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Separate collection of household food waste for anaerobic degradation – Comparison of different techniques from a systems perspective

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ABSTRACT

Four systems for household food waste collection are compared in relation the environmental impact categories eutrophication potential, acidification potential, global warming potential as well as energy use. Also, a hotspot analysis is performed in order to suggest improvements in each of the compared collection systems. Separate collection of household food waste in paper bags (with and without drying prior to collection) with use of kitchen grinders and with use of vacuum system in kitchen sinks were compared. In all cases, food waste was used for anaerobic digestion with energy and nutrient recovery in all cases. Compared systems all resulted in net avoidance of assessed environmental impact categories; eutrophication potential (−0.1 to −2.4 kg NO_3^-eq/ton food waste), acidification potential (−0.4 to −1.0 kg SO_2^-eq/ton food waste), global warming potential (−790 to −960 kg CO_2^-eq/ton food waste) and primary energy use (−1.7 to −3.6 GJ/ton food waste). Collection with vacuum system results in the largest net avoidence of primary energy use, while disposal of food waste in paper bags for decentralized drying before collection result in a larger net avoidence of global warming, eutrophication and acidification. However, both these systems not have been taken into use in large scale systems yet and further investigations are needed in order to confirm the outcomes from the comparison. Ranking of scenarios differ largely if considering only emissions in the foreground system, indicating the importance of taking also downstream emissions into consideration when comparing different collection systems. The hot spot identification shows that losses of organic matter in mechanical pretreatment as well as tank connected food waste disposal systems and energy in drying and vacuum systems reply to the largest impact on the results in each system respectively.

1. Introduction

On average, each EU citizen generated 522 kg municipal waste in 2008 (European Environmental Agency (EEA), 2010). A further increase to 680 kg per person is projected by 2020 (EEA, 2010). The compostable fraction has been assumed to equal 28% of the generated municipal solid waste, equal to 190 kg/household and year in 2020 (European Commissions, 2003). Household food waste is on of the fractions addressed as compostable in cited projection. More specific studies made on the generation of household food waste have been made in some EU-member countries. A recently performed British study shows that 1.8 million tons of food waste (including weight from water added during the preparation this arises to 3.5 million tons) is generated by British households each year (WRAP, 2009). The global warming potential (GWP) from production, manufacturing and distribution of this non-eaten food has been estimated to 4.6 million tons of CO_2^-eq (WRAP, 2009). Similar studies in Sweden (Swedish Waste Management Association, 2005; Konsumentföreningen Stockholm, 2009) show that Swedish households generate between 100–116 kg food waste per capita and year. The same studies also show that a large part of the generated household food waste could be avoided. However, for the non-avoidable part, user-friendly and resource efficient systems for separate collection can be of relevance in order to utilize the inherent energy and nutrients in food waste.

Several different systems for separate collection of food waste for later biological treatment have been implemented in European countries during the last decades. Highly efficient systems based on source separation of various streams of bio-waste exist already in Austria, Germany, Luxembourg, Sweden, Belgium, The Netherlands, Cataluña (Spain) and certain regions in Italy (ACR+, 2005). These systems each have their inherent advantages and disadvantages in relation to user-friendliness, resource use and economic investments. Several studies on the technical performance of different collection systems have been performed previously (Nilsson et al., 1990; Bolzonella et al., 2003; Swedish Waste Management Association, 2007, 2009a,b; Davidsson et al., 2011). However, the knowledge of environmental benefits and drawbacks related to different collection systems is still limited.

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Table 1
Characteristics of disposed food waste.

Parameter	Value	Reference
Dry substance (DS)	35%	Davidsson et al. (2011)
VS (% of DS)	80%	Hansen et al. (2007)
N (kg/ton DS)	26.9	Davidsson et al. (2011)
P (kg/ton DS)	2.1	Davidsson et al. (2011)
K (kg/ton DS)	8.3	Davidsson et al. (2011)
C (kg/ton DS)	416	Davidsson et al. (2011)
Degradation in AD-plant (% of VS)	77%	Davidsson et al. (2007)[a]
CH4 production (Nm^3/ton disposed food waste)	100	Davidsson et al. (2007)[a]
Disposed food waste per household and year	100 kg	Konsumentföreningen Stockholm (2009)

[a] 300–400 Nm^3/ton disposed VS from food waste.

The aim of the present study was to compare a number of different systems for source-separation and collection of household food waste using life-cycle assessment methodology (ISO, 2006a,b). The comparison is done in relation to three environmental impact categories (GWP, acidification (AP) and eutrophication (EP)) as well as primary energy use (PEU). These categories were chosen as they are believed to be of large importance to several of the Swedish Environmental Quality Objectives (Swedish Government, 2011), that these are areas where the environmental impact from compared system could be assumed to differ. However, it should be taken into consideration that the number of impact categories is limited and the comparison is therefore far from holistic. Further, the aim is also to identify hot spots, i.e. parts of the collection and treatment chain connected with large negative environmental impacts, in order to suggest improvements in each of the compared collection systems. The study was performed according to the four phases described in the ISO life cycle assessment (LCA) standard: goal scope and definition; life cycle inventory (LCI); impact assessment and interpretation (ISO, 2000). According to the ISO standard (ISO, 2000) an LCI should include all relevant inputs and outputs of a product system and sensitivity analysis should focus on the most significant issues, to determine the influence on variations in assumptions, methods and data.

1.1. Goal and scope definition

The boundaries of the investigated systems are set to the use of disposal materials, direct energy use connected to collection and transportation of food waste disposed in respective system. However, the different collection systems might influence environmental impacts related to later parts of the treatment chain. In order to address these differences, also the further anaerobic treatment of collected food waste, treatment of residues from pre-treatment of source-separated food waste and use of digestate is addressed in the study. Thus, the aim of the study was to investigate environmental impact connected not only to upstream emissions (connected for example with production of materials needed for the collection and transportation of OFMSW) and direct emissions, such as through combustion of fuels in collection vehicles. Also processes in the downstream, or compensatory system (Gentil et al., 2009), where to be addressed with the hypothesis that these are relevant to the net environmental impacts from compared systems. The functional unit in the study is the collection, transportation and treatment of 1 ton of source-separated wet food waste (Table 1).

2. Description of compared systems

2.1. Inventory analysis

The systems compared in the study were chosen based on a survey amongst Swedish municipalities, in order to include the currently most used systems for separate collection of household food waste in Sweden (Swedish Waste Management Association, 2009a,b,c). In addition, a system under development, not yet taken into use in full scale, was added to the comparison (Fig. 1). Key input data in all systems are collected in Table 2.

A. Food waste is separated in paper bags in perforated plastic vessels and disposed in designated waste bins in recycling buildings. Environmental impacts related to production of waste bins used for food waste collection and the washing of the same (twice a year) was not assessed. Previous studies have shown that collection of food waste in paper bags results in weight reduction of 14–27% (Bernstad, 2010 and Swedish Waste Management Association, 2010 respectively). Mechanical pretreatment is needed before filled paper bags can enter the anaerobic digestion plant. Energy consumption, losses of biodegradable material and energy value in produced residues are based on Truedsson (2010), assuming 30% of potential CH_4 production and nitrogen in residues. Residues are combusted with 85% energy recovery, substituting electricity production (20.3%) and thermal energy (88.7%). All data related to the combustion processes are gathered from Sysav (2010).
B. Same as A but food waste is disposed in a facility for drying of food waste at low temperature (18–25 °C, depending on outdoor temperature). Nutrient and energy content is assumed to remain intact (Waste Refinery, 2010). Energy use for drying was based on experiences from a pilot study (Swedish Waste Management Association, 2009a,b,c). Dried food waste is collected and transported for AD without prior pre-treatment. As paper bags not are separated through pre-treatment, they are assumed to contribute to the biogas production. Energy and resource use for construction of the drying facility are not included in the assessment.
C. The system consists of food waste grinders (FWG) in kitchen sinks connected to a pipe system separated from the general wastewater system. Grinded food waste is led to a settling tank divided in three-sections. Supernatant is led to the wastewater treatment plant (WWTP) and settled waste (sludge) is collected by a tank vehicle and transported for further anaerobic biological treatment. Energy use connected to grinding and the environmental impacts related to production of grinders were based on information from producers Annerhall (2010) and Lundie and Peters (2005). The expected lifetime was assumed to 15 years. Losses of organic matter and nutrients from the tank-system could have an effect on the treatment of wastewater in the WWTP. The effect in the WWTP will depend largely on the chosen wastewater treatment process. An increased organic load could increase the energy demand in the WWTP (Bolzonella et al., 2003), but could also decrease the need for external carbon sources. An increased nitrogen and phosphorus concentration in incoming wastewater can improve the C/N-ratio and an improved nitrogen removal as well as a reduced requirement for iron salt for phosphorus removal has been stated as a result of inclusion of food waste disposer in sewage systems (Bolzonella et al., 2003). Thus, the net-effect of WWTP-treatment from food waste grinders is still an area for further investigation. As it is assumed that the loss of nitrogen and organic matter from the tank-system is relatively low, the WWTP-processes are not included in the base case, but investigated in later sensitivity analyses. It is assumed that 10% of the biodegradable matter, N, P and K is lost from the tank system. The removal efficiencies for BOD, N, P and K in the WWTP are assumed to 95, 70, 95 and 0% respectively and non-removed compounds are released to marine waters (Sjölunda, 2009).