations of keywords resulted in the following outcomes: 147 keywords related to the combination of "Food waste" and "Environmental impact", 93 keywords related to the combination of "Food waste" and "Food security", and 54 keywords related to "Food waste" in combination with "Environmental impact" and "Food security". Figures 3–5 were generated by setting a minimum number of co-occurrences of 20, 10, and 3, respectively.

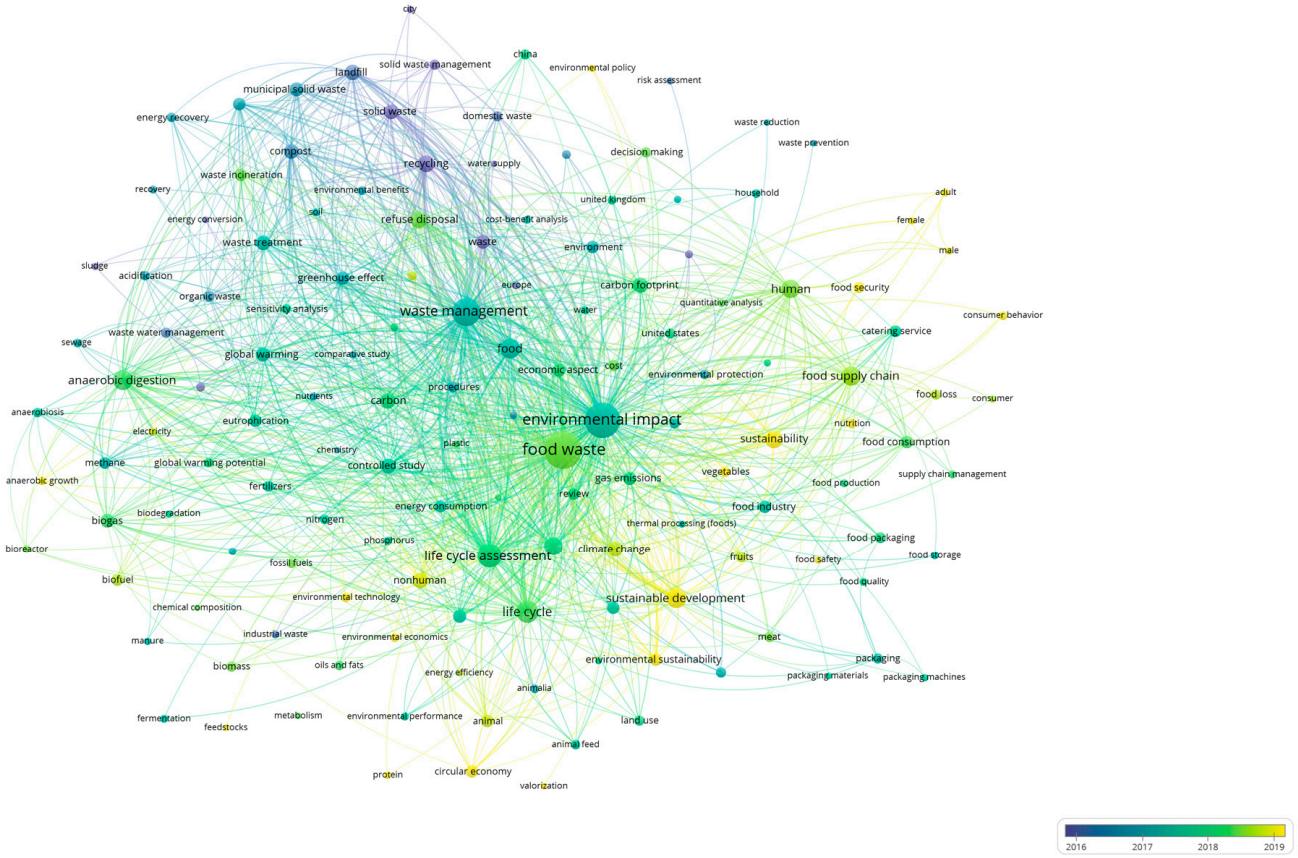


Figure 3. Co-occurrence of keywords network overlay map based on total link strength ("Food waste" AND "Environmental impact").

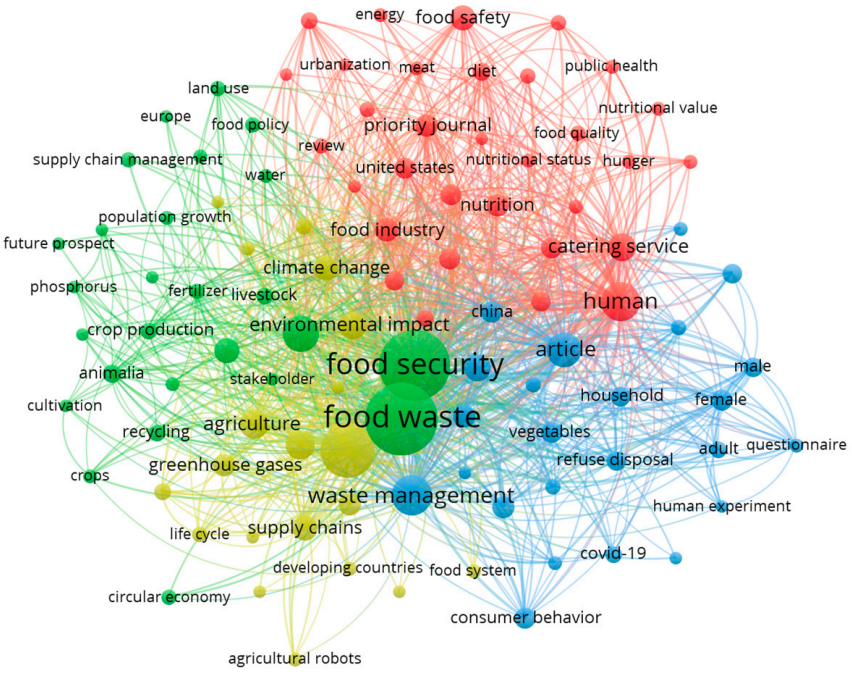


Figure 4. Co-occurrence of keywords network overlay map based on total link strength ("Food waste" AND "Food security").

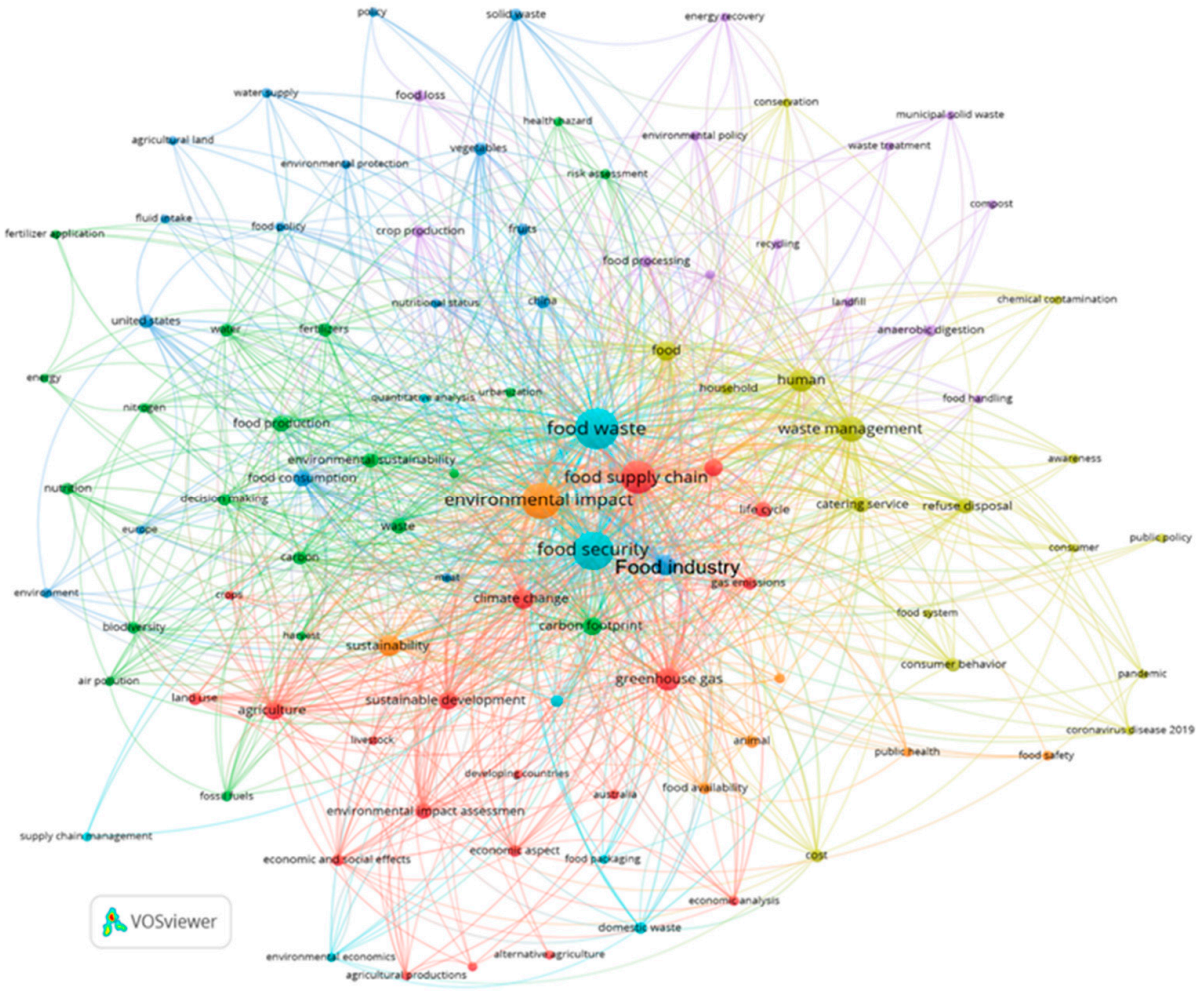


Figure 5. Co-occurrence of keywords network map based on total link strength ("Food waste" AND "Environmental impact" AND "Food security").

The items shown in the maps are represented by nodes, the greater their size, the more they appear in the related literature.

The scientific literature on "Food waste" and "Environmental impact" resulted in more links to the topics of sustainable development and life cycle assessment (Table 4). To answer the research question Q2, the overlay map of the temporal trend of keywords (Figure 3) was generated, showing that, in the past, the research interests were more focused on waste management, composting, landfill, and anaerobic digestion. Instead, more recent literature focuses more on sustainability, linking the problem of food waste to climate change, food security, the circular economy, and consumer behavior. These more recent keywords indicate that the issue of food waste is currently being addressed differently, by attempting to prevent food waste production rather than dealing with waste disposal. Furthermore, the map shows four well-defined clusters of keywords associated with the environmental impact of food waste. The first cluster is related to the FSC in general along with its specific stages, among which are agriculture and food consumption, both considered as steps, where most of the losses and waste occur as shown in Section 2. The second cluster is focused on waste management with all its practices, such as landfills, composting, and anaerobic digestion. Whereas, the third cluster includes environmental accounting methodologies, such as life cycle assessment. Finally, the last cluster includes more recent keywords addressing sustainability aspects related to sustainable development, climate change, and the circular economy [43–45].

Table 4. Top keywords based on total link strength for the three keywords combinations.

Search Combinations	Top Keywords	Total Link Strength
"Food waste" AND "environmental impact"	waste management	5334
	life cycle assessment	4101
	life cycle	3415
	food	2717
	anaerobic digestion	2658
	sustainable development	2244
"Food waste" AND "food security"	food supply chain	1527
	human	1203
	waste management	986
	food	635
	catering service	632
	food consumption	574
"Food waste" AND "environmental impact" AND "food security"	food supply chain	509
	waste management	342
	human	311
	food	259
	greenhouse gas	256
	carbon footprint	235

The results of the keywords analysis related to "Food waste" and "Food security" (Figure 4) show four well-identified clusters, mainly related to agriculture, the environment, sustainable development, and the food supply chain. Even though the analysis was performed on the social aspect of food waste, the multiscale aspect of the issue is clearly shown in the map.

Figure 5 shows the co-occurrence keywords network map of "Food waste" in relation to "Environmental impact" and "Food security". The results showed a similar keywords trend, but with a more holistic approach, where the environmental, social, and economic perspective were integrated. The most frequent keywords were linked to the food supply chain, climate change, greenhouses gases, and carbon footprint (Table 4, Figure 5). It is worth mentioning that sustainability of food systems and agriculture were included in the map, in addition to keywords related to possible solutions and alternatives to the food waste issue, such as consumer behavior, awareness, food policy, and environmental economics.

6.3. Co-Authorship Countries Network

The co-authorship countries network analysis had similar results to the three keywords combinations: UK, USA, and China were the highest in terms of number of documents (Table 5). The top countries in food waste research are the United States, the United Kingdom, China, the Netherlands, and Italy. They are also among the high-income countries with the highest amounts of FWL in the world, as well as associated emissions and impacts. The network map linking "Food waste" and "Environmental impact" shown in Figure 6 resulted in 44 countries. Furthermore, the map shows a high level of collaboration among all leading countries in the field. Indeed, high-income countries have the resources to fund and prioritize research on critical issues, such as FWL [46]. The same analyses revealed that most of the countries that published fewer documents, with a maximum of one document related to each of the three keyword combinations (e.g., Argentina, Tunisia, Iraq, Cuba, Nepal, Ecuador, Malawi, and Ghana) are middle-low-income countries.

Table 5. Top leading countries on food waste research based on total link strength.

"Food Waste" AND "Environmental Impact"		**"Food Waste" AND "Food Security"**		**"Food Waste" AND "Environmental Impact" AND "Food Security"**	
Country	Total Link Strength	Country	Total Link Strength	Country	Total Link Strength
United Kingdom	120	United Kingdom	101	United Kingdom	27
United States	96	United States	78	United States	26
China	94	China	51	Netherlands	14
Sweden	66	Australia	50	China	13
Italy	55	Italy	43	Malaysia	13
Spain	48	Netherlands	38	Canada	12
France	46	Sweden	34	Germany	10
Netherlands	46	Malaysia	29	Sweden	9
Australia	41	Germany	28	France	8
Germany	41	France	27	Australia	7
Canada	39	India	26	Pakistan	7

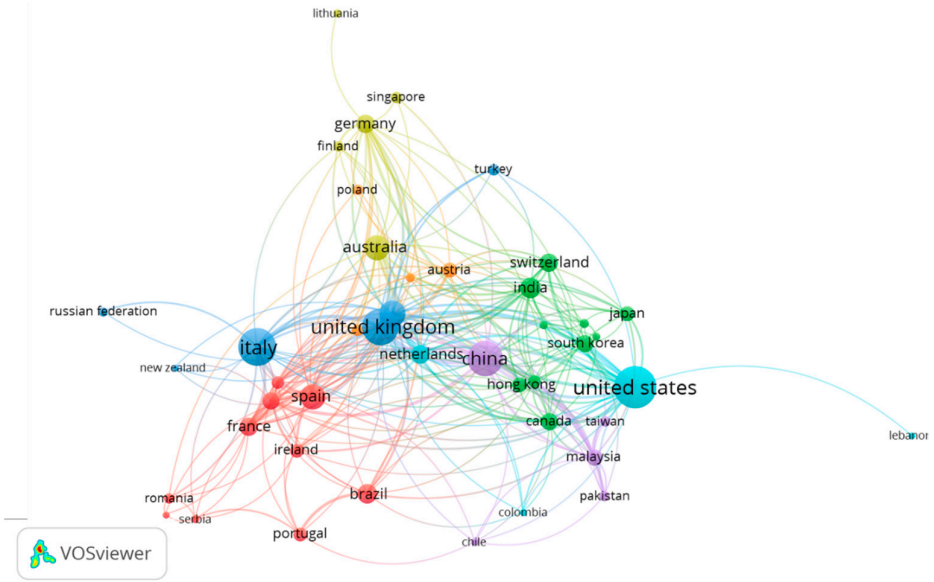


Figure 6. Co-authorship countries network map based on total link strength ("Food waste" AND "Environmental impact").

6.4. Co-Authorship Authors Network

Analyzing the co-authorship among authors allows for the identification of the most productive authors on the subject. This information is also relevant for expanding networks and making fruitful collaborations [43]. Among the results of the three keywords combinations, the authors map related to the environmental impact of food waste has the largest set of connected authors, as shown in Figure 7. By setting a minimum of three documents/author, the results showed 158 authors, of which 52 were connected and collaborated. The most productive authors are shown in Table 6.

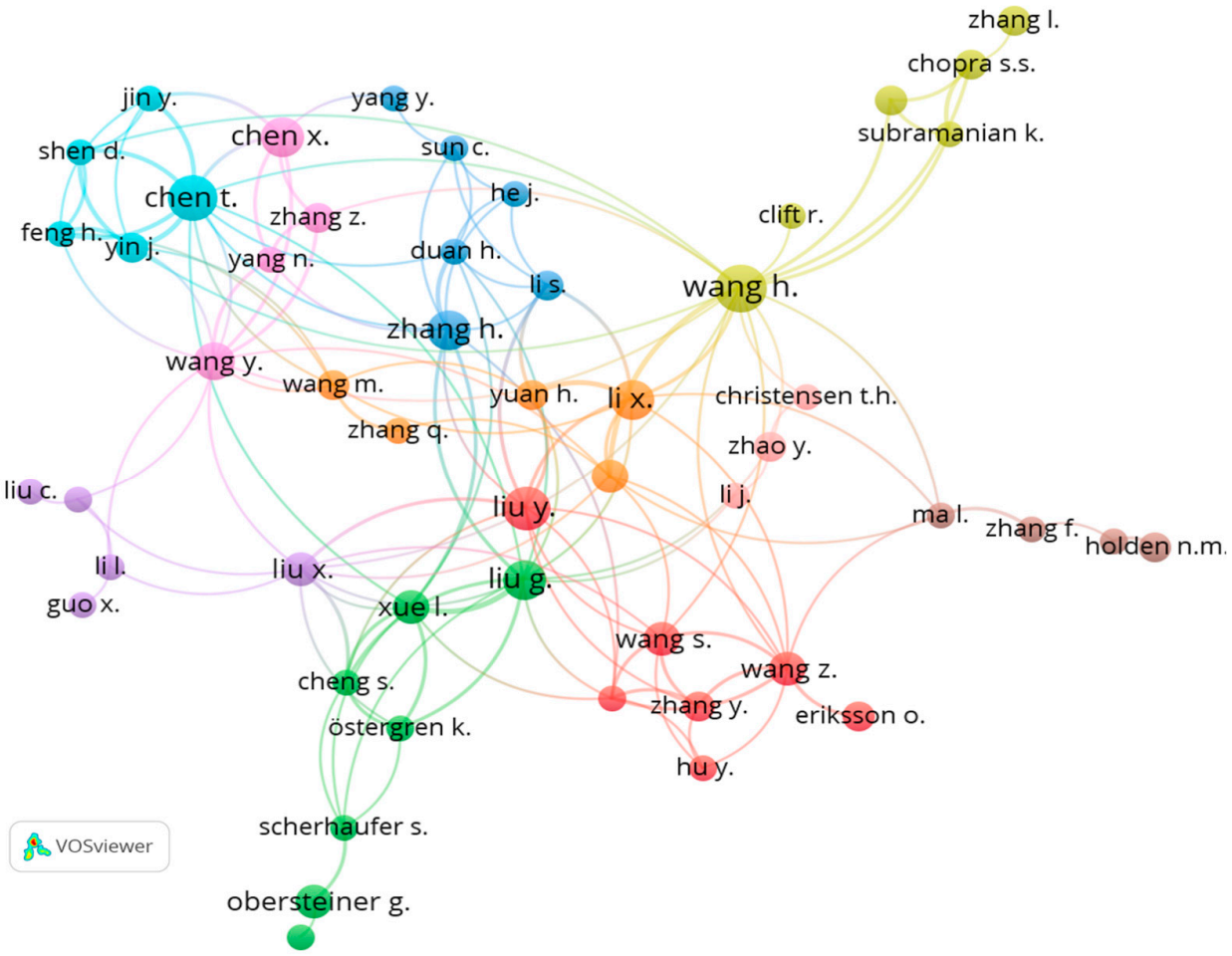


Figure 7. Co-authorship authors network map of "Food waste" AND "environmental impact".

Table 6. Top authors based on number of documents published on food waste.

"Food Waste" AND "Environmental Impact"			"Food Waste" AND "Food Security"			"Food Waste" AND "Environmental Impact" AND "Food Security"		
Author	Number of Documents	Total Link Strength	Author	Number of Documents	Total Link Strength	Author	Number of Documents	Total Link Strength
Wang H.	10	24	Irani Z.	6	8	Haines A.	3	32
Chen T.	9	22	Sharif A.M.	6	8	Aldaco R.	2	16
Eriksson M.	9	5	Abiad M.G.	5	5	Blanckenberg A.	2	4
Azapagic A.	8	13	Dou Z.	4	3	Candy S.	2	9
Liu Y.	8	14	Galanakis C.M.	4	0	Eriksson M.	2	6
Chen X.	7	11	Neff r.a.	4	1	Fawole O.A.	2	4

Authors working on food waste topics in relation to food security resulted in 161 (minimum number of two documents/authors), of which only 38 authors were connected (Figure 8). Finally, the authorship analysis of the food waste issue in relation to both environmental impact and food security showed 331 authors publishing at least one document in this field, out of which only 33 were connected (Figure 9a,b).

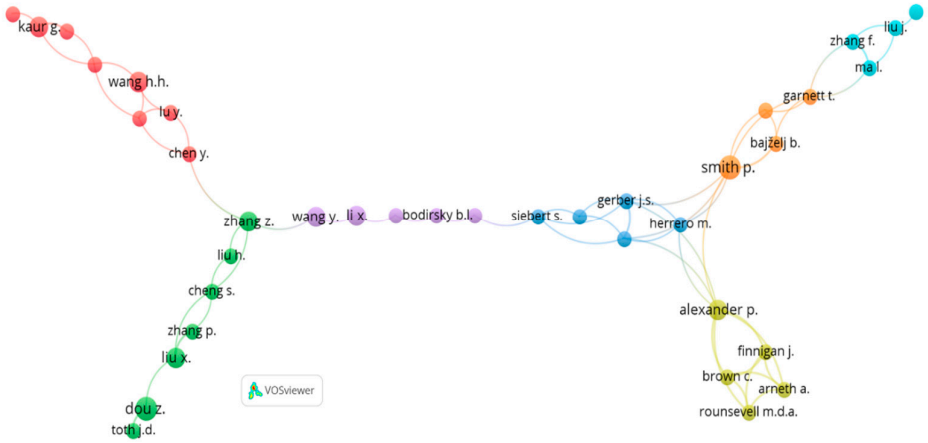
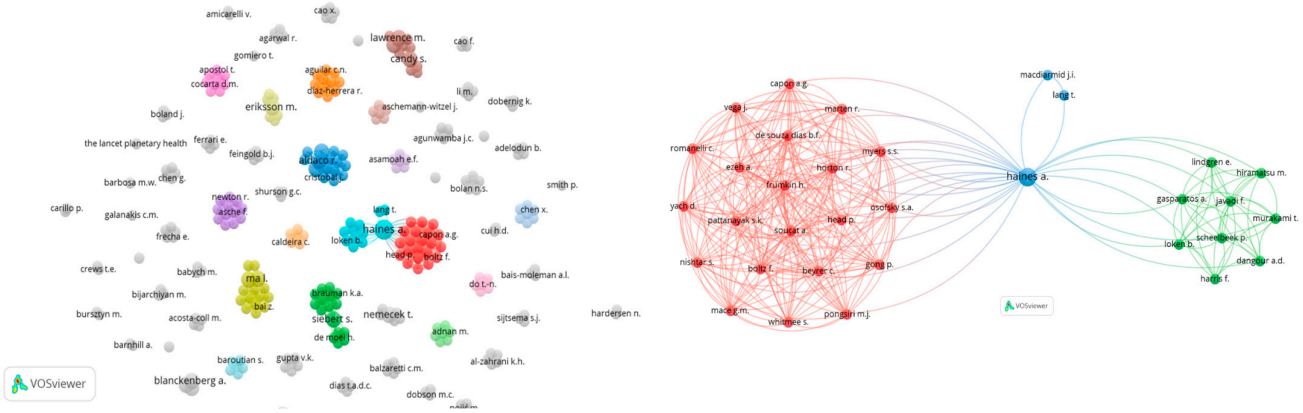


Figure 8. Co-authorship authors network map of "Food waste" AND "Food security".



(**a**) (**b**)

Figure 9. (**a**,**b**). Co-authorship authors network map of "Food waste" AND "Food security" AND "Environmental impact". (**a**) Set of all authors with a minimum of two publications; (**b**) set of only the connected authors.

7. Conclusions

The FWL problem represents a global multiscale issue that needs to be explored in depth by the scientific community. Through this work, we explored the main aspects of the scientific literature on FWL. The results of the literature review highlighted that the wide range of definitions in the scientific literature makes it challenging to unify the concept and the accounting methods, since each definition includes a specific type of food (edible or inedible, food loss or food waste, avoidable and unavoidable). Therefore, comparing results to reach a unified understanding of the current global situation remains an important task. Additionally, the data on FWL is insufficient, collected by different methodologies, with different accuracy levels, and the lower capacity of some countries makes it very challenging to address the actual extent of the problem. Indeed, standardized definitions and methodologies must be adopted and consistently updated to properly monitor FWL. On the other hand, since the FWL problem can be addressed in different ways, by adopting an environmental, social, and economic perspective, an integrated and holistic understanding of FWL remains challenging.

The second part of the paper explored the main global scientific literature on food waste in combination with two specific keywords: environmental impact and food security. The results showed that the topic of food waste is increasingly receiving interest from the scientific community, especially in the last decade, reaching 14,984 documents in 2022. The relationship between food waste and its environmental impact received more attention

compared to food security (1143 versus 616 documents). Nevertheless, food security linked to food waste is a timely topic that is continuously rising. The present study also allowed for understanding the evolution in food waste scientific research, identifying the most important topics and research trends. The results showed a clear research shift from an older approach of food waste based on the downstream notion of "waste" to a more modern approach based on sustainability, food security, consumer behavior, and the circular economy, addressing the problem of food waste by preventing it with upstream actions and policies.

Considering the remarkable ethical, environmental, social, and economic implications of FWL, the outcomes of this study display the need for developing interdisciplinary approaches and methodologies capable of providing a comprehensive understanding of the FWL issue. Finally, an integrated perspective on FWL could also help by raising the awareness of citizens and policy makers about the urgent need for developing more sustainable food production and consumption patterns.

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Nomenclature

GHG	Greenhouse gases
FWL	Food waste and loss
FAO	Food and Agriculture Organization of the United Nations
FSC	Food supply chain
SDG	Sustainable Development Goal
UN	United Nations
USA	Unites States of America
KSA	Kingdom of Saudi Arabia
UAE	United Arab Emirates

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