Food Loss–Food Waste–Food Security: A New Research Agenda

Fabio Gaetano Santeramo and Emilia Lamonaca *

Department of Agriculture, Food, Natural Resources and Engineering (DAFNE), University of Foggia, 71121 Foggia, Italy; fabio.santeramo@unifg.it

* Correspondence: emilia.lamonaca@unifg.it

Abstract: The food loss and waste (FLW)–food security nexus is a relevant issue in the societal debate, in that it contributes to understanding the challenges posed by a continuous and unsustainable development of agri-food systems and supply chains. An overview on the state-of-the-art academic research on the implications of FLW on food security is provided. The aim is to identify publication patterns and inform on key topics emerging from the literature on the FLW–food security nexus. Based on a systematic and a bibliometric approach, the analysis concludes that “Water-Energy-Food Security nexus” and “Reduction of FLW” are the dominant thematic areas within the literature on the nexus between FLW and food security. Future research should explore the FLW–food security nexus through evidence-based and scenario analyses, informing stakeholders about nexus interactions and highlighting synergies between different resource uses in a circular and green economy perspective.

Keywords: agri-food system; agri-food supply chain; green economy; containment policy; water-energy-food nexus; bibliometric analysis; systematic review

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1. Background

Food loss and waste (FLW) are among the most challenging concerns of the modern society [1]. The implications of FLW for food security animate the societal debate. In fact, while the global demand for food grows, millions of people suffer from undernourishment worldwide [2,3]. The concept of food insecurity relates not only to hungry people, but also to the insecurity with respect to macro- and micro-nutrients: unbalanced diets may contribute to food insecurity [4,5].

Different definitions have been proposed for food loss and waste without reaching a broad consensus (for a detailed review of definitions, target issues and inconsistency between definitions see Chaboud and Daviron [6]). As suggested by Chaboud and Daviron [6], the interpretation and use of terms “food loss” and “food waste” depend on the use of food products and the nutritional value of FLW. FLW tends to be associated with food products originally intended for human consumption but which are not consumed because of loss, waste, or redirection to other uses [2]. However, food products may lose nutritional value if they are not optimally used in relation to their nutritional potential [7,8]. Schuster and Torero [9] define food loss as the unexpected reduction in the quantity and quality (i.e., loss of original characteristics, particularly safety of food products) of food during the production (e.g., pre-harvest, harvest, breeding) and post-harvest stages (including post-production procedures, such as handling, storage, transport, and processing, such as canning, packaging). In these stages, food losses may be related to pests and diseases, inefficient or poor harvesting techniques, changes in prices and price volatility or lack of agricultural inputs for food production. For instance, volatile prices may affect stock levels; when prices are below the expected price, it is convenient to store food products and to sell them when prices are expected to be higher [10,11]. However, food products stored for a long time may perish contributing to FLW with consequences on food security [12,13]. Food waste occurs at the distribution (e.g., retail, transport) and consumption (e.g., preparation) levels and refers to the dispose of food suitable for the human consumption [9]. According

to the FAO guidelines, in a supply chain perspective, both food losses and food waste may be considered food wastage, that is, the decrease in edible food mass that was originally intended for human consumption. Overall, about one-third of the global food production is lost or wasted along the food supply chain [14]. The unsustainable and wasteful use of resources throughout the supply chains is detrimental for the society: FLW contributes to the reduction of food access and availability [15], undermining food security [16,17]. Loss and waste of food redirected for animal feed or other non-food uses may prevent the use of other resources that contribute to food availability (e.g., reduction in the amount of agricultural land, need for fertilisers). FLW may provide food for certain population categories and income or employment for stakeholders involved in the recycling of loss and waste. Moreover, food access is related to the price/affordability of food: food being too cheap fosters the likelihood of food being wasted, especially at the consumption level and in developed societies.

Containing FLW at any stage of supply chains (i.e., agricultural production and harvest, processing, distribution and retail, restaurants and catering, domestic consumption) is crucial to contribute to the reduction of food insecurity, in accordance with the Sustainable Development Goals (SDGs) [18,19]. The reduction of FLW is a central topic for policy design and interventions: international organisations, national and local governments, civil society actors and retailers have undertaken several initiatives to reduce FLW (for a review, see Schuster and Torero [9]).

2. The State-of-the-Art of Academic Research on the FLW-Food Security Nexus

The implications of FLW on food security are an attractive multidisciplinary research area contributing to identifying and understanding societal challenges posed by the constant (unsustainable) development of agri-food systems. We provide an overview on the state-of-the-art academic research on the FLW-food security nexus through a systematic and bibliometric approach. The systematic search of the literature on FLW and food security took place in January 2021 and focused on documents indexed in the Scopus database, including studies since 1990 until 2020 (no time limits were set in the bibliographic search [20]). The document search was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol [21]. In a first phase, documents were selected when in the title, abstract or keywords one of the terms “food waste”, “food loss” or “food lost” interacted with the term “food security”. The terms “food waste”, “food loss” and “food lost” allowed us to identify the broader topic covered by this study; the term “food security” was applied to restrict the search to the implications of FLW on food security. This search led to a preliminary sample of 440 documents from which only peer-reviewed articles published in academic journals in English were selected [22,23]. The final number of documents obtained was 327.

The first author linking the food loss and food security issues was B.T. Nyambo [24] who, in 1993, claimed that farmers in South Nyanza District in Kenya, adopting improved post-harvest grain handling technology, tend to reduce food losses enhancing food security. Since this pioneering study, the linkages between FLW and food security remained unexplored until the first decade of the 21st century when Marsh et al. [25] investigated the impact on food security of losses in the global food supply caused by international transports: they estimated losses of 250–750 USD per year for the major categories of traded agricultural commodities. In 2004, T.E. Crews and M.B. Peoples [26] concluded that obtaining nitrogen from agricultural (i.e., legumes) versus industrial sources is potentially more sustainable in terms of ecological integrity, energy contribution and food security. They further suggested that food waste tends to be lower in countries able to reduce or eliminate the dependence on synthetic nitrogen through the adoption of less meat-intensive diets. Differently from previous studies, Eikenberry and Smith [27] moved the attention to the last part of food supply chains, highlighting the need to increase research on the use of dumpsters as a source of food. As they pointed out, food recovery and donation programmes managing food wasted (more than 96 billion pounds each year in the United

States only) may contribute to improve the wellbeing of food insecure dwellers. Among more recent articles, Pelau et al. [28] in 2020 show that certain characteristics of the national culture, such as socio-demographic characteristics and consumption patterns, are factors that affect the quantity of wasted food.

Since 2009, the number of peer-reviewed documents published in academic journals has increased exponentially (Figure 1) indicating the growing research interests on the FLW–food security nexus. The academic debate approached the issue both with review and empirical studies. Despite an increase in review articles in the last three years (Figure 1), they cover only 20% of published documents.

Figure 1. Documents by year of publication.

The main research areas in the literature on the FLW–food security nexus are Agricultural and Biological Sciences and Environmental Science, with 150 and 147 documents respectively, followed by Social Sciences (101 documents). The top 10 source titles covering one-third of published documents fall in these areas: *Sustainability Switzerland* (24 documents), *Journal of Cleaner Production* (17 documents), *Resources Conservation and Recycling* (14 documents), *Food Security* (11 documents), *Science of the Total Environment* (9 documents), *Global Food Security* (8 documents), *Food Policy* (7 documents), *Foods* (6 documents), *Trends in Food Science and Technology* (6 documents) and *British Food Journal* (5 documents). The most active scholars are Z. Irani and A.M. Sharif from the University of Bradford (United Kingdom) with six articles each. Their research explores the relevance of interventions to reduce food waste in food supply chains thus improving the levels of food security (e.g., Irani and Sharif, [29,30]).

The bibliometric technique of term co-occurrence allows to identify the main thematic streams in the literature on the implications of FLW on food security. The 34 most relevant terms included in the titles and abstracts of the sample of 327 documents were extracted using the binary counting method in the VOSViewer programme [31]. Considering only the presence or absence of a term in a document, the binary counting method identified 9250 terms of which only 127 terms met the threshold of the minimum number of occurrences of a term. The threshold, set equal to 5% of the total number of documents in the sample, was 16. VOSViewer automatically extracted the 60% most relevant of the 127 terms

(i.e., 76 terms). The final number of terms (34) was obtained by removing irrelevant terms from those 76 terms: they are listed in Table A1 in Appendix A. Figure 2 shows the relationships between the most relevant terms in the literature related to FLW and food security. Shorter distances between terms in the network indicate stronger relationships between them. Based on the frequency of co-occurrence, the most relevant terms are also classified into two main clusters (i.e., thematic areas within the literature on the nexus between FLW and food security): “Water-Energy-Food Security nexus” (red cluster), and “Reduction of food loss and food waste” (green cluster). Closer relationships occur between terms in the same thematic cluster. The red cluster, associated with resource-related keywords such as energy, water and land, identifies the research area dedicated to the sustainable use of natural resources, especially in the context of food production, from the perspective of global food security. The cluster appears to be methodological oriented, concerning analyses of the environmental impacts and greenhouse gas emissions associated with agriculture and food systems. The green cluster is associated with keywords that hint at food waste reduction (e.g., storage, technology, policymaker, economy) to achieve the goal of food security. A particular attention is devoted to perishable products such as fruit and vegetable that are more likely to be wasted.

Figure 2. Networks of term co-occurrence.

The Water-Energy-Food Security nexus is crucial to achieve the UN Sustainable Development Goals (SDGs): the domains “water”, “energy” and “food” are strictly interrelated and the achievement of social, economic, and environmental goals in a perspective of sustainable development depends on an efficient management of these resources [32,33].

Currently, almost 800 million people are food insecure [34]. Global projections indicate that, by 2050, the demand for water, energy and food will significantly increase driven by growing population, economic development and growth, rapid urbanisation, changing diets and climate change [32]. The energy and food sectors are crucially dependent on water, but water is a finite resource: the strict nexus between water, energy, and food calls for the need to ensure a better management of linked resources [35].

Reducing FLW has a great potential for cutting the resources (i.e., water, energy) used for producing and supplying food which is then wasted. It is unsustainable that food production and supply chains are highly resource intensive, particularly if this high-intensive use of resources is geared towards the production and supply of food which is then wasted. Accordingly, the benefits of reducing FLW would be in terms of reduced environmental impacts related to the production and consumption of food, and increased levels of food security. Policies to contain food loss and food waste, however, need to be based on the stakeholder involvement. A dialogue between policymakers and stakeholders would increase awareness on the linkages between resources (i.e., water-energy-food nexus): relevant information may be provided by stakeholders and decision-making processes may be legitimised by a sense of ownership among stakeholders [32]. Efficient containment policies along the entire agri-food supply chains may contribute to save water and energy and to implement an integrated resource use in a green economy.

3. Conclusions

Identifying, assessing, and managing the nexus between FLW and food security is promising research area. FLW imply an inefficient use of resources (i.e., water, energy, food) within the agri-food systems with detrimental impacts on food security levels. Policy measures to contain FLW at different stages of the food production and supply chains are crucial to reduce the impacts on food security [2,34,36]. It is important that future research examines the interrelations between FLW and food security. Given the multidisciplinary character of the issue, academics from different research areas (e.g., agricultural sciences, agricultural economics, development economics, environmental sciences, engineering) may contribute understanding the effects of FLW on food security and deepening on the topics emerged from this analysis: i.e., “Water-Energy-Food Security nexus” and “Reduction of food loss and food waste”. Based on our findings on previous publication patterns, evidence-based and scenario analyses would be informative on the synergies between different supply chains, providing insights on a more efficient management of resources based on the principles of the circular and green economy approach: i.e., reduction, reuse, recycle [37]. The challenge of future research will consist in providing insights and finding solutions *“more oriented towards the protection of the environment, the preservation of the natural resources, in order to facilitate the emergence of strategies able to promote the circular economy and to reduce food wastage”* [38].

Several actions may be undertaken to reduce FLW and achieve the target of zero losses and waste. It is essential to avoid and prevent food loss during processing, through the identification of causes of FLW, the activation of training courses for personnel at any stages of the supply chains, the optimisation of the production. In addition, food manufacturers may help growers and consumers in the goal of reducing food loss. Support to growers includes, for instance, transforming perishable raw materials into shelf-stable products, positioning factories near fields, working with supply chain partners to improve storage, cold chain facilities and transportation. Past experiences are relevant to successful implement these supporting activities [39]. Actions in support of consumers may be the extension of the shelf life through packaging and processing innovation, the introduction of clear date labels or storage, freezing, defrosting and preparation instructions, the supply of a variety of portion sizes, the provision of information on packaging and labelling innovations that help prevent food spoilage. Other actions include the redirection of food to people through different channels (e.g., food banks or markets) or to feed animals and to industrial use [40]. A sustainable alternative may be the transformation of food loss

and by-products into fertiliser or compost for soil enrichment or into renewable energy: indeed, an increasing amount of biofuels is produced from waste streams from the food sector [41,42].

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Appendix A

Table A1. List of the 34 relevant terms included in the bibliometric analysis and divided by thematic clusters.

Water-Energy-Food Security Nexus	Reduction of Food Loss and Food Waste
Global food security	Loss
Diet	Food waste reduction
Availability	Storage
Food system	Policy maker
Food Production	Technology
Energy	Economy
Water	Food chain
Land	Food supply chain
Agriculture	Supply chain
Natural resources	Farm
Environmental impact	Household
Greenhouse gas emission	Human consumption
Climate change	Fruit
Environmental sustainability	Vegetable
Sustainability	Protein
Population	Food safety
Global population	Hunger

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