Journal of Environmental Management xxx (2016) 1–10

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

An environmental analysis of options for utilising wasted food and food residue

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ARTICLE INFO

Article history:
Received 28 July 2016
Received in revised form
8 September 2016
Accepted 11 September 2016
Available online xxx

Keywords:
Waste management
Life cycle assessment
Carbon return on investment
Circular economy
Waste reduction
Ireland

ABSTRACT

The potential environmental impact of wasted food minimisation versus its utilisation in a circular bioeconomy is investigated based on a case study of Ireland. The amount of wasted food and food residue (WFFR) produced in 2010 was used for business-as-usual, (a) and four management options were assessed, (b) minimisation, (c) composting, (d) anaerobic digestion and (e) incineration. The environmental impacts Global Warming Potential (GWP), Acidification Potential (AP) and Eutrophication Potential (EP) were considered. A carbon return on investment (CRoI) was calculated for the three processing technologies (c–e). The results showed that a minimisation strategy for wasted food would result in the greatest reduction of all three impacts, −4.5 Mt CO_2-e (GWP), −11.4 kt PO_4^{3}-e (EP) and −43.9 kt SO_2-e (AP) compared to business as usual. For WFFR utilisation in the circular bioeconomy, anaerobic digestion resulted in the lowest environmental impact and best CRoI of −0.84 kg CO_2-e per Euro. From an economic perspective, for minimisation to be beneficial, 0.15 kg of wasted food would need to be reduced per Euro spent.

1. Introduction

Global demand for food is increasing (Tilman et al., 2011) and sustainably meeting this demand represents a major challenge (West et al., 2014). Modern industrial economies rely on a continuous input of natural resources to produce goods and services, including food, so the continued consumption of non-renewable resources will ultimately limit food supply (Sattari et al., 2016). Agriculture is at particular risk because it relies on mineral fertiliser to maintain the yields necessary to meet future demand for food and feed production (Tilman et al., 2002). In the European Union there is an emphasis on reducing mineral fertiliser use in agriculture (Fertiplus, 2015; Refertil, 2015), a situation also seen in Ireland (Yan et al., 2009; CANtogether, 2016), but to maintain security of supply, alternative sources of plant nutrition will be required (Tilman et al., 2002).

Wasted food and food residues (WFFR) contain large amounts of nutrients: (i) phosphorus (P), which is a finite material estimated to reach peak production by 2033 (Cordell et al., 2009); (ii) nitrogen (N), which is associated with a large environmental impact; and (iii) potassium (K), required for the growth and reproduction of plants. The Food and Agriculture Organization of the United Nations (FAO, 2015) estimated that approximately one third of global food production is wasted. In Ireland, ~1,267,749 t of WFFR was produced in 2010 (Ireland Central Statistics Office, 2012; EPA, 2012) and Oldfield and Holden (2014a, 2014b) estimated that this contained about 4204 t of available N, 1996 t of available P and 2313 t of available K, which could be theoretically recovered and utilised through circulation rather than raw material consumption. Such recycling of nutrients from WFFR would divert mass from landfill, transforming "waste" materials into a value-added product (Mirabella et al., 2014).

A number of technologies can transform WFFR into value-added nutrient products (Bernstad and la Cour Jansen, 2012), but composting and anaerobic digestion (AD) are currently the two most important for nutrient recovery from organic wastes (Blengini, 2008; Berglund and Börjesson, 2006). In Europe, composting and AD account for 95% of current biological treatment operations for organic waste (European Commission, 2008; ORBIT/ECN, 2008). Composting has the potential to recover between 0.5 and 10 kg N, 0.5–1.9 kg P and 1–5.4 kg K per tonne of WFFR (Boldrin et al., 2009; Crowe et al., 2002), while AD can recover approximately 5.5–7.8 kg N, 0.08–0.15 kg P and 0.2–0.3 kg K per m^3 of digestate (Möller et al., 2009).

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http://dx.doi.org/10.1016/j.jenvman.2016.09.035
0301-4797/

The environmental impacts of management options for WFFR needs to be known in order to define the best strategy for a given situation (Ekvall et al., 2007) and the recovery of nutrients must compete with technologies that handle the material efficiently and effectively, which may be of greater social importance, such as incineration. Life cycle assessment (LCA) has been used to assess waste handling for many years (Bernstad and la Cour Jansen, 2012; Laurent et al., 2014a, b). Recent attention has focused on how to evolve LCA applied to the traditional waste hierarchy (Ekvall et al., 2007), where the function is to handle the waste, towards approaches that incorporate waste prevention (Bernstad Saraiva Schott and Andersson, 2015; Cleary, 2010; Nessi et al., 2013). The focus is now moving towards circular economy concepts of creating or maintaining the value of material flows and can be seen in studies where 'waste' is utilised as a feedstock for technology that derives a value-added product (Martínez-Blanco et al., 2009; Ruggieri et al., 2009). Therefore this study considers both WFFR prevention and WFFR utilisation.

Aspects that need to be addressed when considering WFFR utilisation are (i) multi-functionality of products (e.g. composting provides waste handling (Blengini, 2008)), nutrient recovery (Ruggieri et al., 2009), carbon sequestration (Boldrin et al., 2009), soil organic matter (Martínez-Blanco et al., 2009) and microbial biomass substrate supporting biodiversity (Martínez-Blanco et al., 2009); (ii) the system boundary and allocation (i.e. separating the upstream and downstream/life cycle stages within a circular system (open-loop recycling)) (Nicholson. et al., 2009); and (iii) multi-actor perspectives on waste definition (where waste for one actor is a resource for another) (Cheyne, 2002). In the context of this study there is currently no prescribed method to incorporate recycling and waste prevention. Therefore the approach taken was to follow a similar method to that of Bernstad Saraiva Schott and Andersson (2015), whereby WFFR processing was compared to wasted food prevention.

The objectives of this study were: (i) to calculate the potential environmental impacts using LCA of four WFFR management options (reduction, composting, AD and incineration) compared to business-as-usual in 2010, considering the need to recover nutrients for primary production and the generation of energy as well as the primary function of handling waste; and (ii) to estimate the carbon return on investment (CRoI) for each option (composting, AD and incineration).

2. Materials and methods

2.1. Goal and scope

The LCA was conducted following ISO standards (2006a; 2006b), and implemented in GaBi v 6 software (ThinkStep, 2015). Foreground data was taken from Irish sources and peer reviewed journals, and background data from ecoinvent (Ecoinvent, 2015) and GaBi V6 (Thinkstep, 2015).

The goal was to quantify potential environmental impacts of WFFR reduction and utilisation compared to business as usual in Ireland in order to identify the key environmental impacts of each management option and to provide information to better understand the impact of policy decisions on WFFR management. The study was conducted for a scientific audience and regulators with the comparison restricted to the options noted.

The scope included the technologies, composting, AD and incineration that have the capacity to manage WFFR. Both composting and AD recover nutrients while incineration and AD produce energy. As the primary function of all options is to handle waste, the functional unit was the annual amount of WFFR managed in Ireland (1,267,749 t), using data for 2010, which was the most recent complete data available at the start of the study. The system included WFFR collection, transport, treatment and use (Fig. 1). The CML midpoint methodology for global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) was used (Guinée et al., 2002). Interpretation was carried out according to ISO 14040 (2006a) and included contribution and sensitivity analysis.

The interpretation was supplemented with a 'Carbon Return on Investment' (CRoI, kg CO_2-e/€) analysis, i.e. the amount of potential carbon reduced per unit investment in capital infrastructure (Equation (1))

$$CRoI = \frac{GWP}{I_m} \tag{1}$$

where, GWP = global warming potential impact per kg of feedstock (kg CO_2-e/tonne) and I_m = financial investment in technology per kg of feedstock (€/tonne).

WFFR management options were assessed (Table 1): (a) baseline was business-as-usual (BaU), landfill and composting; (b) WFFR reduction with residue and minimal wasted food being either composted or used as AD feedstock; (c) composting of all WFFR; (d) AD and composting; and (e) incineration and composting.

In 2010, 1,267,749 t of food was wasted and not consumed in Ireland (SI Fig. #1) (RPS, 2008; 2010), and assuming a 30% wastage rate (UNRIC, 2015). This means ~4,225,830 t of food was available for purchase. This was taken as the amount of food produced for all options. Assuming 20% of WFFR is residue and cannot be avoided (EPA, 2013a) then 253,549 t was unavoidable (e.g. chicken carcasses, orange peel etc.) in 2010 and 1,014,199 tonnes was avoidable wasted food.

For the baseline BaU (Option a), data were taken from a status report of the composting industry which found that in 2010, 127,674 t of WFFR was composted (43,139 t of household WFFR, 20,698 t of commercial WFFR and 63,837 t collected at civic amenity centres) representing about 72% of composting capacity in Ireland at the time (McGovern, 2012). It was assumed that the remaining 1,140,075 t WFFR was sent to landfill with no energy recovery (Table 1). The uncertainty around the amount of WFFR composted was assessed by running scenarios with 100% of composting capacity utilised (176,000 t WFFR composted) (Option a-2) and 0% composting capacity used (Option a-3), i.e. 100% WFFR directed to landfill.

Option b evaluated a hypothetical, successful food waste prevention programme that would mean a reduction in the amount of food required to meet demand (Table 1). As it is untenable to assume no losses in the food chain, 4% wasted food was assumed and a food residue amount calculated based on a proportion to the food production required (8.6%). The increased efficiency was assumed to result in an avoided burden of food production of 845,167 t. In 2010, Ireland had the capacity to process 176,000 t WFFR through composting, therefore the remaining 246,582 t would go to landfill. Three scenarios were then evaluated, for WFFR to all be processed through either, composting (Option b-2), AD (Option b-3) or incineration (Option b-4).

Option c assumed no change to the 2010 food production amount and a fixed amount of WFFR generation, and modelled the composting of 100% of WFFR within Ireland with a view to recycling nutrients (NPK) for land application (Table 1).

Option d assumed no change to the 2010 food production amount and a fixed amount of WFFR generation. The starting point was to assume 100% of the 2010 composting capacity was utilised (176,000 t) with the remainder of WFFR (1,091,749 t) being processed by AD (Table 1). A scenario (Option d-2) was then evaluated with 100% WFFR going to AD.