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Food waste generation and industrial uses: A review

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ABSTRACT

Food waste is made up of materials intended for human consumption that are subsequently discharged, lost, degraded or contaminated. The problem of food waste is currently on an increase, involving all sectors of waste management from collection to disposal; the identifying of sustainable solutions extends to all contributors to the food supply chains, agricultural and industrial sectors, as well as retailers and final consumers. A series of solutions may be implemented in the appropriate management of food waste, and prioritised in a similar way to waste management hierarchy. The most sought-after solutions are represented by avoidance and donation of edible fractions to social services. Food waste is also employed in industrial processes for the production of biofuels or biopolymers. Further steps foresee the recovery of nutrients and fixation of carbon by composting. Final and less desirable options are incineration and landfilling. A considerable amount of research has been carried out on food waste with a view to the recovery of energy or related products. The present review aims to provide an overview of current debate on food waste definitions, generation and reduction strategies, and conversion technologies emerging from the biorefinery concept.

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1. Introduction

Food loss and food waste are often used in scientific literature to identify materials intended for human consumption that are subsequently discharged, lost, degraded or contaminated. The Food and Agriculture Organisation of the United Nations (FAO) defined food loss (FL) as any change in the availability, edibility, wholesomeness or quality of edible material that prevents it from being consumed by people. This definition was provided for the post-harvest period of food ending when it comes into the possession of the final consumer (FAO, 1981). Gustavsson et al. (2011) reported a similar definition of FL but included also the production stage of a food supply chain (FSC) and not only postharvest and processing stages. Parfitt et al. (2010) defined food waste (FW) as the food loss occurring at the retail and final consumption stages and its generation is related to retailers' and consumers' behaviour. Recently the European Project FUSIONS (Östergren et al., 2014) defined FW by using the resource flows of the agri-food system. FW was defined as "*any food, and inedible parts of food, removed from (lost to or diverted from) the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).*" Any food being produced for human consumption, but which leaves the food supply chain, is considered FW while organic materials produced for the non-food production chain are not considered FW (Östergren et al., 2014). The definitions of FL and FW therefore overlap. These terms are used in literature for material discharged at both the manufacturing and retail stages and the consumption or household levels, highlighting the need for commonly-agreed and improved definitions (Williams et al., 2015).

Discharge of food material occurs along the entire Food Supply Chain (FSC) and it involves all sectors of waste management from collection to disposal. Detailed analysis of a FSC system will highlight how the generation of waste material (food losses, organic waste or food waste) affects all sectors involved in the production, distribution and consumption of food (Parfitt et al., 2010; Pfaltzgraff et al., 2013). A FSC starts with the production of food from the agricultural sector where both farming and husbandry produce waste or sub-products that may be either organic waste (i.e. cornstalk, manure), food waste or food loss (i.e. low quality fruits or vegetable, damaged productions left in the field, good products or co-products with a low or absent commercial value). The food processing and manufacturing industry produces food losses and food waste throughout the entire production phase due to reasons such as: damage during transport or non-appropriate transport systems, problems during storage, losses during processing or contamination, inappropriate packaging. The retail system and markets also generate FL and FW, largely

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due to problems in conservation or handling, and lack of cooling/-cold storage (Parfitt et al., 2010).

The generation of FW by the end consumer is caused by over- or non-appropriate purchasing, bad storage conditions, over-preparation, portioning and cooking as well as confusion between the terms "best before" or "use by" dates (Papargyropoulou et al., 2014). The generation of FW at household level is influenced by a series of interconnected factors, mainly socio-demographic characters of the household, consumption behaviour and food patterns (Glanz and Schneider, 2009).

FL and FW generation produces an impact at an environmental, social and economical level. From an environmental point of view, FL and FW contributes to Green House Gas (GHG) emissions during final disposal in landfills (uncontrolled methane release) and during activities associated with food production, processing, manufacturing, transportation, storage and distribution. Other environmental impacts associated with FL and FW are natural resource depletion in terms of soil, nutrients, water and energy, disruption of biogenic cycles due to intensive agricultural activities and all other characteristic impacts at any step of the FSC. Social impacts of FL and FW may be ascribed to ethical and moral dimension within the general concept of global food security. Economical impacts are due to the costs related to food wastage and their effects on farmers and consumer incomes (Lipinski et al., 2013; Papargyropoulou et al., 2014).

Similar to the Waste Management Hierarchy introduced in Europe, based on a hierarchy of solutions of distinct steps (waste prevention, reuse, recovery and recycling of materials, energy recovery and safe landfilling of residues) and often graphically represented by a reverse triangle (Cossu, 2009), the Environmental Protection Agency (EPA, 2014) defined the following hierarchy concept in relation to FW management: source reduction, feed hungry people, feed animals, industrial uses, composting, incineration or landfilling.

The first steps to be taken in reducing FW generation should commence by tackling the undesirable food surplus, and preventing over-production and over-supply of food (Papargyropoulou et al., 2014; Smil, 2004). The subsequent steps in the hierarchy foresee the utilisation of FW as animal feed or in the industrial sector. Several options are available for an industrial-scale use, ranging from the use of food waste for energy production by means of anaerobic digestion (e.g. bio-hydrogen or bio-methane productions) to the production of specific chemical compounds as precursors for plastic material production, chemical or pharmaceutical applications. Composting can be applied to recover nutrients or as a carbon sequestration process, through the formation of humic substances. Composting can be used to treat FW or residues from industrial processes (e.g. digestate). Landfilling or incineration represents the last and least desirable option. It is an acknowledged fact that biodegradable organic material is the main source of adverse environmental impacts and risks in traditional landfilling (odours, fires, VOC's, groundwater contamination by leachate, global climate changes, etc.) (*see also* Manfredi et al., 2010; Thomsen et al., 2012; Beylot et al., 2013) while thermal treatment, although providing for energy recovery, is limited by the low heating values of organic waste (Nelles et al., 2010). Accordingly, these options are not highly sought after (Papargyropoulou et al., 2014; Vandermeersch et al., 2014).

This paper reviews the data available on the magnitude of food waste generation, the strategies for food waste reduction and the possibilities reported and discussed in scientific literature for industrial uses of food waste.

2. Generation of food waste

The Food and Agriculture Organisation of the United Nations estimated that 32% of all food produced in the world was lost or wasted in 2009 (Gustavsson et al., 2011; Buzby and Hyman, 2012). While 870 million people are reported as being chronically undernourished, approximately 1.3 billion tons/year, i.e. one third of the food produced for human consumption, is wasted globally (Kojima and Ishikawa, 2013). In United States nearly 61 million tons of food waste are generated every year (GMA, 2012). Dee (2013) reported a food waste generation rate of 4 million tons per year in Australia. Other food waste generation data regards South Korea with 6.24 million tons per year (Hou, 2013), China with 92.4 million tons per year (Lin et al., 2011) and Japan where about 21 million tons of food waste were generated in 2010 (Kojima and Ishikawa, 2013). In Europe, food waste generation is estimated at 90 million tons annually (EC, 2013). Studies indicate the United Kingdom (UK) as the Country with the highest FW generation rate in Europe, reaching more than 14 million tons in 2013 (WRAP, 2013; Thi et al., 2015; Youngs et al., 1983). Quested et al. (2013) reported a generation of food waste at household level of 160 kg per year in UK, representing 12% of the food and drink entering a home and 30% of the general waste stream from UK household. Nellman et al. (2009) reported that a percentage ranging between 25% and 50% of food produced is wasted through the supply chain.

The order of magnitude of food waste generation is consistent and is not limited to developed Countries. Gustavsson et al. (2011) reported data on FW generation from different parts of the world, indicating that FW generation displays a similar order of magnitude in both industrialised Countries and developing Countries (DCs). Nevertheless, industrialised and developing Countries differ substantially. In the latter, more than 40% of food losses occur at the postharvest and processing stages, while in the former, about 40% of losses occur at the retail and consumer levels and, on a per-capita basis, much more food is wasted in the industrialised World than in DCs (Gustavsson et al., 2011).

The causes of food losses and waste in low-income Countries are mainly linked to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems. Many smallholder farmers in DCs live on the margins of food insecurity, and a reduction in food losses could have an immediate and significant impact on their livelihoods. Food supply chains in DCs should be strengthened, encouraging small farmers to organize, diversify and upscale their production and marketing. Investments in infrastructure, transportation, food industries and packaging industries should also be boosted, with both the public and private sectors playing an important role in achieving this.

The causes of food losses and waste in medium/high-income Countries relate mainly to consumer behaviour as well as to a lack of coordination between the various actors in the supply chain. Farmer-buyer sales agreements may contribute towards the wastage of farm crops. Food may also be wasted due to quality standards, with food items that do not fit with the required shape or appearance being rejected. On a consumer level, inadequate planning and expiry of "best before dates" likewise lead to large amounts of waste, combined with the at-times careless attitude of consumers. Food waste in industrialised Countries can be reduced by raising awareness amongst the food industries, retailers and consumers. This inevitably implies the unnecessary use of huge amounts of resources used in food production, and consequent increase in GHG emissions (Gustavsson et al., 2011).

In terms of the wasted investments, Nahman and de Lange (2013) estimated costs of edible food waste throughout the value chain in South Africa at approximately € 7.3 billion per annum, equivalent to 2.1% of annual gross domestic product. In the Unites States € 85 billion worth of food was estimated to be thrown away every year (Parfitt et al., 2010), € 28 billion in China (Zhou, 2013), € 27.8 billion in Australia (Dee, 2013), € 40 billion in Europe and nearly € 17 billion in the UK (WRAP, 2015).

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