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Technological and consumer strategies to tackle food wasting

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Abstract

Around one third of the globally produced food is annually discarded worldwide This amount would be able to satisfy ten times the need of undernourished people. If nothing is done, the mass of discarded food could further rise, compromising the right to food of future generations.

Almost all food discards are nowadays disposed of or used for energy recovery. Strategies for recovery of value-added compounds have also been proposed. However, more sustainable options are available. In this context, food science skills are required to develop novel approaches that could allow both reducing disposal of discards and preventing their generation. Effective technological strategies are expected to directly reduce food loss within the production chain but also to drive consumer towards more sustainable choices and behaviours.

This review paper summarises recent developments in possible technological and consumer strategies to tackle food wasting. To this aim, after defining, classifying and quantifying food discards, reasons and responsibilities of discard generation are analysed in the light of the current regulatory efforts. Based on this survey, an overview of possible interventions is provided, underlying their synergistic effects on waste reduction/prevention at industrial and domestic levels.

Keywords: food waste; food loss; reuse; recycle; shelf life; communication

1. Introduction and definitions

Food discard actually occurs at all stages of food life cycle, starting from harvesting, through processing and production, until domestic handling and final consumption (Lipinski et al. 2013; Schneider 2008).

The EU generically defines “waste” as “any substance or object which the holder discards or intends or is required to discard”. This definition may be applied to food “from farm to fork”.

Two different terms are generally used, “food loss” and “food waste”, according to the chain stages in which discard is generated (Beretta et al. 2013; Lipinski et al. 2013; UK Parliament 2014).

"Food loss" indicates food discarded from the supply chain at primary production, processing and distribution steps (Schneider 2008). On the contrary, a debate is ongoing on the exact definition of "food waste". According to the FAO (Food and Agriculture Organization of the United Nations), it can be defined as "the mass of food wasted in the part of food chains leading to edible products going to human consumption" (FAO 2015). A further definition of food waste is provided by WRAP (Waste and Resources Action Programme) as "any food or drink produced for human consumption that has, or has had, the reasonable potential to be eaten, together with any associated unavoidable parts, which are removed from the food supply chain" (WRAP 2013). Similarly, the FUSIONS project, a Pan-European initiative, working on standard food waste definition and measurement, defines food waste as "any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed" (Östergen and Gustavsson 2014). These waste definitions actually refer to discards occurring along the whole food chain, including those generated at primary production level, which should be indicated as "food losses".

However, according to Gustavsson et al. (2011), "food waste" is the result of an intended decision, particularly in relation to consumers. The term "food waste" would thus refer to the end of the food chain, considering only purchase and final consumption. This distinction, which was adopted in the present paper, allows avoiding the overlapping of the terms "food loss" and "food waste" that actually refer to discards occurring at different points of the chain (Beretta et al. 2013).

2. Classification

According to Table 1, food loss and food waste can be classified based on the supply chain steps (i.e. from primary production to final consumption) in which they are generated. Further classifications can be developed considering specific food, social or environmental criteria, detailing a wide range of subcategories (Lebersorger and Schneider 2011).

The most commonly used classification criterion is based on food category and is actually the only one that describes discards that are generated in all steps of the food chain. The classification criterion of discarded parts refers to the life cycle stage at which the product becomes a loss/waste. Original food is the whole product, never employed for consumption. The partly used food represents what is left after using a part of product, considering processing or domestic handling (i.e. industry and kitchen by-products), while leftovers represent what remains on the plate or in the pot after a meal. The sorting criterion of avoidability, that allows to discriminate discarded food according to the possibility or not to prevent its generation, is the most commonly used at domestic level (Beretta et al. 2013; Williams et al. 2012). To this regard, "avoidable" food waste is intended as any food or drink that prior to disposal was edible. The "possibly avoidable" waste refers to food and drink that some people eat and others do not (e.g. bread crusts), or that can be eaten only when a food is prepared in a particular way (e.g. potato skins). The “unavoidable” waste is reported as the waste arising from food preparation that is not edible under normal circumstances (e.g. pineapple skin) (Parfitt et al. 2010). Avoidability often relies on subjective choices, determined by social aspects. The latter also affect disposal option, that may differently impact on the environment. Possibly reusable food is still suitable for consumption without further processing operation (e.g. products not responding to aesthetic specification). Recyclable discards can be used by industry for energy or value-added compounds recovery (e.g., anaerobic digestion or extraction of bioactive molecules), or composted at home without a third part intervention. Finally, no recovery is viable for not recyclable discards, which are thus subjected to landfill or sea disposal. Depending on the extent of product manufacturing, food discard is characterized by different resource content (i.e. land, water, energy and labour). For instance, the loss of environmental resources associated to waste of raw fresh vegetables, fresh-cut vegetables and ready-to-eat vegetable meals is progressively higher, dramatically affecting the impact of discard on environment.

3. Food loss

3.1. Reasons

Food losses arise at each supply chain level due to specific reasons. Food losses mainly depend on production and processing technologies, as well as on logistic control, which are affected by the local development (Table 2). Losses generated in low-income countries are generally higher due to the limited control of environmental parameters during distribution and retail (technical limitations, inadequate storage facilities and infrastructures, uncoordinated market systems) (Girotto et al. 2015). Food losses depend thus on three global drivers (Parfitt et al. 2010):

- Urbanization and contraction of the agricultural sector with extension of the food supply chains.
- Diet shift towards vulnerable and shorter shelf-life items.
- Increased global trade of food coming from farther countries.

3.2. Methods for quantification

At the primary production, monitoring losses represents one of the most critical issues, requiring specific research. By contrast, producers and retailers often voluntarily assess their own food losses in the attempt to avoid them and reduce costs (Lebersorger and Schneider 2011). Interviews to supply chain and logistics managers are the main information source relevant to food losses (Sert et al. 2015). However, these are company sensitive data that are rarely disseminated, limiting information about total amounts of lost food according to the different classifications (Table 1) (Schneider 2008). For this reason, policy and NGO generally obtain food loss data by applying loss factors, assembled from published studies, to the amount of food available for human consumption (Scott Kantor et al. 1997).

3.3.Quantification and responsibility

According to Nellman et al. (2009), between 25 and 50% of produced food is lost through the supply chain. Crop losses at the primary production may vary from 5 to 50%, according to the reasons exposed in Table 2. Similarly, loss varies significantly in post-harvest, from 20 to 75% of harvested items, depending on product and situation (Gunders 2012). Williams et al. (2012) reported that processing and packaging steps bring on the greater amount of food losses (70 kg/pro capita/year), while only a minor part is ascribed to retailers (8 kg/pro capita/year). The risk of food loss increases with the number of passages from one step of the chain to the following one. To this regard, it is noteworthy that a typical food product is generally handled more than 30 times before it is displayed at the supermarket (Scott Kantor et al. 1997).

4. Food waste

4.1.Reasons

Social development undeniably affects food wasted by consumers. Food wasting is eased by the almost constant food surplus availability in high-income countries, the major drop in prices and the growing alienation from food value (Ambler-Edwards 2009; Smil 2004). Individual reasons leading to food waste are quite assorted, depending not only on product characteristics, but also on external and contextual forces (Defra 2009). Actually, consumers' attitude (e.g. fresh products consumption, taste preferences, attention towards healthy diets) and the excessive amount of incoming goods (e.g. offers, presents, unplanned purchase) often represent the root causes for food waste (Kranert 2012). In the light of these considerations, most of the food wasted at domestic level would be certainly avoidable (Beretta et al. 2013). Domestic food waste reasons are reported to arise from three leading causes (Farr-Wharton et al. 2014; Kranert 2012; Parfitt et al. 2010; Gunders 2012; Williams et al. 2012; Gaiani 2013; Kantor 1997), as exposed in Table 3. Further, determinants to consumer behavior have been studied with reference to the identification of possible motivations and barriers to minimizing household food waste (Stefan et al 2013; Graham-Rowe et al, 2014; Stancu et al 2016). In addition, media and public policy potentially pull domestic practices in conflicting directions, leading to opposite trends: on the one hand campaigns to reduce food waste, on the other hand agencies concerned with food safety. As a result, the domestic organization of daily life often ends with wasted food (Watson and Meah 2013).

4.2. Methods for quantification

Different tools have been used for food waste assessment, each of them presenting some weaknesses that compromise the quality and reliability of acquired data.

Indirect estimates from waste coefficients are based on the elaboration of accessible data about food supply and consumption (e.g. statistical models relating population metabolism and body weight), to obtain trends about the food waste phenomenon in a long-term period. However, these estimates often provide information not accounting for waste quantification at local levels (Parfitt et al. 2010). On the contrary, methods involving consumers (i.e. questionnaire surveys and kitchen diaries) generally provide data that are strictly affected by geographical location and cultural aspects, as well as by season and duration of the study (Beretta et al. 2013). In particular, questionnaire surveys analyse the participants' subjective viewpoint by asking consumers to answer to quantitative or qualitative interviews in public places or in private households. The interviewed consumers generally have to choose among a predefined answers list, inhibiting the spontaneous information flow (Williams et al. 2012). Additionally, even if consumers' surveys in public places allow the researchers to reach a significant magnitude of data, they are usually carried out in unrealistic conditions. Kitchen diaries provide detailed instructions and definitions, since consumers are asked to report on a diary the avoidable daily amount of food waste, usually expressed in volume terms. Despite innovative monitoring tools such as mobile phone apps and websites (i.e. leanpath.com) are nowadays available, studies involving private households are usually limited by the lack of a representative number of participating households (Beretta et al. 2013). Further, besides providing the participant subjective viewpoint, kitchen diaries often lead to an underestimation of losses, since consumers may consciously or unconsciously minimise their wasting tendency due to intrinsic moral and ethical implications of waste behaviour (Lebersorger and Schneider 2011; Beretta et al. 2013; Kantor et al. 1997). Additionally, methods involving consumers generally consider only food and drinks consumed at home, thus excluding a significant amount of items, eaten for example "on-the-go" or in the workplace (Williams et al. 2012; Parfitt et al. 2010). Such a criticism is also typical of data obtained by waste composition analysis, in which waste is collected by the researchers, divided according to proper food categories and measured in terms of weight or volume. This approach can overcome the participants' subjectivity and may be used to investigate waste phenomena at local levels. However, the exact classification and quantification of individual wasted items is seldom possible since reliable data can only be obtained if objective and accurate measurements are performed during the entire observation period (Lebersorger and Schneider 2011; Schneider 2008). For instance, imprecise data could be obtained if food waste is differently handled before measurement (e.g. quantification of waste in the presence or absence of its packaging; sampling in domestic waste bins, waste containers, collection vehicles; small particles sieving before waste measurement) (Lebersorger and Schneider 2011). Finally, waste composition analysis only provides data about the items disposed of into residual waste bins and does not consider other disposal paths such as feed to pets and home composting.

The application of all these methodologies, which can also be combined, allows collecting a wide range of information about food waste for several purposes at different levels. However, most of the available data are not comparable since they are produced according to different food waste definition and classification. In addition, it is nearly impossible to reproduce methodologies and results reported in the literature. In the light of these considerations, there is a clear need of developing standard methods for waste quantification, to be internationally recognised and applied.

4.3.Quantification and responsibilities

Private households discard the greater amount of food, wasting 76 kg/pro capita/year. This amount corresponds to 42% of the food discarded along the whole supply chain (Williams et al. 2012; Waste Watcher 2013). In Europe and USA, food wasted by consumers has been estimated to vary between the 15 and 30% of all purchased food. According to the EPA (Environmental Protection Agency), the percentage of the purchased product that is wasted varies depending on food category (i.e. 50% of salad; 25% of fruit and vegetables such as potatoes, bananas and apple; 20% of bread/bakery products; 10% of meat/fish and dairy products). However, different studies provide different food waste estimates for each food category (Table 4).

Fruits and vegetables are generally estimated to represent *circa* 25-30% of total food waste, followed by dairy and grain products. Waste percentages are significantly affected by geographical location. Actually, fresh fruits and vegetables account for the largest portion of Turkish food waste, while in the Netherlands a high proportion of dairy products is wasted (Parfitt et al. 2010). Similarly, absolute estimates of total food waste often differ when obtained by applying different methodologies, as exposed in Table 5.

Waste composition analysis, household surveys and kitchen diaries (WRAP and Peckcan) produced comparable results, higher than those obtained by indirect estimates from waste coefficients (USEPA and DEFRA). The latter also showed a high variability, especially if a wide time span is considered (USEPA).

Even if consumers believe that industry and retailers generate most food discard, they are actually the main waste producers among all food chain actors. Food waste is significantly affected by household characteristics (Parfitt et al. 2010; Williams et al. 2012). In absolute terms, larger households waste more than smaller ones. However, per capita food waste is higher for small households and especially for single-person ones. Households with children tend to waste more than those without and youths waste more than older people, with retired ones wasting the least. It was also demonstrated that Hispanic households in the USA show lower food waste rates. Households with lower income and frequently purchasing food produce smaller amount of waste. Finally, consumer perception and awareness towards waste issues affect their food-wasting tendency. According to Waste Watcher (2013), women usually charged with purchase and coming from larger households show the highest concern about food waste. However, 53% of consumers declares that the global amount of wasted food is negligible whilst 94% of consumers recognizes that they are daily responsible for a remarkable food waste amount. These conflicting data indicate a significant consumers' confusion towards the waste issue.

5. Decreasing food loss and waste

As stated in the literature, the first step towards a more sustainable management of food discard is to adopt a sustainable production and consumption approach, thus tackling food loss and waste throughout the global food supply chain (Papargyropoulou et al. 2014).

In particular, the so-called "waste hierarchy" orders possible management options according to their sustainability, intended as environmental impact as well as social and economic benefits. It also introduces the prevention concept, intended as reduction of discard generation (Figure 1).

Disposal often represents the cheapest and easiest management way, but it is the less desirable disposal option, since biodegradable organic material does not return to its original state in nature (Fehr et al. 2002). On the contrary, the most sustainable option is discard reduction/prevention. However, it is not always applicable, depending on the nature of discard (Papargyropoulou et al. 2014).

Actually, the waste hierarchy has been developed to raise general awareness and encourage people to think beyond traditional management options (Table 1) (Ohlsson 2004; Tucker 2007; European Commission 2014). Although it represents a tool to identify the best management options, no quantitative data about its efficacy is currently available.

5.1. The role of food technology

Food technology may exert a key role to face food discard issues, promoting technical solutions, able to improve the overall quality of the food product, in terms of safety, security as well as sustainability. To this purpose, it is essential to clearly identify the possibilities of reducing food products discard.

5.1.1. Reduction

According to the "waste hierarchy" (Figure 1), the more desirable option is to reduce losses in the food industry, avoiding the production of food surplus (Zorpas and Lasaridi 2013; Papargyropoulou et al. 2014). The latter is physiologically implemented by food companies to accomplish the business goals and guarantee the required flexibility to meet market demand fluctuation. Inadequate production planning is thus at the basis of food losses. Identifying efficient strategies for resource saving requires a review of the supplies used within the industry, considering each operation. This implies a holistic evaluation of what supply is actually used for the different processes. The output of this analysis describes the material flows to/from the production process and, when considered on historical basis, allows identifying eventual corrective actions for supply conservation. Major savings could be generated by improving adherence to market demand through statistical prediction. In addition, processing losses could be minimised by modulating raw material selection and harmonising stock supply with production cycles. However, primary production strictly depends on raw material variability and season. For this reason, harmonisation is not always feasible and is fraught with the risk of relocating waste generation from processing to primary production. When harmonisation is not practicable, discard decrease may be obtained by complete processing of all raw material, even via production line diversification (e.g. chilled, minimal processing, canning, drying). It is evident that any corrective actions should be tested for effectiveness and eventual drawbacks.

Since food losses occurring during processing may be due to processing errors or inadequate control of the unit operation (Table 2), optimising the existing technology (e.g. adoption of in-line/on-line sensors) as well as developing new technologies can play a key role in losses reduction. For instance, dough swarfs generated in the bakery industry could be minimized by properly designed rolling mills. Highly efficient ovens able to bake homogeneously the products, as well as handling systems lowering product damage would reduce the percentage of items not complying with the requirements. These examples highlight that more research is needed to extend this preventive approach to several food industry fields, pursuing not only capital saving, but also environmental protection.

5.1.2. Reuse

A second option to manage discards is to reuse outputs coming from a given unit operation to perform another one, desirably within the same industry. This means modifying the production process and/or implementing production diversification, to allow potentially discarded material to re-enter in the production cycle as raw material or semi-finished product. Discard characteristics may thus require only negligible changes, to make them suitable for the desired operation.

Actually, reuse of discards represents a common practice in many industries. For instance, in the bakery industry, dough swarfs generated during lamination are kneaded again, while improperly cooked bakery products are grounded and reused in other formulations. Analogously, the meat/fish industry recovers processing swarfs and blood, converting them into structured products (e.g. frankfurters, surimi). Dairy industry generally employs whey deriving from cheese making to obtain other products such as ricotta cheese. Wines and beer not fulfilling the requirements are generally directed to secondary production lines (e.g. grappa, vinegar). Thresh from beer production can also be employed to obtain bakery products. Similarly, fresh fruits and vegetables unsuitable for fresh consumption, due to inadequate characteristics (e.g. over-ripening, size, shape), are gainfully directed to canning and juice or jam production. Processing not only avoids discards, but also adds value to them (Rolle 2006). However, this advantage may become negligible when transport to a different processing plant is required, increasing costs.

5.1.3. Recycle

Even if processing is efficiently performed, by applying adequate prevention or reuse strategies and optimizing technological solutions, a huge amount of food is inevitably lost, due the presence of unusable and inedible parts. Composite products discards (e.g. stuffed pastries, pizza) cannot be re-used, since the separation of single components (e.g. filling, glaze, tomato sauce, dough) is hardly achievable and would be too expensive. It is thus necessary turning from prevention to management strategies. Among these, the best option should be chosen along with the waste hierarchy (Figure 1), to guarantee the highest sustainability.

Donation, which is often a valuable option for consumers, can also be performed by producers. Substandard raw materials, products resulting from overproduction or items not sold due to low prices but still accomplishing legal requirements of food safety can be handed over to organizations supplying people in need (Schneider 2013; Segrè and Falasconi 2011). The food surplus unfit for human consumption can be addressed to livestock. This is actually one of the most traditional management practices performed for cereals and dairy discards. However, this option depends on the food origin and relevant regulation, such as those hindering animal based feed for livestock (EC Reg. No 999/2001; EC Reg. No 1234/2003; Otles et al. 2015).

Composting of food losses can also be performed by industries to produce fertilizers. On site composting has a lower environmental impact, if compared with the centralized one, which requires transport to an external composting facility (Lundie and Peters 2005).

5.1.4. Recovery

Biofuel and bioenergy can be produced from losses by applying anaerobic digestion, pyrolysis and gasification, hydrothermal carbonization or incineration (Girotto et al. 2015). The residues from biofuels production can further be used as soil fertilizers (Notarnicola et al. 2012). Energy recovery would reduce the use of non-renewable resources, apparently decreasing global warming impacts. However, there is an increasing concern about emissions adversely affecting the environment, as well as about the high operative cost (Otles et al. 2015).

Considerable amounts of high value added compounds can also be recovered through fermentation, biochemical processing or chemical extraction of most production losses, as exposed in Table 6.

Even if recovering materials allows developing new products having a considerable market value, such an option is costly and requires an operative context where production and discard management strategies are efficiently interconnected.

5.1.5. Shelf life extension

Food technology can also indirectly affect food wasted during retailing and at household level. The application of novel technologies to extend the ingredient/product shelf life have been claimed to potentially reduce food loss and waste generated upon distribution and purchase. Among these technologies are innovative active/intelligent packaging and non-thermal decontamination techniques such as those based on electromagnetic (e.g. UV- light, pulsed light), mechanic (e.g. ultrasounds, high pressure, high pressure homogenization) or chemical stresses (e.g. ozone, non-thermal plasma). However, discard reduction by implementation of these technologies may result in a sale decrease, potentially limiting company investments in these technologies. Companies obviously tend to focus on avoiding food discard before sale but care less for product destiny after it. In addition, according to Amani and Gadde (2015), the relation between shelf life extension and discard reduction does not appear to be straightforward and it would be necessary to monitor the effectiveness of the application of shelf life extending interventions on the actual food discards. For instance, a product with a longer shelf life will be stored by consumers for a longer time, running a higher risk of being forgotten in the pantry and exceed the expiration date. The latter has probably an important responsibility for domestic waste generation, especially for shelf stable products. Most of them are generally attributed an expiration date that is selected based on the necessity to increase product turnover on the shelves and not following a real safety or quality risk. Identifying the optimal turnover frequency, would allow using products still suitable for consumption even if no more appealing the standard consumer. These products could be allocated on appropriate markets for substandard products (Girotto et al. 2015). Being generally the choice of expiration date a specific task of the producer, the waste responsibility is often not directly attributable to consumers, but relies on the producer itself. In this context, legislation on expiration dates, that has inadvertently increased food waste, should be re-examined within a more inclusive competing-risk framework (Godfray et al. 2010). The evolution of expiration date from a simple consumer protection to the wider concept of the protection of a sustainable food-consumer relation could significantly reduce food waste generation. Expiration dates should thus be defined considering not only product safety and quality, but also environmental and social impact. These aspects should be merged with food technology through a pioneering interdisciplinary approach, in order to develop a methodology for defining shelf life values able to concomitantly satisfy consumers and minimise food waste.

5.1.6. Communication

Label information may also affect food consumption decision. While communication of environmental impact (e.g. land, water and energy footprint) is expected to positively affect purchase choices, no information is available about consumer reactions towards the communication of discards use in food production (Table 6). However, a negative reaction could be envisaged, as in the case of reused water (The Australian Industry Group 2008).

On the other hand, label information is certainly expected to influence the waste behavior of consumers. Beyond expiration date, preservation instructions and environmental impact of products' waste can be easily printed on labels together with compulsory information and would alert consumers to the scale of the waste issue, increasing their awareness (Watson and Meah 2013). This can be accomplished by supporting consumer food literacy about domestic food handling and favouring real-time information of current food stocks to reduce stockpiling (Tsiros 2004; Farr-Wharton et al. 2012). However, Watson and Meah (2013) asserted that campaigns emphasizing issues of environmental responsibility have limited potential in reducing food waste, since non-wasting behaviour are mainly driven by innate thriftiness rather than by environmental and ethical concerns. This suggests the need for innovative communication strategies enabling people to enact thriftiness.

5.2. The role of consumers

Currently, food waste is principally disposed of as rubbish (45%) according to different management systems, such as sewer, kerbside collection and delivery to recycling centre. Home composting (around 25%) and feed to animals (around 25%) are also common while donation is chosen only for 5% of the total amount of food waste (Parfitt et al. 2010). Most food waste prevention activities are private initiatives, lacking explicit normative pressures and following unknown social norms (Tucker 2007). They mainly turn into buying only the amount of product that is needed (Zorpas and Lasaridi 2013). To this regard, it is noteworthy that perception of food need significantly differs among consumers. For instance, people affected by some food disorders may tend to buy and consume excessive food amounts. Even if the exceeding food is not directly wasted, its nutritional value is misused with not negligible medical and social costs.

Several surveys indicate that waste prevention is a relatively poorly understood concept, since many people intend it as synonymous of recycle. Sometimes waste prevention behaviours are even negatively correlated with recycle, so the latter may hinder waste prevention (Defra 2009).

Consumers are generally conscious that further investigation is needed to improve the ability of reducing food waste at domestic level, even if during the last years some tools have already been developed (Kranert 2012; Gunders 2012). Consumers recognized that only a part of these tools is well implemented, while some others still need improvements for an effective applicability (Table 7) (WRAP 2013; Waste Watcher 2013).

Half of the consumers claim that information about the food waste issue is still insufficient and not efficaciously communicated on the product label. In addition, consumers ask for instruction on composting and donation (Tucker 2007; Waste Watcher 2013). To this regard, food banks and food rescue programs have been established in the US since the 1960's (O'Connor 2014). Freeganism may also be intended as a way of donation, since private people consume only items wasted by others (Schneider 2008). Among the tools exposed in Table 7, the implemented ones are largely targeting waste prevention. Efforts should then be focused to favor not implemented tools supporting sustainable waste management at domestic level. Indeed, consumer are aware that efforts are still needed to reduce food waste and optimize its management. To this regard, they are conscious that the food waste issue could be effectively tackled only within an adequate normative framework regulating waste generation and management at national and supranational levels (European Parliament 2012).

5.3. Regulatory efforts

The "Zero Hunger Challenge" represents the UN Secretary General Ban Ki-moon's vision of a world free from hunger and malnutrition, where all food systems are sustainable (UN 2015a). Turning this vision into reality includes an effort to reduce food waste, recovering its potential for human nutrition. During the last years, public administration, universities and private organizations have been presenting documents aimed to find reliable solutions to the food waste problem. The member states of the United Nations have defined the "Sustainable Development Goals" (UN 2015b). One of these specifically addresses to eradicating the problem of hunger by 2030 (UN 2015c). In 2010, the "Joint declaration against food waste" was presented at the European Parliament in Brussels (LMM 2010). This document depicted objectives to reduce food discard along the supply chain. It asks the EU Parliament and Commission to take common actions on a global and European scale in order to decrease food discard by at least 50% within 2025. As a result, the European Parliament analysed the food loss and waste problem from various perspectives and established some concrete and measurable objectives. The European resolution (2012) is intended to be locally adopted by the Member States. For instance, the Italian public administrations produced the "Carta per una rete di enti territoriali a spreco zero" to implement effective actions into the relevant territory. The "Milan Charter" was published in April 2015 by Mipaaf and signed by more than one million consumers, industries and public organizations from its publication until its formal deliver to the UN Secretary General Ban Ki-moon on the occasion of the World Food Day on October 16th (OnuItalia 2015; The Milan Charter). It makes clear commitments on the fundamental human right to food, affirming that only a collective action of the present generation would be able to tackle undernutrition, malnutrition and waste, guaranteeing the right to food for future generations. It also requires taking actions and implementing practices to guarantee a sustainable management of food production and waste.

Politics is thus advocated to ensure that the food waste issue is reflected in a new policymaking, able to produce regulation in line with the principles of the Charter, while guaranteeing the food safety and quality requirements declared by the EU policy (European Commission 2015). Effective actions can actually be performed only within a framework of institutions and public-private partnerships facilitating R&D knowledge transfer and technological access (Ambler-Edwards 2009). For instance, the European Commission is supporting research and innovation on sustainable waste management through the "Horizon 2020" program with the ultimate goal of technological transfer from research to industry (European Commission n.d.).

6. Conclusions

The goal of future research should be not only developing solutions for an efficient management of discards generated through the food chain but also trying to decrease and desirably eradicate them. Balancing primary production, food production and consumption would be the easiest way to avoid food loss and waste generation. This challenging harmonisation could be achieved by synergistically implement multiple strategies, based on: (i) diversification of production lines depending on raw material supply and characteristics; (ii) application of innovative technological solutions; (iii) adequate labelling and communication interventions; (iv) donation initiatives at multiple levels of the food chain and (v) development of a regulatory framework supporting food discard decrease.

This integrated approach would provide a new definition of food quality that includes not only sensory and nutritional aspects, but also the potential environmental and social impact of food products, with special attention to the issue of food loss and waste generation.

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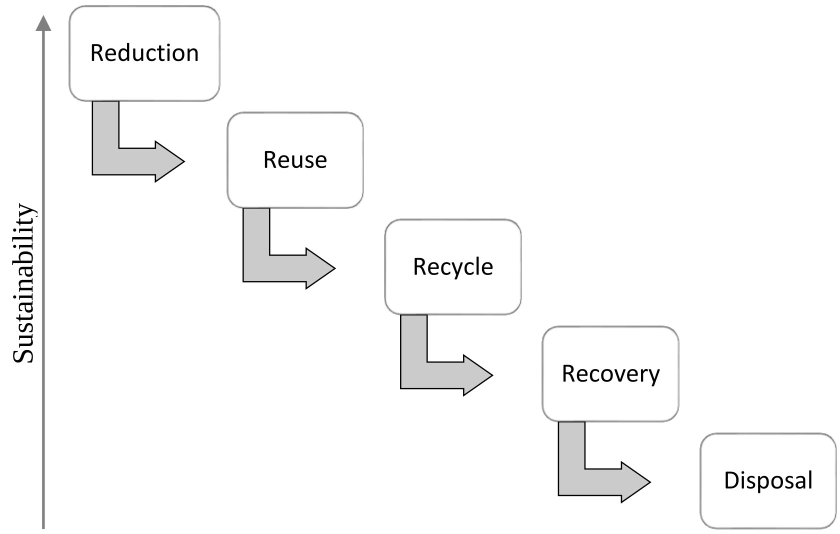

Figure 1. Management options according to the waste hierarchy.

Table 1. Criteria for food loss and waste classification.

Classification criteria		Food loss				Food waste	
		Primary production	Post-harvest	Processing Packaging	Distribution Retail	Handling	Consumption
Food category	Fruit	v	v	v	v	v	v
	Vegetables	v	v	v	v	v	v
	Drinks	v	v	v	v	v	v
	Bakery	v	v	v	v	v	v
	Meat and fish	v	v	v	v	v	v
	Dairy products	v	v	v	v	v	v
Discarded part	Original food	v	v	v	v		
	Partly used food			v		v	
	Leftovers						v
Avoidability	Avoidable				v	v	v
	Possibly avoidable	v	v	v	v	v	v
	Unavoidable	v		v		v	
Disposal option	Reusable		v		v	v	v
	Recyclable	v	v	v	v		
	Not recyclable					v	v
Resources content	Raw	v	v		v	v	
	Processed			v	v	v	v
	Ready-to-eat					v	v

Table 2. Food loss reasons at each level of the food supply chain (adapted from Kantor et al. 1997).

Primary production	Post-harvest	Processing and packaging	Distribution and retail
Severe weather	Inadequate pest control	Inedible parts	Inadequate storage conditions
Disease	Microbiological spoilage	Substandard products	Inadequate distribution procedures Packaging damage
Predation	Biochemical spoilage	Processing swarfs	
Damages from mechanization	Mechanical damage	Packaging damage	Passed expiration date
Inadequate production practices	Shrinkage	Wrong handling	
Substandard raw material	Inadequate storage practices of raw material	Inadequate storage practices of semi-finished and finished product	

Table 3. Domestic food waste reasons classified according to their causes.

Inadequate food supply Management	Incorrect food handling and storage	Limited food literacy/knowledge
Wrong purchase and meal planning (e.g. changes in plans, purchase of already spoiled food)	Excessive discard during preparation	Unawareness about “best before” and “use by” dates
Inconvenient packaging (e.g. over-sized, difficult to empty)	Cooking mistakes	Unawareness about “secondary shelf life”
Forgot food (e.g. presents, products for an eventuality)	Leftovers due to dislike or excessive serving size	Misunderstanding of label information
	Food spoilage (e.g. off odour, off flavour and bad aspect)	

Table 4. Estimates of waste distribution by food category, obtained in different studies.

Food category	Food waste (%w/w)		
	(Kantor et al. 1997)	(Gunders 2012)	(Lebersorger and Schneider 2011)
Fruits and vegetables	29	30	26
Milk and dairy	18	19	12
Grain products	15	14	15
Meat, fish, poultry	8	18	11[a]
Fats and oils	7	7	-
Confectionery – desserts	-	-	12
Caloric sweeteners	12	10	-
Other	11	-	24

[a] data refers to meat only.

Table 5. Estimates of overall food waste obtained in different studies (adapted from Parfitt et al. 2010).

Country	Source	Methodology	Food waste (kg/household/year)
USA	Jones (2004)	Indirect estimates from waste coefficients combined with waste composition analysis	212
USA	USEPA (2009)	Indirect estimates from waste coefficients combined with waste composition analysis (time span 1960-2008)	154-233
England	DEFRA (2010)	Indirect estimates from waste coefficients combined with waste composition analysis	240
UK	WRAP (2009)	Waste composition analysis, household surveys and kitchen diaries	270
Turkey	Peckan et al. (2006)	Household surveys	298

Table 6. Recovery options and possible applications relevant to main food categories (Tosh and Yada 2010; Wolfe and Liu 2003; Rodríguez et al. 2006; Galanakis 2015).

Product	Discard	Recovered material	Function	Application
Fruit and vegetables	Peels, leaves, pomace, skins, seeds, cores, kernels, stems	Polyphenols, vitamins, essential oils, pigments, enzymes, dietary fibres	Ingredient, bioactive, additive	Food, pharmaceutics, cosmetics
Cereals	Straw, bran, germ layers	Cellulose, hemicellulose, lignin, gluten, starch, fermentable sugars	Ingredient, cultural medium	Food, packaging, bioconversion
Roots and tubers	Peels, pulp waste	Carbohydrates, polyphenols, dietary fibres, pectin	Ingredient, bioactive, cultural medium	Food, bioconversion
Legumes	Husk, powder, broken, shrivelled or unprocessed seeds	Tannins, insoluble dietary fibre	Bioactive, moisturizing, structuring, emulsifying, foaming	Food
Seed oils	Defatted oilseed cake	Proteins, dietary fibres, colorants, bioactive compounds, oil	Bioactive, additive	Food, cosmetics, pharmaceutics
Meat	Swarfs, offal, blood, connective tissue	Proteins, lipids, minerals, collagen, bioactive peptides	Foaming agent, gelator, emulsifier, thickener, filmogen agent, antimicrobial, mineral-binding agent, opioid, antihypertensive, microencapsulation agent	Food
			Implantable biomaterials, liposomes scaffolds, gene transfer	Medicine, biotechnology
Fish	Swarfs, waste-water	PUFA, carotenoids, antioxidants peptides, proteins, pigments, collagen, chitin, chitosan, calcium	Biofilms, edible coatings, antimicrobial agent, food supplement, emulsifier, thickener, water purification, chromatography	Food, chemical analysis, purification systems
Dairy	Sludge, whey, cheese residues	Carbohydrates, fats, protein concentrates/isolates, lactose	Bioactive, foaming agent, emulsifier, food supplement	Food

Table 7. Implemented and not implemented tools to prevent domestic food waste.

State	Tool
Implemented	Media campaigns
	Online initiatives, exchange/donations platforms
	Education on food quality and shelf life
	Wise purchase advices (meal planning, lists)
	Imperfect product purchasing
	Storage recommendations
	Cooking tools
	Leftovers saving and unused ingredients freezing
	Smaller portion serving
Not implemented	Education about product freshness and life-cycle
	Education about composting
	User friendly labelled information
	Recipes with leftovers
	Information about food donation and freeganism