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Environmental impacts of food waste: Learnings and challenges from a case study on UK

Davide Tonini [a,*], Paola Federica Albizzati [b], Thomas Fruergaard Astrup [b]

[a] Joint Research Centre of the European Commission, Edificio Expo, Inca Garcilaso 3, 41092 Seville, Spain
[b] Technical University of Denmark, Department of Environmental Engineering, Bygninstorvet 113, 2800 Lyngby, Denmark

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ABSTRACT

Food waste, particularly when avoidable, incurs loss of resources and considerable environmental impacts due to the multiple processes involved in the life cycle. This study applies a bottom-up life cycle assessment method to quantify the environmental impacts of the avoidable food waste generated by four sectors of the food supply chain in United Kingdom, namely processing, wholesale and retail, food service, and households. The impacts were quantified for ten environmental impact categories, from Global Warming to Water Depletion, including indirect land use change impacts due to demand for land. The Global Warming impact of the avoidable food waste was quantified between 2000 and 3600 kg CO_2-eq. t^{-1}. The range reflected the different compositions of the waste in each sector. Prominent contributors to the impact, across all the environmental categories assessed, were land use changes and food production. Food preparation, for households and food service sectors, also provided an important contribution to the Global Warming impacts, while waste management partly mitigated the overall impacts by incurring significant savings when landfilling was replaced with anaerobic digestion and incineration. To further improve these results, it is recommended to focus future efforts on providing improved data regarding the breakdown of specific food products within the mixed waste, indirect land use change effects, and the share of food waste undergoing cooking. Learning from this and previous studies, we highlight the challenges related to modelling and methodological choices. Particularly, food production datasets should be chosen and used carefully, to avoid double counting and overestimation of the final impacts.

1. Introduction

About one third of the food produced globally is lost or wasted corresponding to an annual generation of roughly 1.3 billion tonne of food waste (Gustavsson et al., 2011). In Europe this figure is estimated to about 88 Mt corresponding to ca. 173 kg per capita (Stenmarck et al., 2016; data for EU28 as for 2012); in economic terms, this incurs a loss of 143 billion€ each year. Food waste is often distinguished between unavoidable and avoidable, the latter intended as the food (and eventually drinks) which at some point, prior to being thrown out, was edible (Quested and Johnson, 2009). The avoidable portion represents a waste of resources, as food demands land-use, energy, chemicals and materials in order to be produced and delivered to the different actors involved in the food supply chain. Such a loss of resources inevitably translates into considerable environmental impacts that ideally may be avoided by prevention or mitigated by enforcing best waste management practices.

A number of studies have assessed the impact of food waste using life cycle thinking approaches. Typically, there are two main methods to perform this assessment: applying top-down approaches, using for example input-output tables and related figures for the impacts, or bottom-up approaches, using more detailed products databases. Advantages and disadvantages of the two methods have been discussed elsewhere (Reutter et al., 2017). The same authors, applying environmentally-extended

Abbreviations: AC, acidification; AEN, aquatic eutrophication, nitrogen; AEP, aquatic eutrophication, phosphorous; ARD, abiotic resource depletion; dLUC, direct land use change; EF, ecological footprint; ET, Ecotoxicity; EU, Europe; EU28, Europe, 28 member states; FRD, fossil resource depletion; LCA, life cycle assessment; LUC, land use change; HTc, human toxicity, cancer; iLUC, indirect land use change; GW, global warming; MSW, municipal solid waste; OD, ozone depletion; PM, particulate matter; POF, photochemical ozone formation; RD, fossil resource depletion; SI, supporting information; TE, terrestrial eutrophication; UK, United Kingdom; WD, water depletion.

* Corresponding author.
E-mail address: mccorms1@tcd.ie (D. Tonini).

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input-output analysis, found that Australian food waste represents 9% of the total water use and 6% of greenhouse gas (GHG) emissions at the national level amounting to a total of 57,507 Gg CO_2-eq. annually. Applying a top-down approach and using global statistics from FAO (Food and Agriculture Organization of the United Nations), Kummu et al. (2012) concluded that food waste embeds ca. 23–24% of the total use of cropland, freshwater resource, and fertilizers for food production. Song et al. (2015) combined national statistics and surveys on consumption patterns with bottom-up life cycle inventories for food products to derive carbon, water and ecological footprints of household food waste in China, estimating an impact of 2500 kg CO_2-eq. t^{-1}. Other studies used instead a bottom-up LCA approach. For example, Bernstad and Andersson (2015), using a bottom-up LCA approach integrated with data derived from dedicated sampling campaigns, concluded that the impact of the avoidable food waste generated by Swedish households ranged between 800 and 1400 kg CO_2-eq. t^{-1}. Oldfield et al. (2016) quantified the impact of food waste in the Irish food supply chain to ca. 5600 kg CO_2-eq t^{-1}. Scholz et al. (2015) used a bottom-up LCA approach to quantify the average carbon footprint of the food waste generated by a supermarket chain in Sweden, estimating it to 1600 kg CO_2-eq. t^{-1}. A similar study was also performed by Brancoli et al. (2017) that quantified an impact of 2800–3100 kg CO_2-eq. t^{-1} depending on the waste management scenarios. Martinez-Sanchez et al. (2016), focusing on the indirect effects of prevention for the case of Denmark, estimated the impact of food waste from Danish households to ca. 1200 kg CO_2-eq. t^{-1}, again using bottom-up LCA. Chapagain and James (2011) calculated carbon and water footprint of the total and avoidable food waste generated by UK households, estimating that these correspond to 6% and 3% of the total water and C-footprint of the UK.

It should be noticed that all the above mentioned studies, except for Martinez-Sanchez et al. (2016) and Chapagain and James (2011), did not include a thororugh quantification of the environmental impacts associated with land use changes (LUCs) induced by the cultivation of food, later becoming waste. In LCA the LUC impacts are typically distinct into direct and indirect (dLUC/iLUC). While the first refers to a change in the use of the land, the second refers to the upstream consequences of demanding land regardless of the final use of it and reflects market-mediated effects occurring globally, beyond the border of the region under assessment (Schmidt et al., 2015). Accounting for these, when addressing biomass resources incurring a demand for land, is crucial to the LCA results as learned from the extensive literature and discussion on bioenergy/biofuels. This is particularly true for carbon-footprint results, typically worsen when iLUC impacts are included (e.g. Edwards et al., 2010; Hamelin et al., 2014; Searchinger, 2010, 2008; Tonini et al., 2016a, 2017; Wenzel et al., 2014). In addition to this, the majority of the studies only addressed one or a few impact categories (e.g. carbon and water footprint) and one waste generator (or sector of the supply chain), mainly households or wholesale/retail sectors as earlier mentioned. Further, no study, the authors are aware of, has so far attempted to address and identify the main source of uncertainties in the life cycle assessment of food waste, using state-of-the-art approaches. Last, when modelling land use changes and waste management system, methodological challenges related to possible double countings and other modelling issues arise. This may be due to the way life cycle datasets are provided, for example the emissions or processes included. No study, the authors are aware of, has so far attempted to identify and discuss these issues.

Keeping in mind these limitations and in the attempt to bridge the gap we find in the current status of the research, this study aims to: (i) quantify the environmental impacts of food waste generated by different sectors of the food supply chain, using UK as case study; (ii) identify the main contributors to the impacts within the supply chain; (iii) determine the main source of uncertainties and the need for further research efforts on data collection to improve the robustness of the results. In addition, based on the learnings from this and previous research, this study also attempts to highlight and discuss some of the main challenges arising when performing this type of studies. The focus is placed on the modelling of the waste composition, land use changes, waste management, and on the most important modelling parameters and scenario uncertainties.

2. Materials and method

2.1. Definitions

We followed the definitions given in the recent FUSIONS study (Östergren et al., 2014); accordingly, *food waste* is intended as the fraction of food and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bioenergy production, cogeneration, incineration, disposal to sewer, landfill or discarded to sea). This excludes (from being considered *food waste*) the fraction of food and inedible parts of food that is used for animal feeding or for production of biomaterials. Notice that *food waste* is different from *food losses* defined as un-harvested crops (left on-field), losses of livestock pre-slaughter (dead during breeding or dead during transport to slaughter) or losses of milk due to mastitis and cow sickness (Östergren et al., 2014). Similar definitions may be found in other studies (Gustavsson et al., 2011; Östergren et al., 2014; Stancu et al., 2015). Both *food losses* and *food waste* refer to food items intended for human consumption and include both avoidable and unavoidable waste. The *avoidable* food waste is here intended as the food (and eventually drinks) which at some point, prior to being thrown out, was edible conforming with Quested and Johnson (2009).

2.2. Scope and functional unit

The functional unit of the study is the life cycle (cradle-to-grave, i.e. from provision to waste handling) of one tonne of avoidable food waste generated by four individual sectors of the United Kingdom food supply chain, which are: (I) Processing, (II) Wholesale & Retail, (III) Food Service, and (IV) Households. From now onwards, this naming (with capitals) will be used to refer to each of these waste generators and to the associated scenario. Food waste at farming sector was not addressed due to lack of reliable data, as also stressed in WRAP (2017). The food waste generated at these four stages of the food supply chain differs both in terms of composition and also in terms of supply chain activities and waste management practices involved. The assessment encompasses the entire life cycle of the avoidable food waste from production of the food (then becoming waste) and associated land use changes, to distribution (production of the packaging, transport and store operations), eventual meal preparation, up to final waste treatment, recycling, and eventual disposal (including end-of-life of the packaging). It should be noted that, differently from other waste management LCA studies typically disregarding upstream activities prior to waste generation, all activities prior to generation of the waste were included in order to quantify the actual life cycle environmental impact of the avoidable food waste generated. The assessment was performed following the ISO standards for LCA (ISO, 2006a, 2006b). A consequential approach was applied (Weidema et al., 2009; Weidema, 2003). The geographic scope of the study is United Kingdom, i.e. the foreground inventory data for food waste composition, technologies, and the legislative context were as much as possible specific to UK conditions. Most data

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