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Prioritizing and optimizing sustainable measures for food waste prevention and management

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ABSTRACT

Food waste has gained prominence in the European political debate thanks to the recent Circular Economy package. Currently the waste hierarchy, introduced by the Waste Framework Directive, has been the rule followed to prioritize food waste prevention and management measures according to the environmental criteria. But when considering other criteria along with the environmental one, such as the economic, other tools are needed for the prioritization and optimization. This paper addresses the situation in which a decision-maker has to design a food waste prevention programme considering the limited economic resources in order to achieve the highest environmental impact prevention along the whole food life cycle. A methodology using Life Cycle Assessment and mathematical programing is proposed and its capabilities are shown through a case study. Results show that the order established in the waste hierarchy is generally followed. The proposed methodology revealed to be especially helpful in identifying "quick wins" – measures that should be always prioritized since they avoid a high environmental impact at a low cost. Besides, in order to aggregate the environmental scores related to a variety of impact categories, different weighting sets were proposed. In general, results show that the relevance of the weighting set in the prioritization of the measures appears to be limited. Finally, the correlation between reducing food waste generation and reducing environmental impact along the Food Supply Chain has been studied. Results highlight that when planning food waste prevention strategies, it is important to set the targets at the level of environmental impact instead of setting the targets at the level of avoided food waste generation (in mass).

1. Introduction

According to the Food and Agriculture Organization of the United Nations (FAO), up to one third of all food is lost or wasted worldwide throughout the supply chain. This corresponds to about 1.3 billion tonnes per year and represents a waste of resources, water, energy, land, and other inputs used for producing that food, including labour (FAO, 2011). For Europe, Brautigam et al. (2014) reported that the quantity spoiled is around 143 million tonnes per year (data for 2006). Those estimates are highly uncertain, as shown – among others – in Cristobal et al. (2016), mostly due to: different methods for quantifying food waste exist, different databases for the calculation are used (e.g. FAOSTAT and EUROSTAT), and a lack of harmonization in the nomenclature (Corrado et al., 2017).

Thanks to the recent Circular Economy (CE) package (EC, 2015a), food waste prevention has gained prominence in the European political debate. In fact, the CE Action Plan (EC, 2015b) included food waste within the so-called "priority areas", i.e. areas that should be carefully considered to strengthen the circularity of the European economy. Previously, other EC's policy documents explicitly stressed on the importance of waste prevention to achieve sustainable use of resources, such as the "Community Strategy for Waste Management" (EC, 1989) and the "Thematic Strategy on the prevention and recycling of waste" (EC, 2005). But, it was with the Waste Framework Directive (WFD) (EC, 2008) that the first mandatory provisions concerning waste prevention were established. In fact, the WFD presented the key legally binding principle upon which European waste management is based: the so-called "waste hierarchy". The waste hierarchy establishes a priority order for waste management intended to ensure that the most environmentally sound waste management options are chosen. According to such hierarchy, waste prevention is the preferred option, while landfilling of waste is the least desirable option. Also, the WFD requires European Member States to prepare so-called "waste management plans" that should show how MS are going to implement the objectives and provisions

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Nomenclature

Sets	
A	set of impact categories indexed by a
I	set of actions indexed by i
J	set of food supply chains indexed by j
K	set of stages of the food supply chain indexed by k
T	set of time periods indexed by t
Iprev (I)	sub-set of prevention actions indexed by iprev
Ireu (I)	sub-set of reuse actions indexed by ireu
Irere (I)	sub-set of recycle and recovery actions indexed by irere
AFC	annual financial cost
B	budget
EI	environmental impact
EIA	environmental impact avoided
Inh	number of inhabitants in the geographical area considered
N	normalisation factor
Q	quantity
r	discount rate
t	time period
TEI	total environmental impact
TEIA	total environmental impact avoided
TFC	total annual financial cost
TQ	total quantity
w	weighting set
x	binary variable
α	unavoidable fraction of food waste

made by the WFD and, in particular, the implementation of the waste hierarchy. In addition, further stressing on the strategic importance of waste prevention, according to the WFD, MS are required to develop "waste prevention programmes", which shall clearly identify waste prevention measures and targets. To support MS in the development of their waste prevention programmes, the Commission prepared general guidelines (EC, 2012a), as well as guidelines specifically focused on food waste (EC, 2011).

As stated by Van Ewijk and Stegemann (2016), the priority order in the waste hierarchy mainly relates to the ability of each option to achieve diversion from landfill but also equates with the least environmental impact. Towards ensuring that the most environmentally sound options can always be identified, the WFD allows to deviate from the hierarchy for specific waste streams, if this is justified by life cycle thinking on the overall environmental impacts of the different waste management options. In fact, many examples of application of Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) to waste management exist in literature (Laurent et al., 2014a; Laurent et al., 2014b) that show that in certain cases (Finnveden et al., 2005; Eriksson et al., 2015), or for certain materials such as food waste (DEFRA, 2011a), the priority order indicated by the hierarchy may not hold true e.g., anaerobic digestion (i.e. recovery) can be better (for the environment) than composting (i.e. recycle). As concluded by Laurent et al. (2014a), due to the strong dependence of each waste on its context and local specificities, the waste hierarchy should be used with caution as it can be misleading and overshadow the support that LCA brings in the management of solid waste. Furthermore, as shown by Gharfalkar et al., (2015) there are a number of conceptual gaps and disparities in literature (WRAP, 2011; DEFRA, 2011b, EC, 2012b) in the understanding of the waste hierarchy and the definitions of different measures in the WFD, making the classification of some measures within the hierarchy not clear.

Mourad (2016) shown that there exists a competition among three management options of the waste hierarchy (i.e. prevention, reuse and recycle-recovery). This competition entails environmental, social and economic interests. In this line, Gharfalkar et al. (2015) concluded that the waste hierarchy acts as a priority guideline, but for the final decision of implementing different prevention and management measures LCA-based methodologies may be required to ascertain the option that delivers the best overall environmental, human health, economic and social impact. Certainly, the inclusion of the other two pillars of sustainability (i.e. economic and social) exerts a strong influence on the decision making process.

A literature review revealed that there is a knowledge gap concerning evaluation methodologies and reliable results of implementing food waste prevention measures, as stated by Schneider (2013). Gentil et al. (2011), using a LCA methodology, evaluated the environmental consequences of food waste prevention on waste management systems and on the wider society. Hamilton et al. (2015) used a multi-layer systems framework for comparing quantitatively food waste recycling and prevention strategies in Norway. But till now, up to the knowledge of the authors, there is limited knowledge on the evaluation of food waste prevention and management strategies including both economic and environmental dimensions. Towards filling such gap, the main aim of this paper is to propose a novel methodology based on LCA and mathematical programming for planning food waste prevention and management measures, taking into account environmental and economic indicators. This paper addresses the situation in which a decision-maker has to design a food waste prevention programme considering the limited economic resources in order to achieve the highest environmental impact prevention along the whole food life cycle. For the time being, the social dimension has been excluded from this analysis due to lack of indicators and reliable data. It will serve as a tool for decision makers to identify the optimal combination of food waste prevention and management measures to be prioritized in order to maximize the environmental impact benefit along the whole Food Supply Chain (FSC) within a defined budget. This methodology will be developed through an integer linear programming (ILP) model. The environmental impact benefit will be measured through an indicator that aggregates 15 different impact categories by means of normalisation and weighting. This paper also presents a case study which results will be analyzed and compared with the provisions made by the waste hierarchy discussing the possible misalignments (e.g. recovery options are prioritized over recycling or reuse options). In addition, six different weighing sets will be used and their results discussed.

This paper is organized as follows. Section 2 provides the methodological approach that includes: the quantification of food waste prevented by a given measure (Section 2.1); the calculation of the environmental impact(s) prevented by each measure depending if they are prevention, re-use or recycle-recovery measures (Section 2.2); the calculation of the economic indicator for each measure (Section 2.3); the problem statement and the mathematical formulation of the model (Section 2.4). Section 3 presents the case study. Section 4 analyzes and discusses the results. Finally, Section 5 presents the conclusions drawn from the study.

2. Methodological approach

The methodological approach developed to assess and prioritize different options for food waste prevention and management con-