Opening the black box of food waste reduction

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Introduction

This paper presents the development of a bottom-up model of surplus food generation and management by combining conceptual arguments with an empirical analysis of the food supply chain. The objective was to devise a methodology that can be used to understand and quantify surplus food, "recoverable" surplus food and food waste, at company, sector and country levels.

There are several issues related to food waste, food security and the management of surplus food that have created a need for research in this area. Food waste is acknowledged to be a huge problem worldwide, even though the definition of various terms and information collection processes are not yet well harmonized. Gustavsson et al. (2011) estimated that food wastage is particularly severe in developed countries, with estimates as high as 280–300 kg per capita per year in Europe and North America. In the United States, food waste and losses at the retail and consumer levels were found to amount to 188 kg per capita per year, or an overall value of 165.6 billion dollars (Buzby and Hyman, 2012). Countries in the European Union (EU) are reported to generate 179 kg per capita of food waste every year, exclusive of agricultural waste (O'Connor, 2013). The picture, though patchy, is at variance with the available data on food security, even in developed regions (see section 'Literature review'). In 2011, 5.7% of American households experienced a disruption to their normal eating patterns due to limited resources (Coleman-Jensen et al., 2012), and 8.8% of EU inhabitants suffered severe material deprivations, which in many cases entailed insufficient protein in the diet (Eurostat, 2013). The incongruity between food waste and food security data is a strong indicator that an integrated approach to these two issues could be of significant value.

Surplus food management is increasingly acknowledged to be a lever for the mitigation of food insecurity, especially in developed countries. Both surplus food reduction at the source and its recovery for human consumption are critical elements in the global food security effort, along with the growth of agricultural productivity, the evolution of dietary habits (especially in developed countries) and the enhancement of food-chain infrastructure (especially in developing countries). Surplus food can be recovered and donated to help those in need (Kantor et al., 1997; Tarasuk and Eakin, 2003; Parfitt et al., 2010; Gentilini, 2013; Garnett, 2013), or can be reduced at the source for a more efficient use of input resources (Cuéllar and Webber, 2010; Buzby et al., 2011; Buzby and Hyman, 2012). At the same time, reducing food waste is, per se, an important part of the effort to attain environmental goals. In fact, both source reduction and recovery are high-priority strategies in the food waste hierarchy (EPA, 2006).

Finally, the research presented in this paper was motivated by the belief that a bottom-up approach is needed to understand and model surplus food generation and management throughout the food supply chain, and to obtain sound empirical information. Until several years ago, there were relatively few analytical and empirical studies on sustainable food management, and some methodological concerns were raised in relation to these studies (see section 'Literature review'). More recently, there have been quite a few in-depth studies that have addressed this issue in

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developed countries (e.g. Griffin et al., 2009; Mena et al., 2011; Sonnino and McWilliam, 2011; Buzby and Hyman, 2012; Beretta et al., 2013). The literature in this emerging field of research has provided two much needed additions to the pre-existing research: the scope of the analysis has now been explicitly defined (e.g. food waste is distinguished from food scraps), and it has been made evident that generalizations cannot be made. There is, in fact, considerable variability between available estimates of food waste and losses due to differences in geographic setting, sample size, and supply chain stage considered.

Suggestions from recent studies have been incorporated in the work presented in this paper. Accordingly, a micro-level perspective has been assumed, i.e. individual players (e.g. farmers, manufacturers, retailers) have been analysed, and an empirically-based methodology for analysing the food supply chain has been proposed. Current ideas presented in the literature are encompassed in the conceptualisation of surplus food management and recovery proposed here. The focus is on two key concepts: "Surplus Food", i.e. the edible food that is produced, manufactured, retailed or served but for various reasons is not sold to or consumed by the intended customer; and "Food Waste", i.e. the surplus food that is not recovered to feed people, to feed animals, to produce new products (e.g. jams or juices), new materials (e.g. fertilizers) or energy.

This paper also makes two original contributions to this developing field of research: it presents a unified conceptual model that can support the analysis of both the supply chain as a whole and its individual stages, and, coherently with the bottom-up vision, the conceptual model has been customised within the different stages of the food supply chain, i.e. agriculture and fishing, manufacturing, retail trade, food service and household consumption.

There are a number of reasons why the proposed methodology can be a useful tool. The unified model provides policy-makers and managers with a common language, i.e. clear-cut concepts and keywords that can be used at a company, sector or country levels. Customisation of the model to describe the different supply chain segments provides a means of differentiating surplus food and food waste generated by different companies and sectors based on the "degree of recoverability". This information, in turn, is essential if policy-makers are to determine targets that are challenging yet attainable, and to prioritize recovery efforts. Finally, this methodology can be used to monitor and quantify surplus food and food waste. This is necessary if managers are to be able to implement strategies that are coherent with the food waste hierarchy, and for policymakers to design bottom-up quantitative assessment plans.

The remainder of the paper is organized as follows. The main contributions to the literature on surplus food management are discussed in section 'Literature review'. The research framework in terms of objectives and methodology is presented in section 'Research framework'. In section 'ASRW model: conceptualisation' a conceptual model for assessing surplus food and food waste is proposed. In section 'ASRW model: refinement and customisation' the model is customised across supply chain stages. Finally, in section 'ASRW model implementation' the model is applied to three case studies. Conclusions and suggestions for further research are proposed in the final section.

Literature review

This section presents a review of the extant research on the generation and management of surplus food and food waste. The literature was reviewed according to five perspectives: relevance of the issue; scope of existing analyses; methodologies used to assess the phenomenon; quantitative estimates of surplus food; strategies and policies for managing surplus food.

Food security and the relevance of surplus food management

The FAO (United Nations' Food and Agriculture Organization) stated in 1996 that "food security" exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (Pinstrup-Andersen, 2009).[3] This definition highlights the two main aspects of food insecurity and poverty: (i) food availability and access (Pinstrup-Andersen, 2009), and (ii) food safety, i.e. safe and healthy food, in contrast to eating issues such as obesity and malnutrition (Aiking and De Boer, 2004). Over 820 million undernourished people live in developing countries, but food security is also an issue in developed regions, where 15.7 million people are undernourished (FAO, 2013).

A multifaceted and coherent global strategy is needed to address the food security challenge (Godfray and Charles, 2010), especially as the world population is projected to reach 9.6 billion in 2050. As in the past, an environmentally sustainable increase in agricultural productivity is crucial to solving the problem of feeding the world over the long term (Beddington, 2010; OECD, 2013). Another element is related to dietary changes, particularly to a reduction of meat fractions in both emerging and rich countries (Godfray and Charles, 2010). Finally, food security is also dependent on the management of food waste (Kantor et al., 1997).

Gustavsson et al. (2011) estimated that global food losses and waste throughout the food supply chain have reached 1.3 billion tonnes per year, i.e. one-third of global food production. However, different strategies are needed to tackle the food waste issue in developing and developed countries. In the developing world, food losses are mainly attributable to the absence of food-chain infrastructure and a lack of knowledge or investment in technologies (Godfray and Charles, 2010). The issues are different in developed countries, where surplus food generation plays a prominent role (e.g. overstocking or preparing too much food due to difficulties in predicting the number of customers) (Buzby and Hyman, 2012).

Therefore, when focusing on developed countries, surplus food management is a key element of the food security issue. The recovery of surplus food is a way of providing food to those who need it (Parfitt et al., 2010). Its reduction at the source can free up valuable resources that can be better used to respond to the food security challenge. Indeed, as highlighted by Buzby et al. (2011), Buzby and Hyman (2012), food waste represents a significant amount of economic resources consumed throughout the food lifecycle (production, warehousing, transportation). Engström and Carlsson-Kanyama (2004) estimated food losses to be 287 million portions each year at food service institutions in Sweden, corresponding to a monetary value of just under 1 billion euros. Cuéllar and Webber (2010) estimated that the energy embedded in wasted food represents approximately 2% of annual energy consumption in the United States. Moreover, food production causes negative impacts on the environment, mainly in terms of greenhouse gas emissions (Levis et al., 2010), water consumption (Darlington and Rahimifard, 2006), pollution (Garnett, 2013) and decreased biodiversity (Engström and Carlsson-Kanyama, 2004).

As discussed in the introduction, the responsible management of surplus food can represent part of the solution to food security and environmental challenges, namely the need to feed more people while making the food value chain more environmentally sustainable and resilient (Garnett, 2013).

[3] Food poverty entails an only slightly different definition, i.e. the situation whereby a person does not have reasonable access to food that would provide a healthy diet, because of insufficient income, or unreasonable difficulties of distance, transport or similar, or inadequate information (Alexander and Smajne, 2008).

Scope of analysis

A key aspect of the literature review is the scope of analysis, which varies significantly between studies. Definitions of terms related to surplus food management (e.g. food losses and food waste) are not yet shared universally (Buzby and Hyman, 2012), making it difficult to compare the findings of studies on the management of surplus food between different countries. In some cases the scope is "food losses" (Beretta et al., 2013; Buzby and Hyman, 2012; Kantor et al., 1997; Mena et al., 2011), in others, "food waste" (Griffin et al., 2009; Kummu et al., 2012; Parfitt et al., 2010; Sonnino and McWilliam, 2011). "Food losses" usually refers to edible food, lost at any stage of the supply chain, such as meats, bread, discarded or unserved restaurant-prepared food, or products that are unmarketable for aesthetic reasons, but otherwise edible and safe (Kantor et al., 1997), and excludes only the inedible part that cannot be used for human consumption (Tarasuk and Eakin, 2005). "Food waste" is often defined as food lost at any stage of the supply chain, including crops damaged during harvesting, food damaged during transport or food discarded and mixed with other wastes (Griffin et al., 2009), i.e. edible food losses mixed with garbage or leftovers that are not necessarily edible. In addition, a distinction should be made between the different types of waste generated in a production process. For example, Darlington and Rahimifard (2006) distinguish between the wastage of finished products and the waste from production, including process waste, overproduction waste and bulk organic waste.

For these reasons, there are two main shortcomings in the literature. First, the comparison of the results between different studies is difficult. Second, since there is no distinction between edible and non-edible food losses in many studies, the results cannot be directly used in the pursuit of both social and environmental goals.

Methodologies

The methodologies used to analyse and quantify the phenomenon (surplus food and food waste) also differ significantly.

With the exception of the agriculture stage, in which detailed food balance sheets are used (e.g. Gustavsson et al., 2011), the quantification of food losses is very difficult (Parfitt et al., 2010) and has led to the development of different approaches (Hall et al., 2009). These differ in the way in which food losses are estimated at different stages and for different countries.

With reference to food losses and food waste estimates, the majority of academic papers use third-party sources (Buzby and Hyman, 2012; Griffin et al., 2009; Kantor et al., 1997; Kummu et al., 2012). In other cases, a sample of companies (Mena et al., 2011) is considered. Finally a mix of third-party sources and data from a sample of companies has also been used (Beretta et al., 2013). In order to avoid incurring aggregation biases in the estimates, the different stages are always analysed separately (i.e. manufacturing, retail trade, food service, household consumption) and are often differentiated by product categories (e.g. ambient-temperature and chilled and frozen products, as in Mena et al., 2011). The sample size is not usually high (e.g. 43 case studies in Mena et al., 2011, 4 cases for the retailer stage in WRAP, 2010, 31 firms in Beretta et al., 2013), because detailed data are difficult to find (Griffin et al., 2009).

Two approaches have been used to estimate the overall extent of food losses and food waste: (i) an analysis of municipal solid waste (e.g. Hall et al., 2009; Ondersteijn et al., 2006); and (ii) inferential methods, applying waste factors measured in sample populations to the whole food system (e.g. Kantor et al., 1997; Griffin et al., 2009). The first approach may lead to an over-assessment of food losses because it considers all the different categories of food waste (i.e. edible and non-edible). As to the second approach, the inference is carried out using official statistical data and then used in projections. For example, estimates by Kantor et al. (1997), Buzby and Hyman (2012) are based on the amount of available food published annually by the USDA's Economic Research Service (ERS), adjusted for a percentage of non-edible food parts. Griffin et al. (2009) considered the number of companies located in one U.S. county as the inferential basis. In some studies, the sector turnover is considered as the inferential basis (e.g. WRAP, 2010 for the retail stage). In Gustavsson et al. (2011) the amount of food losses is obtained using a "mass flow model". The starting point, for all commodities, is agricultural production volume. Then, by applying appropriate coefficients (mostly obtained from the literature), the edible mass and the food losses for each stage of the supply chain are computed.

Surplus food and food waste quantification

Due to differences in conceptual models and methodologies, quantitative results are hard to compare. Country-specific analyses of industrialized countries are relatively more homogenous and their results can be summarized as follows. Kantor et al. (1997) analysed the U.S. food supply chain and found that the food losses, i.e. wasted edible products, represent 1% of the production volume at the retail trade stage and 26% at the household consumption stage. If this amount is divided by the number of U.S. inhabitants, it is found that food losses of 9.41 kg/year per capita are generated at the retail stage, while 157 kg/year per capita are generated at the household consumption stage. Likewise food losses from the whole Swiss supply chain amount to 299 kg/year per capita, including 12 and 135 kg/year per capita respectively at retail and household stages (Beretta et al., 2013). Finally, similar results at the U.S. household consumption stage were obtained by Buzby and Hyman (2012), with an amount of food losses equal to 123.9 kg/year per capita.

Again with respect to the U.S., and considering food waste, Griffin et al. (2009) quantified a surprisingly smaller food waste value, i.e. wasted edible and non-edible products: 21 kg/year per capita at the agriculture stage, 1 kg/year per capita at the manufacturing stage, 20 kg/year per capita at the retail level and 63 kg/year per capita at the household consumption stage. In the British food supply chain, according to WRAP (2010), 42 kg/year per capita of food waste is generated at the manufacturing stage, 6 kg/year per capita at the retail trade stage, 134 kg/year per capita at the household consumption stage.

Managing surplus food

The amount of food waste also depends on surplus food management policies. Firstly, surplus food can be used in food recovery, meaning the collection of wholesome food from farmers' fields, retail stores or food service establishments for distribution to the poor and hungry; secondly, surplus food can be re-used as livestock feed, compost, biodiesel or other fuels (Kantor et al., 1997). Finally, there is the possibility of waste disposal.

The comparison between alternatives is very often considered in environmental terms (e.g. Lundie and Peters, 2005). Johnston and Green (2004) emphasise the need to create a food recovery hierarchy that prioritises food donation to the hungry. In this regard, it should be considered that not all surplus food is economically recoverable. Kantor et al. (1997) show that food recovery efforts are often limited by financial and logistical constraints that make it difficult to supply recovered food to potential recipients. These constraints are underscored by the need to maintain food safety. Despite the numerous studies in which the various surplus food management policies are illustrated, few provide a quantitative representation of them. Notable exceptions are Kantor et al.

(1997), Griffin et al. (2009), according to whom in the U.S. a percentage of between 3% and 5% of surplus food is donated to charity organisations (e.g. food banks).

Research framework

Objectives

As shown in the previous section, studies on food management to-date are characterised by a certain degree of ambiguity on the subject definition and methods of analysis. Secondly, many studies concentrate on a portion of the supply chain. Finally, most of the literature does not identify the characteristics of the stages of the supply chain in which edible surplus food is generated, thus neglecting the various hurdles in managing surplus food and the different degrees of food recoverability. For example, managing surplus packaged food at distribution centres is very different from recovering unsold food (e.g. pizzas, sandwiches) at a snack bar.

The objective of this paper is threefold:

- To present a conceptual model of surplus food generation and management (called ASRW, i.e. Availability-Surplus-Recoverability-Waste) along the integrated food supply chain, thereby clearly defining the scope of the analysis and the constructs to be analysed (surplus food and food waste in particular).
- To customise the model by considering various stages in the food supply chain – i.e. agriculture and fishing, manufacturing, retail trade, food service, household consumption – and to determine the most relevant sources of surplus food, the degree of recoverability of surplus food, the most appropriate ways to recover it at each stage.
- To provide preliminary results from the application of the conceptual model to three Italian cases, i.e. one international manufacturer, one domestic retailer and one international food service company, in order to illustrate how the model can be applied at a corporate level to assess food waste and to identify strategies to reduce food waste.

The model emphasises the social perspective (i.e. war on food poverty), while retaining an economic perspective (i.e. the impact of surplus food management at each company).

Methodology

To be consistent with the aforementioned objectives, the research was divided into three steps:

- Step 1: conceptualisation of the ASRW model.
- Step 2: refinement and customisation of the model.
- Step 3: application of the model.

The three steps combine different approaches. Following an extensive literature review, a set of key problems, theoretical constructs, and relations was identified and a preliminary conceptual framework, i.e. an early version of the ASRW conceptual model (step 1), was created. A bottom-up approach was then taken, which involved conducting 30 exploratory case studies (business case studies and interviews with experts), in order to refine the conceptual model, to adapt it to different supply chain stages and to prepare the protocols for empirical analysis (step 2). The process, which iterated information collection and theory development, resulted in the development of an empirically-grounded ASRW model (see sections 'ASRW model: conceptualisation' and 'ASRW model: refinement and customisation'). Finally, 3 confirmatory case studies were conducted, in order to test the potential of the model as an investigative tool, and to obtain initial empirical findings on the sources, significance, and management of surplus food (step 3) (see section 'ASRW model implementation').

The case study methodology was adopted because it is particularly appropriate at the early stages of the investigation of a phenomenon (Eisenhardt, 1989; Yin, 1994), and when the goal is the development of a new theory (Van De Ven, 1989; Voss et al., 2002). The following subsections provide a more detailed description of how the case study approach was used in steps 2 and 3 of the methodology.

Exploratory case studies

The exploratory case studies had multiple objectives. First, they helped to refine the ASRW model, i.e. to identify the main sources of surplus food and to understand the modes through which surplus food is managed throughout the different supply chain stages. They were then used in the preparation of a protocol for the subsequent confirmatory case studies. Finally, they were used to produce an initial set of quantitative findings on surplus food and food waste.

The exploratory case studies included 10 interviews with industry experts and 20 case studies at firms involved in the food supply chain (see Table 1). The industry expert panel included scholars (3), managers of trade associations (4), and managers of non-governmental food recovery organizations (3). For the company case studies, 20 firms operating in various stages of the food supply chain were examined. The interviewees were managers with significant sector and supply chain structure expertise. For reasons of confidentiality, the names of companies and interviewees are not provided.

Regarding the selection of the case studies, as Pettigrew (1988) noted, it is advisable to choose such cases as "extreme situations and polar types in which the process of interest is transparently observable", due to the limited number of companies which can usually be studied. According to Eisenhardt (1989), the iteration between theory development and data analysis can be stopped when incremental learning is minimal.

Finally, protocols for a large-scale empirical survey were developed. For instance, for the manufacturing, retail trade and food service stages the protocol consists of three sections (Yin, 1994). In 'Protocol - Section I', following an overview of the research project, the interviewer requests general information about the company: annual turnover, annual sales volume (expressed in tonnes), structure of the production and logistics network, and sales & operational planning process descriptions. In 'Protocol - Section II', the interviewer delves further into the topic of surplus food and requests an initial estimate of surplus food. It is important at this stage to share sources of data and information on actions taken by the firm to reduce surplus food. In 'Protocol - Section III', the interviewer requests even more detailed information on sources and management modalities for surplus food, obtaining numerical data to use in the analysis.

Confirmatory case studies

Protocols for the empirical analysis were used to conduct three confirmatory case studies. The purpose of this step was to illustrate how the ASRW model can be used to assess surplus food and food waste, and to identify strategies to reduce food waste at companies.

The confirmatory case studies involved multiple in-depth face-to-face interviews (3–4 h conversations) with managers representing various departments in the company (e.g. operations, administration, social responsibility). The companies involved in these case studies were different from those involved in the exploratory case studies. Companies already involved in surplus food donation were considered – making it possible to study the

Table 1
Exploratory case studies.

Case number	Stage	Job title of interviewee	Main characteristics of companies and industry experts
1	Agriculture and fishing	General manager	National association of apple producers
2		Quality manager	National association of fruit and vegetable producers
3		Company owner	National seafood distributor
4		Quality manager	National breeding company
5	Manufacturing	General and suppliers accounting manager	National company that produces conserve, sauce, and dry convenience food
6		Logistics manager	International company that produces chocolate food
7		Logistics and purchasing manager	International company that produces jam and snacks
8		Logistics manager	National company that produces ham and ham-convenience food
9		Supply chain manager	International company that produces yogurt
10		General manager-chilled products	International company that produces vegetable and vegetable-convenience food
11		Operations manager	International company that produces frozen fish products
12		Logistics manager	International company that produces bakery products and frozen bread
13	Retail trade	Logistics manager	International retail company with 3 DCs and more than 100 POSes
14		Logistics manager	National retail company with 4 DCs and more than 300 POSes
15		Logistics manager	National retail company with more than 20 DCs and more and 1000 POSes
16		Store manager	International POS over 2500 m^2 and €70 million of food turnover
17	Food Service	Planning and control manager	National company that prepares more than 70 million meals per year
18		Quality and food safety manager	International company that prepares more than 20 million meals per year
19		Quality health and safety environment director	International commercial catering company with more than 500 POSes
20		Store manager	National commercial catering company that prepares more than 130 thousand meals per year
21	/	Full professor	Expert in supply chain management within the agri-food system
22	/	Full professor	Expert in agricultural policies
23	/	Full professor	Expert in agricultural policies
24	/	Manager of no-food organization	Expert in surplus management (70,000 tonnes of food managed per year)
25	/	Manager of no-food organization	Expert in surplus management in collective catering services (1500 tonnes of food managed per year)
26	/	Manager of no-food organization	Expert in surplus management (15,000 tonnes of food managed per year)
27	/	Manager of Governmental agency	Expert in agricultural policies
28	/	Manager of an association that represents trade companies	Expert in organization of points of sale
29	/	Manager of an association of food firms	Expert in food production technologies
30	/	Manager of an association of farmers	Expert in harvest technologies

various unique aspects of the ASRW model – that represent different supply chain stages: a multinational manufacturer selling chilled products (case A), a large-scale retailer (case B) and a multinational company operating in the food service stage (case C).

ASRW model: conceptualisation

For the purpose of this paper "*food availability*" is defined as all food produced throughout the food supply chain. It includes foods in different stages (agriculture and fishing, manufacturing, retail trade, food service, household consumption) and of different types (raw materials, semi-processed food, and finished products). As illustrated in Fig. 1, food availability includes three food categories: "consumed food", "surplus food" and "food scrap".

- Consumed food is the edible food that is delivered through the traditional market and is consumed by humans (e.g. staples acquired by customers at a supermarket and then consumed).
- Surplus food is the edible food that is produced, manufactured, retailed or served but for various reasons is not sold to or consumed by the intended customer.
- Food scrap consists of non-edible food, i.e. food no longer suitable for human consumption. It includes production line leftovers at the manufacturing stage (e.g. chocolate leftovers generated during the cutting process), damaged/broken products that fail to meet quality standards (e.g. melted ice-cream) and the non-edible parts of otherwise edible food (e.g. vegetable peels or apple cores).

Surplus food can be recovered and used in a variety of ways. Four main "*surplus food management policies*" were considered:

- Feeding humans. Surplus food is used to feed people. Examples are donations to food banks and charitable institutions, or sales through secondary markets (e.g. bakery thrift stores).
- Feeding animals. Surplus food is used to feed animals, directly (e.g. providing surplus food to zoos or livestock farms) or indirectly (i.e. converting surplus food into animal feed through industrial processes).
- Waste recovery. Surplus food is provided to companies that produce other goods (e.g. fertilizers or cosmetics) or energy.
- Waste disposal. Surplus food is disposed of by environmentally-unfriendly methods (e.g. burying the surplus food in landfills).

On a second level, in relation to the management policies previously defined, the conceptual model introduces the concept of "*food waste*" according to three different perspectives (i.e. social, zootechnical and environmental). Food waste from a social perspective is defined as surplus food that is not used for feeding people. On the other hand, food waste from a zootechnical perspective is defined as surplus food that is not used for feeding humans or animals. Finally, food waste from an environmental perspective is defined as surplus food that is not re-used or recovered in any form and is disposed of.

The transition from surplus food to food waste is also a function of the "*degree of recoverability*" (DoR). Surplus food recoverability for human consumption is inherently different at different stages in the food supply chain and for different kinds of products. For instance, edible and healthy grains not collected from the fields are only somewhat recoverable because they must undergo a physical transformation in order to be consumed by people; conversely, an edible, healthy packaged product not sold in a store due to dented packaging has a higher intrinsic recoverability, as it is ready to eat.

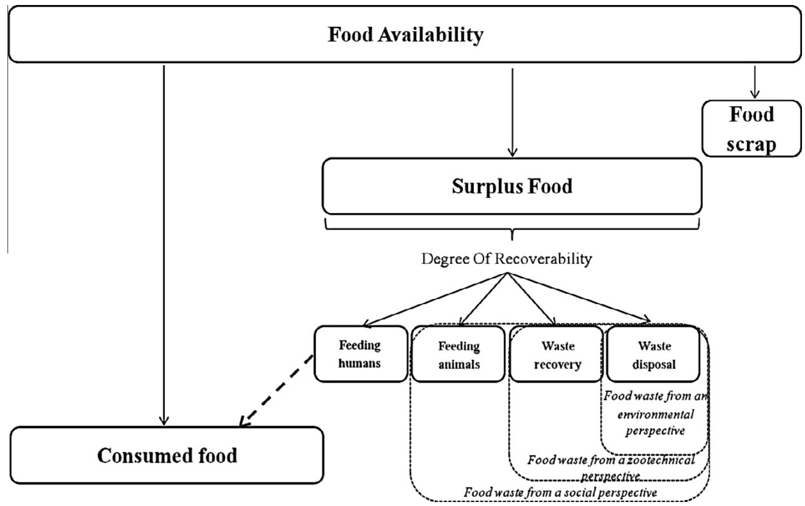

Fig. 1. The ASRW conceptual model.

DoR in turn depends on the intrinsic recoverability (IR) of surplus food, and on the required management intensity (MI).

IR is the degree to which a potential beneficiary could use surplus food for human consumption in the absence of additional management efforts by farmers/manufacturers/retailers and intermediaries (e.g. food banks and charitable institutions). It depends on:

- The type of product (e.g. shelf life, need for refrigeration).
- The activities typically performed at a certain stage (e.g. certification, scrap elimination).

DoR increases with increasing IR: the larger the IR, the larger the DoR.

MI is the commitment required by farmers/manufacturers/retailers and intermediaries to make surplus food usable to the greatest degree by the final beneficiary. Two distinct components are needed to bring surplus food to the final recipient:

- Maintenance: additional activities necessary to preserve possible use of the surplus food (e.g. transportation, warehousing).
- Enhancement: additional activities that increase the possibility of using surplus food (e.g. hygienic certification).

DoR decreases with increasing MI: the smaller the MI needed, the larger the DoR.

Since both IR and MI depend on the type of product and the stage of the supply chain, it was concluded that DoR should also be specified for each type of product and stage of the supply chain.

ASRW model: refinement and customisation

Following the conceptualisation of the ASRW model (section 'ASRW model: conceptualisation'), information collection – via exploratory case studies – and theory development were iterated to refine the conceptual model and to adapt it to different food supply chain stages. Specifically, the supply chain stages and their products were classified, and then the main sources of surplus food and the modes through which surplus food is managed were analysed within the different supply chain stages.

Segmentation of the food supply chain

The food supply chain extends from farming to the delivery of food products to consumers. To refine and operationalise the ASRW model the supply chain was divided into five main stages: agriculture and fishing (i.e. crop farming, livestock farming and fishing), manufacturing (i.e. firms that use agricultural products to produce food products), retail trade, food service (e.g. collective catering and restaurants) and household consumption. The suppliers of farming materials (e.g. fertilizers, seeds, animal feeds) were not considered because their surplus is not edible food.

The exploratory case studies demonstrated that significant differences exist even within a stage, in the production structure, in the logistics network, in product characteristics (e.g. perishability, storage temperature, usability by the final consumer) and in surplus food sources. These differences imply that specific strategies and surplus food management practices are needed. Therefore, 12 different sub-stages were identified, hereafter referred to as "supply chain segments" (see Table 2; see also subsections 'Agriculture and fishing' through 'Household consumption'). Clearly, further segmentation could be made, but a trade-off exists between the level of disaggregation and the effectiveness of information gathering.

The degree of recoverability, which depends on technological and organisational factors that vary according to the supply chain segment, was identified for each of the 12 segments (Table 3, see subsections 'Agriculture and fishing' through 'Household consumption' for a detailed discussion). In particular, for each segment, intrinsic recoverability and required management intensity were assessed on a 3-level scale (low, medium and high) based on the discussions with case study interviewees and experts. Of course the DoR is also related to the extent to which the country possesses the appropriate transportation and technological infrastructure. Recoverability levels reported in Table 3 are appropriate for advanced economies, but could be unrealistic for middle or low income countries. However, approaching the issue from the sectoral perspective (i.e. 5 stages and 12 segments) rather than from a macro-economic perspective will provide an understanding of the surplus food phenomenon in its complexity, and enable the proposal of strategies and policies for reducing food waste.

Customisation of the model

Agriculture and fishing

The agriculture and fishing stage was divided into 4 segments: fruits and vegetables, cereals, livestock farming and fishing.

According to the exploratory cases, the main sources of surplus food are over-production, non-compliance with market standards (e.g. in terms of size and shape of fruits), over-stocks or discards in wholesale produce markets.

Table 2
Segmentation of the food supply chain in 5 stages and 12 segments.

Stage	Supply chain segment	Products	Players	Main surplus food sources
Agriculture and fishing	Fruits and vegetables	Fruit and vegetables	Farmers, farmers' associations, logistics centres to support agriculture	Non-compliance with market standards
	Cereals	Cereals	Farmers, farmers' associations	
	Livestock farming	Meat/milk	Farmers	Overproduction
	Fishing	Fish	Fishermen, logistics centres in support of fisheries	
Manufacturing	Ambient	Dry products, beverage, juices, oil, wine	Manufacturers	Exceeding internal sell-by date; non-compliance of products and packages with market requirements
	Chilled	Cheese, meat, cold cuts, fish, eggs	Manufacturers	
	Frozen	Frozen fruit and vegetables, ice-cream	Manufacturers	
Retail trade	Distribution centres	All categories	Distribution centres	Exceeding internal sell-by date; package damages;
	Points of sale	All categories	Points of sale	Product returns
Food service	Collective catering	All categories	Corporate, school, hospital canteens	Overproduction
	Commercial catering	All categories	Restaurants, fast food	
Household consumption	Consumer	All categories	Households	Exceeding use-by date; meal leftovers

Table 3
Degree of recoverability in supply chain segments.

Stage	Supply chain segment	Intrinsic recoverability (IR)	Management intensity (MI)	Degree of recoverability
Agriculture and fishing	Fruits and vegetables	High	Medium	Medium
	Cereals	Low	High	Low
	Livestock farming	Low	High	Low
	Fishing	Medium	High	Low
Manufacturing	Ambient	High	Low	High
	Chilled	Medium	Medium	Medium
	Frozen	High	High	Medium
Retail trade	Distribution centres	High	High	High
	Points of sale	Medium	Medium	Medium
Food service	Collective catering	Medium	Medium	Medium
	Commercial catering	Medium	High	Low
Household consumption	Consumer	Low	High	Low

The degree of recoverability for the fruits and vegetables segment was assigned a "medium" level. This reflects a high intrinsic recoverability – i.e. most products can potentially be consumed by people without prior transformation – and a medium management intensity since the delivery of surplus food to the poor, who live primarily in big cities, requires companies, food banks, and charitable organizations to carry out activities such as collection, packaging, storage and transport in a controlled temperature environment. Instead, the cereals segment (e.g. maize) has a low degree of recoverability. Although the cereals segment includes products that are less perishable than fruit and vegetables, products need to undergo a more intense transformation process to be consumable (e.g. the process to transform rough rice into white rice, removing the chaff). The livestock farming segment includes meat obtained from slaughter activities. This segment suffers from a low degree of recoverability, since products cannot be consumed immediately (i.e. low value of intrinsic recoverability), and at the same time they are perishable and have to be stored and transported using refrigeration (i.e. the management intensity is high). The fishing segment displays similar characteristics to livestock farming, but has a higher intrinsic recoverability since most fish can be consumed without specialized transformation.

In the cereals, livestock farming and fishing segments surplus food is managed mainly as recovered waste (e.g. bioenergy and fertilizers), while in the fruits and vegetables segment reuse as animal feed, or even recovery for human consumption, is more frequent.

Manufacturing

The exploratory cases confirmed that manufacturing could be divided into three segments: ambient, chilled and frozen.

The main source of surplus food is products that have reached their internal sell-by date, i.e. the date when products will no longer be accepted by customers. In fact, retailers usually require two thirds of the overall product shelf life upon product delivery; therefore, the manufacturer's "internal sell-by date" is one third of the overall product shelf life. Another typical source of surplus food is products and packaging that do not comply with market requirements (e.g. labels displaying old promotions).

The ambient segment exhibits a high degree of recoverability. In fact, surplus food consists of packaged products (e.g. pasta, beverages), which are ready to be consumed and have a remaining shelf life of at least one week. Once identified, surplus food has just to be stored until food banks or charitable institutions pick it up and deliver it to the needy (i.e. enhancement and maintenance activities are relatively few). The chilled segment presents a medium degree of recoverability because products are ready for consumption (e.g. milk, dairy products, processed meat), but the shelf life is quite short, and manufacturers, food banks and/or charitable organizations must comply with cold chain standards during storage and transport. In the frozen segment, intrinsic recoverability is high (i.e. products are ready for consumption and are characterised by a long shelf-life), however specific and expensive equipment is required for both storage and transport in order to comply with cold chain requirements.

Since the cost of waste disposal services is high and the degree of recoverability is medium or high, manufacturers tend to adopt other strategies for managing surplus food. The higher the DoR, the higher the incidence of donations to food banks and charitable institutions. Animal feed is often a suitable alternative strategy; not only does it avoid disposal costs, but it also yields revenues, although revenue is lower than if the surplus food were sold for human consumption.

Retail trade

Retail trade was divided into 2 segments: distribution centres (DCs) and stores. These two segments are characterised by different logistics capacities and constraints, though they share product categories (i.e. they are vertically-related segments). DCs are mainly logistics facilities capable of handling complex processes, including those related to the management of surplus food, whereas stores are centred on the relationship with customers and have a limited logistics capacity.

The exploratory cases suggested that the main sources of surplus food at DCs are that the internal sell-by date has been reached, non-compliance of packages with market requirements, and product returns from stores. At stores, the main sources of surplus food are reaching the sell-by date and damaged packaging.

In terms of recoverability, the DC segment has a high DoR. Intrinsic recoverability is good because most surplus food consists of packaged products that are ready for consumption and have a remaining shelf life of at least one week. The management intensity has been assigned a low value because surplus food, once identified, needs only to be stored, and can be picked up by food banks and charitable organizations in large quantities. On the other hand, the stores segment has a medium–low DoR. In fact, there is a mix of high and low DoR products, and even packaged goods have few days of remaining shelf life. Second, management of these products is not trivial since the space for storing surplus food at stores is very small, and food banks and charitable organisations must make frequent pick-ups of surplus food due to the short shelf life of products.

In the DC segment the re-use of surplus food for human consumption, or as animal feed, is frequent, while stores manage surplus food mainly through waste disposal, with minimal donations to charities, due to the low DoR and the absence of economic incentives (i.e. waste disposal tariffs are mainly fixed fees).

Food service

In the food service stage two segments were considered: collective catering (e.g. canteens at schools, companies or hospitals) and commercial catering (e.g. cafés, restaurants). These two segments differ in terms of cooking activities, service, and customer experience.

The main source of surplus food is overproduction due to errors in demand forecasting.

Surplus food in collective catering mainly includes cooked products not yet served to customers, which has a medium DoR. Intrinsic recoverability is medium since surplus food is ready for consumption, but has a very short shelf life (i.e. 24 h on average). Management intensity is medium because the catering contractors have to package the surplus food, rapidly lower its temperature using dedicated equipment, and store it in refrigerators. Maintenance activities by food banks and charitable organizations are also intense because they have to pick up small quantities of surplus food from each canteen daily and deliver it to the needy the same day. For the commercial catering segment, the DoR of surplus food is even lower. In fact, more effort is needed in commercial catering because the quantities of surplus food that can be collected from each restaurant are comparatively low and pick-ups must be frequent due to a lack of storage space in restaurants. As a result, logistics costs are extremely high for both parties, i.e. donors and receivers.

Surplus food in the food service industry is managed mainly through waste disposal, similarly to what occurs at stores, and for similar reasons. However, where the degree of recoverability is higher – usually in collective catering – donation to food banks and charitable institutions is more frequent.

Household consumption

The degree of recoverability at the household consumption stage is low as a result of a low value of intrinsic recoverability and high management intensity. Surplus food at home includes both products that are bought but not consumed before the end of their shelf life, and products that are cooked but not consumed. As a consequence of the null or low residual shelf life, the intrinsic recoverability is very low. The enhancement and maintenance activities would also be very significant, due to disconnection across a large number of individual households, and the absence of special equipment to rapidly cool the food at home. As a consequence, surplus food is mainly managed through waste disposal.

ASRW model implementation

The ASRW model was applied to three cases: one manufacturer, one large-scale retailer, and one food service company. The main findings of these three confirmatory case studies are presented in order to illustrate the application of the model at a corporate level, e.g. to exemplify possible sources of surplus food and strategies to reduce food waste. All data refer to the Italian market, where the three companies operate.

Case A

Case A is a manufacturer of chilled products (e.g. yogurt, custards and snacks) with an annual turnover of 100 million Euros and annual sales volumes of around 58,000 tonnes. Products are characterised by a short shelf life (approximately 30 days) and by seasonal demand. Customers are mainly large retailers, served by two national warehouses. Due to sales contracts, the company must ensure 20 days of residual shelf life when products are delivered to the customer. Therefore, the company's internal sell-by date is 10 days after production.

For the manufacturer in Case A, surplus food is the edible food that is manufactured but not sold to customers, excluding food scraps and non-edible products. For example, the food produced during the setup of production lines has mixed flavours and is considered non-edible. The value of surplus food is approximately 300 tonnes per year, equal to 0.5% of annual sales volumes.

The company keeps track of the sources of surplus food. The main source is the exceeding of the internal sell-by date within national warehouses (80% of SF). This is a possible and not-uncommon occurrence due to the very short interval before the internal sell-by date is reached. Damage caused to packages during warehousing and transportation is the second source of SF (18%), as the product packaging is somewhat fragile.

Surplus food is managed in two ways: donation to food banks (50%) and sale to firms that produce animal feed (50%). The company prioritises donation to food banks, but when food banks are unable to collect and redistribute the surplus food (e.g. an exceedingly high amount of surplus food) the company follows the second-in-rank strategy. This behaviour is consistent with the degree of recoverability that characterises the chilled food segment (see subsection 'Manufacturing'), which is, on average, medium. The result, according to the ASRW model, is that food waste at a social level amounts to 150 tonnes per year, corresponding to 0.25% of the sales volume and 50% of the surplus food.

Case B

Case B is a large retailer with more than 1000 stores in Italy (hypermarkets, supermarkets, local stores, discount stores), about 13 billion Euros in turnover, and over 12,000 products on the shelves. Stores are supplied by a network of Distribution Centres (DCs). One DC and 5 hypermarkets, located in Northern Italy, were analysed.

At this particular DC, surplus food is the food that is bought from suppliers but not delivered to stores. Surplus food does not include products returned to suppliers or products that are repackaged after being damaged and then re-inserted in the distribution system. According to the supply chain manager, surplus food generated at the DC from chilled and frozen products is negligible, as chilled products are mainly managed using cross-docking and frozen products have a long shelf life. Therefore, the surplus food consists mainly of ambient products and amounts to 900 tonnes per year, or 0.3% of the DC's overall product flow (300,000 tonnes per year). The main reason surplus food is generated (60%) is that it reaches the internal sell-by date. The internal "life" of a product at the DC is a small fraction of the overall "shelf life" because the majority of the products' shelf life must be available to stores. The DC has developed a hierarchy of destinations for surplus food: donation to 20 food banks and charitable organizations (55%), sale to firms that produce animal feed (10%), and conferral to waste management companies (35%). The last of these is used only in when the other two options are not possible. This behaviour is consistent with the high degree of recoverability that characterises ambient products at DCs. According to the ASRW model, food waste at a social level amounts to 405 tonnes per year, corresponding to 0.13% of the annual DC outbound flow and 45% of the overall surplus food.

At hypermarkets, surplus food is the food that is delivered from DCs but is not sold to customers. There is less accurate data available on surplus food at hypermarkets than at DCs. Store managers suggested that an upper bound on the quantity of surplus food generated at the store level is represented by "inventory shrinkage", which includes goods considered to be lost because of pilferage or packaging damage, as well as expired products. Based on inventory shrinkage data and store managers' assessment regarding the proportion of inventory shrinkage that can be classified as surplus food (mainly expired products and damaged packaging), the value of surplus food was estimated to be approximately 6 million Euros per year, or 2% of annual sales. Given an average product value density of 2.5 Euros per kg, the overall amount of surplus food generated at the five stores is 2400 tonnes per year. The main sources of surplus food at the store level are reaching the product sell-by date and, to a lesser extent, damaged packaging. Surplus food is managed in two ways: donation to food banks and charitable institutions, involving different organizations at each hypermarket (5%), and disposal by municipal waste management companies (95%). The prevalence of disposal is partly explained by the standard practice of keeping products on the shelves until the expiration date, thereby limiting the opportunities for redistributing the products as surplus food. Overall, at the five stores, food waste at a social level – i.e. not recovered for human consumption – amounts to 2270 tonnes per year, or 1.9% of sales.

Case C

Case C is a multinational company in the food services industry. It operates in both collective and commercial catering (e.g. school and corporate canteens, and cafés and restaurants). The case study focused on one of the company's corporate canteens, which prepares 170,000 meals per year. The kitchen is located at the canteen and the ingredients are replenished daily from a company warehouse according to forecast demand (in terms of amount and variety of meals per day). The kitchen is equipped with a special "cooler" to rapidly reduce the temperature of surplus food.

Surplus food consists mainly of cooked products that never leave the kitchen. Overproduction, caused by forecasting errors, is the main reason surplus food is generated. The amount of surplus food generated is approximately 8000 meals per year – 5% of the total – which is equal to 5 tonnes per year. There would be even more surplus food if the food that is not consumed were not reused or recooked: internally recovered food amounts to at least 10% of cooked food.

Surplus food is managed in two ways: donation to food banks (30%) and disposal by municipal waste management companies (70%). In the former case, at the end of the service shift, surplus food is rapidly cooled and then put into single meal boxes. A few hours later, food bank operatives pick up the boxes for immediate distribution to the needy. The proportion of surplus food donated to food banks appears to be consistent with the medium degree of recoverability that characterises the collective catering segment (see subsection 'Food service'). Overall, food waste at a social level amounts to 3.5 tonnes per year, corresponding to 3.3% of cooked food and 70% of surplus food.

In summary, the three case studies demonstrate that the conceptual ASRW model enables researchers and managers to better understand surplus food and food waste at the company level. Moreover, the three case studies confirmed the relevance of the variable "degree of recoverability" as a lens through which surplus food management and food waste can be better analysed.

Conclusions

This paper presents a model that describes surplus food generation and management, and provides a methodology for quantifying surplus food, "recoverable" surplus food and food waste. The authors believe that this model can be used to help companies, governments, and non-profit organizations to design and implement sound strategies to reduce food insecurity and to limit the amount of surplus food that becomes food waste. The model also provides a clear method by which researchers and policymakers can assess surplus food and food waste at the micro (i.e. individual players and sectors) and macro (i.e. the whole country) levels.

First of all, the ASRW model (Availability-Surplus-Recoverability-Waste) was presented in fairly broad terms. The conceptual model was based on the reality of the food supply chain by defining 5 supply chain stages and 12 product segments, and by conducting 30 exploratory case studies and interviews with experts, which shed light on the unique aspects of each segment, providing information that was used to customise and refine the model.

Finally, testing of the model, i.e. three in-depth confirmatory case studies, illustrated how it can be used at the corporate level, and how information on surplus food generation and management can be obtained.

Although the only way to fully validate the ASRW model and obtain robust empirical results is to apply it to a large-scale sample, the confirmatory case studies have shown that the model, in and of itself, has some significant implications for policy-makers and other food supply chain players as well as for researchers.

First of all, the customised model provides a means for differentiating surplus food management strategies according to type of business or sector. Each segment of the supply chain was examined and characterised in terms of most frequent sources of surplus food, degree of recoverability, and typical policies used to manage surplus food. More specifically, the assessment of degrees of recoverability demonstrates that surplus food recovery for human consumption is potentially within easy reach in segments that have a high degree of recoverability (e.g. distribution centres, and manufacturing of ambient products. A more intense communication effort by governments and charitable organizations would likely be all that is needed to further reduce food waste and encourage donation to the food poor in these segments. The sustainable management of surplus food is more challenging in segments with a medium (e.g. stores) or low (e.g. commercial catering) degree of recoverability, where more significant logistical and transactional costs create barriers to the donation of surplus food. It is precisely in this area that the ASRW model can help policymakers and companies to reduce food waste.

A second objective of this paper was to develop a replicable methodology for the assessment of surplus food and food waste. The characterisation of segments within supply chain stages is essential to the design of a large-scale empirical study(i.e. sample definition and preparation of case study protocols or survey questionnaires), and the confirmatory case studies have demonstrated that reliable quantitative results can be obtained by applying the model at the microlevel. A large-scale, standard quantitative assessment strategy may help policymakers identify the most relevant sources of surplus food in each segment. This, in turn, will allow policy-makers (and industry managers) to more easily monitor and control the generation of surplus food, and to better understand whether surplus food can be further reduced at the source. In another respect, it is expected that a broader application of the model will show whether responsible surplus food management practices also exist in critical segments, which is information that can then be disseminated to business associations, companies, sector policymakers, and intermediaries such as food banks.

The development of this conceptual model has resulted in two new contributions to the research on sustainable management in the food supply chain. Up until now there have been no universally accepted definitions for some of the key concepts. As seen in some other recent articles, an attempt has been made in this paper to establish a common language that can be used at company, sector or country levels. The authors have proposed explicit definitions for various terms, and have differentiated between environmental and social perspectives. Furthermore, this paper supplements the pre-existing literature insofar as it also discusses the feasibility of strategies to re-use surplus food and reduce food waste. To this end, the concept of "degree of recoverability" was introduced in the conceptual model, and the assessment showed that the potential for surplus food recovery and food waste reduction varies significantly between segments, due to different structural characteristics.

An assessment of the costs of various surplus food management policies was beyond the scope of this study, however cost effectiveness is just as relevant as improved food security and food waste reduction if the goal of food supply chain sustainability is to be achieved. One of the next steps in the continuing research on this topic should be to find a way to introduce cost factors in the ASRW model Another key step in the progression of this research would be the broader application of the ASRW model to a regional agri-food supply chain, assessing all stages including consumption at home, a task that is currently underway.

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