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A holistic approach to the environmental evaluation of food waste prevention

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ABSTRACT

The environmental evaluation of food waste prevention is considered a challenging task due to the globalised nature of the food supply chain and the limitations of existing evaluation tools. The most significant of these is the rebound effect: the associated environmental burdens of substitutive consumption that arises as a result of economic savings made from food waste prevention. This study introduces a holistic approach to addressing these challenges, with a focus on greenhouse gas (GHG) emissions from household food waste in the UK. It uses a hybrid life-cycle assessment model coupled with a highly detailed multi-regional environmentally extended input output analysis to capture environmental impacts across the global food supply chain. The study also takes into consideration the rebound effect, which was modelled using a linear specification of an almost ideal demand system.

The study finds that food waste prevention could lead to substantial reductions in GHG emissions in the order of 706–896 kg CO_2-eq. per tonne of food waste, with most of these savings (78%) occurring as a result of avoided food production overseas. The rebound effect may however reduce such GHG savings by up to 60%. These findings provide a deeper insight into our understanding of the environmental impacts of food waste prevention: the study demonstrates the need to adopt a holistic approach when developing food waste prevention policies in order to mitigate the rebound effect and highlight the importance of increasing efficiency across the global food supply chain, particularly in developing countries.

1. Introduction

One third of food produced across the globe is thrown away uneaten, and this waste has a large associated environmental burden (IMechE, 2013). Food waste is responsible for 3.3 Bt-CO_2-eq. yr^{-1}, rendering it equivalent to the world's third largest emitter of carbon after the economies of China and USA (FAO, 2013). In order to reduce the environmental impact of food waste, the food waste hierarchy has been adopted in various forms across different countries, providing guidelines on which disposal technologies are most preferable (Papargyropoulou et al., 2014).

Food waste prevention, situated at the top of the food waste hierarchy, is considered to be the most environmentally favorable management option (Papargyropoulou et al., 2014). According to a study published by the European Commission, approximately 44Mt CO_2-eq. yr^{-1} could be avoided by the introduction of a 20% food waste reduction target (EC, 2014). This finding supports the conclusions of other studies that have highlighted the significant environmental benefits of avoiding food waste (Bernstad and Andersson, 2015; Gentil et al., 2011; Martinez-Sanchez, 2016). Nevertheless, reported results are subject to a high level of uncertainty; the reported greenhouse gas (GHG) emissions savings vary widely, ranging from 800 to 4400 kg CO_2-eq. per tonne of food waste (Bernstad and Cánovas, 2015). These variations in literature arise largely due to methodological choices: most studies rely entirely on life cycle assessment approaches, do not consider food imports, and ignore rebound effects. We discuss these three methodological challenges before introducing a new holistic modelling approach to addressing them.

Abbreviations: GHG, greenhouse gas; LCA, life cycle assessment; AD, anaerobic digestion; N/A, not applicable; MRIO, multi-regional input output; SIC, standard industrial classification; MBS, marginal budget shares; AIDS, Almost Ideal Demand System; RE, rebound effect; FEI, freed effective income; WRAP, The Waste and Resources Action Programme.

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Firstly, the majority of studies adopt a conventional process-based Life Cycle Assessment (LCA) approach (Table 1). Excluding Martinez-Sanchez et al.'s study (2016), all of the reviewed studies adopt a bottom-up LCA approach, and hence inherit the widely-discussed limitations of LCA such as system boundary cut-offs, data inconsistencies, study-specific scenarios and assumptions (Bernstad and la Cour Jansen, 2012; Laurent et al., 2014a, 2014b). These limitations, coupled with the multi-faceted nature of food waste, make the environmental evaluation of food waste prevention practices an arduous task. LCA-based studies are generally product-specific and do not consider variations within the same food category due to differences in the source of food products (e.g., imported vs locally produced), food production systems (e.g., wild caught vs aquaculture fish), and the quality of food products (e.g., conventional vs organic) (Audsley et al., 2009; Bernstad and Cánovas, 2015; Chapagain and James, 2011).

The second challenge in modelling food waste prevention lies in the globalisation of the food supply chain. For example, 48% of the UK's food supply in 2008 was imported from abroad, and these imports accounted for 67% of food-related GHG emissions (Ruiter et al., 2016). It is hence vital to account for the source of food products when estimating environmental benefits associated with food waste prevention. Excluding Bernstad and Andersson's study (2015), all of the studies reviewed assume food production occurs domestically or regionally (Audsley et al., 2009; Martinez-Sanchez, 2016; Matsuda et al., 2012; Venkat, 2011).

The final factor that results in substantial variation in estimates of the benefits of reducing food waste is the inclusion, or lack of inclusion, of the rebound effect: the avoidance of food waste in households leads to increased effective income which subsequently results in expenditure on alternative products and services (Binswanger, 2001; Brookes, 1990; Khazzoom, 1980). That is to say, when households avoid food waste, they consequently have more money available that may then be spent on other products and services. As this additional expenditure generates additional GHG emissions, the environmental benefits of reducing food waste can be partially or completely offset. If the economic savings were to be spent on carbon-intensive goods or services (e.g. air travel or domestic heating), it is even plausible for food waste prevention to create higher environmental burdens than if the food waste had not been wasted to begin with (Martinez-Sanchez, 2016).

To summarise, conventional approaches used to estimate the environmental benefits of food waste prevention provide only limited insight, in a world where food is internationally traded and financial savings made from waste avoidance often lead to rebound consumer spending. In order to combat these limitations, this study outlines a holistic approach to quantifying the environmental benefits of food waste prevention. To counter the limitations of conventional bottom-up LCAs, a hybrid LCA approach is used, combining conventional process-based LCA and a top-down input-output-based approach. Secondly, the flow of goods and services throughout the global supply chain was modelled using an economic and multi-regional input output method. Finally, the rebound effect was modelled using an econometric-based marginal expenditure model. The United Kingdom was used as a case study.

2. Methodology

Three scenarios for the environmental benefits of food waste prevention were evaluated: a baseline scenario and two food waste prevention scenarios (Fig. 1).

i. Baseline-scenario: 1 tonne of food is wasted and sent to be processed in an anaerobic digestion (AD) plant. Anaerobic digestion was selected because it is the food waste treatment technology most currently most favoured in the UK (Evangelisti et al., 2014; Salemdeeb and Al-Tabbaa, 2015);
ii. A partial-reduction scenario: a 60% reduction in food waste, with the remaining fraction of food waste (400 kg) being sent to an AD plant; and
iii. A total-reduction scenario: 77% of food waste is prevented and 23% (230 kg) is sent to an AD plant.

The two food waste prevention scenarios are based on figures from the Waste and Resources Action Programme (WRAP), which estimate that 60% of household food waste in the UK is avoidable whilst a further 17% has the potential to be avoided (WRAP, 2013). The remaining 23% of food waste is unavoidable (e.g. egg shells and tea bags) and thus undergoes a conventional disposal route.

Our study adopts a green-consumption approach: households which reduce food waste are assumed to have reduced food purchases, rather than increased consumption. In order to model the environmental benefits of avoiding food waste, we follow Gentil et al.'s approach in considering the quantity of avoided food waste as a virtual waste flow (Gentil et al., 2011). Food waste prevention scenarios therefore also include knock-on savings from food waste avoidance, including avoided household food-related activities (e.g. grocery shopping, storage and preparation). To model these household activities, we used estimates from the literature: shopping is accountable for 70 kg CO_2-eq. per tonne food and the GHG burden associated with home storage and preparation is 420 kg CO_2-eq. per tonne (Brook Lyndhurst, 2008; Pretty et al., 2005). This study additionally takes into account the rebound effect and investigates how the economic savings from food waste prevention activities (the purchase of less food products) may be spent on other activities and consequently reduce the net environmental benefits of food waste prevention (Section 2.3).

This study includes one environmental indicator, greenhouse gas emissions. These are aggregated and presented as a single mid-point impact category (i.e., climate change). The global warming potential metric is used to convert greenhouse gases to equivalent amounts of CO_2 on a time horizon of 100 years (IPCC, 2007).

Table 1
Quantitative studies evaluating the environmental benefit of food waste prevention.

Study	Country	Assessment method	International trade included?	Rebound effect included?
Bernstad and Andersson (2015)	Sweden	Consequential LCA	Y	N
Chapagain and James (2011)	UK	LCA	N	N
Matsuda et al. (2012)	Denmark	LCA	N	N
Gentil et al. (2011)	Denmark	LCA	N	N
Venkat (2011)	USA	LCA	N	N
Audsley et al. (2009)	UK	LCA	N	N
Martinez-Sanchez et al. (2016)	Denmark	Life cycle costing	N	Y

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