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Importance of food waste pre-treatment efficiency for global warming potential in life cycle assessment of anaerobic digestion systems

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ABSTRACT

A need for improvement of food waste (FW) pre-treatment methods has been recognized, but few life cycle assessments (LCA) of FW management systems have considered the pre-treatment with respect to input energy, loss of organic material and nutrients for anaerobic digestion (AD) and/or further treatment of the refuse. The objective of this study was to investigate how FW pre-treatment efficiency impacts the environmental performance of waste management, with respect to global warming potential (GWP). The modeling tool EASETECH was used to perform consequential LCA focusing on the impact of changes in mass distribution within framework conditions that were varied with respect to biogas utilization and energy system, representing different geographical regions and/or different time-frames. The variations of the GWP due to changes in pre-treatment efficiency were generally small, especially when biogas and refuse were substituting the same energy carriers, when energy conversion efficiencies were high and slurry quality good enough to enable digestate use on land. In these cases other environmental aspects, economy and practicality could be guiding when selecting pre-treatment system without large risk of sub-optimization with regards to GWP. However, the methane potential of the slurry is important for the net LCA results and must be included in the sensitivity analysis. Furthermore, when biogas is used as vehicle fuel the importance of pre-treatment is sensitive to assumptions and approach of modelling marginal energy which must be decided based on the focus and timeframe of the study in question.

1. Introduction

European waste management is guided by the waste hierarchy, ranking materials recovery higher than energy recovery. This encourages anaerobic digestion (AD) of food waste, which allows for both energy recovery through biogas production and recovery of nutrients through digestate utilization. In the EU, separate collection of the source separated organic fraction of municipal solid waste (henceforth referred to as food waste (FW)) is encouraged and in Scandinavia this practice is currently being implemented. This brings challenges of choosing best practice in the collection, treatment and recovery chain as to optimize the environmental performance. Life cycle assessment (LCA) is an important support tool for decision making in this context.

FW is a heterogenic feedstock with a total solids (TS) content of 30–40%, and it generally contains contaminants such as plastic, metals and grits. Prior to AD in a conventional wet process, it must therefore, undergo pre-treatment to produce a digestible slurry, separating unwanted components in a refuse fraction, which also contains some part of the digestible material, depending on the selectivity of the pre-treatment. The performance of such pre-treatment methods can be characterized by the mass distribution between the outputs (slurry and refuse), quality of slurry, dilution level, energy input and maintenance costs. A need for improvement of pre-treatment methods to minimize losses of digestible material and nutrients has been recognized (Bernstad et al., 2013). Nonetheless, improved separation efficiency is associated with a risk of compromising the quality of the slurry as well as possible increase in required inputs of energy and manpower.

In general, few life cycle assessments (LCA) of food waste management systems have considered the pre-treatment with respect to input energy, loss of organic material and nutrients for AD and/or further treatment of the refuse (Bernstad and la Cour Jansen,

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2012). It is, however, of importance to investigate the environmental impacts of different efficiencies and the possible consequences on the AD system. Previous LCA studies investigating the environmental impacts of FW pre-treatment efficiency have come to different results regarding the impact of losses of organic material to refuse (Carlsson et al., 2015; Naroznova et al., 2013). These studies were performed as case-studies with special focus on Swedish and Danish conditions, respectively, and were performed using different approaches for modelling marginal heat and electricity. Assumptions of electricity margin, methane yield, and incineration efficiency were identified as important factors for the result. In addition, methodological issues associated with describing mass flows and methane potentials of the FW through pre-treatment were observed.

Each waste management system is associated with its specific framework conditions with respect to technology level, political/economic incentives, infrastructure, energy system and other surrounding systems. For biogas production, the biogas utilization scheme is fundamental (Bernstad et al., 2011; Fruergaard and Astrup, 2011) and is different depending on national incentives, e.g., vehicle fuel production is dominating in Sweden and combined heat and power (CHP) production in Denmark. Moreover, the energy system with respect to source of electricity and heat supply is commonly emphasized as important (Bernstad et al., 2011; Fruergaard et al., 2009; Mathiesen et al., 2009), and the frameworks are in this respect not static but will change over time. Clavreul et al. (2012), outlines the effects of the varying framework conditions on LCA results as scenario/system boundary uncertainty, which should be accounted for by the overall uncertainty assessment. Therefore, generic assessments based on LCA should be used cautiously. However, with its ability to implement a holistic perspective, LCA can provide an understanding of a waste management system in its framework that helps identifying critical aspects and improvement potentials to support decision making.

The objective of this study was to investigate how FW pre-treatment efficiency impacts the environmental performance of waste management based on wet AD, with respect to global warming potential (GWP). Other impact categories were omitted in order to reduce the complexity and maximize the transparency of the study. The impact of changes in mass distribution was analysed within framework conditions that were varied with respect to biogas utilization and energy system, representing different geographical regions and/or different time-frames. Additionally, issues related to the modelling of the main organic waste management variables including waste composition, biochemical methane potential and waste pre-treatment were further investigated.

2. Method

2.1. Scope

The study was performed using consequential LCA, which means that changes in impact potentials induced by changes in the system were modeled. System expansion was used to credit the waste system for changes in production taking place outside the waste system, e.g., by substitution of energy production and use of inorganic fertilizers. The actual technologies affected by changes in the system, i.e., the marginal technologies, were used to model the waste management system (Weidema et al., 1999). The life cycle impact assessment was carried out based on the ILCD2011 recommended methodology (European Commission, 2011), and midpoint impact for global warming (global warming potential, GWP) with 100-year time horizon was evaluated.

The investigation was based on the functional unit defined as "pre-treatment of 1 ton FW intended for biogas production; including AD of the treated biomass, use of biogas, as well as utilization of the pre-treatment and digester residual materials". Waste collection and transportation to the AD plant were not included as this was assumed to be the same in all scenarios. The pre-treatment included pulping with addition of water and subsequent separation with a screw-press into two streams; slurry for biogas production and refuse. This is a method commonly applied for the FW pre-treatment in Scandinavia (Bernstad et al., 2013; Hansen et al., 2007). Five different efficiency scenarios in terms of distribution of organic material between slurry and refuse were considered as detailed later in the paper. Depending on generated slurry quality, two options for utilization of the digester residue – digestate – were distinguished; application on land and incineration. The assumption on quality level was, however, not verified practically. For both digestate utilization options, digestate transportation to a distance of 30 km was included. For slurry digestion, a typical Swedish biogas plant was modeled (detailed further in the paper). Two different biogas utilization options were considered: (A) upgrading of biogas and use as a vehicle fuel and (B) biogas use for combined heat and power (CHP) production. Upgraded biogas was assumed to be used in city busses and substitute diesel. When biogas is used for CHP, use of district heat and electricity marginals is avoided. For the refuse treatment incineration was considered. Avoided use of marginal energy and mineral fertilizers by the refuse and digestate utilization were included. Short-term marginal was identified, i.e., no long-term effects on the existing energy system or capacities. To strengthen the study, variation in energy system regarding district heating and electricity marginals between different geographical regions in Europe and/or time-frames (today and future over 20 years) have been simulated.

The modelling was performed using DTU Environment's LCA model EASETECH (Clavreul et al., 2014) and included use of both default processes available in the model database, e.g., waste incineration and fertilizer application and some developed purposefully for this project, e.g., anaerobic digestion and biogas upgrading. The process inventories cover technology level and practices in Scandinavia and are detailed further in the sections below.

Table 1
Scenarios of varying efficiency in pre-treatment of FW.

	80 ref	70	90	90 dirty	80 high TS
Share of TS (total solids) in the initial waste transferred to the slurry (%)	80	70	90	90	80
Slurry concentration (% TS)	10	10	10	10	15
Slurry quality[a]	Good	Good	Good	Bad	Good

[a] Good quality means the digestate can be used on land, bad quality means digestate is incinerated.

2.2. Scenarios

Five scenarios were defined according to transfer of TS (total solids) from initial waste to slurry, resulting TS percentage in the slurry, and quality of the slurry defined as the suitability for use on farmland (Table 1). The reference case is reflected in scenario 80 ref and corresponds to high efficiency and performance level achieved today. Following Carlsson et al. (2015); 80% of TS was recovered in the slurry, TS content in the slurry was 10% and the slurry contained low amounts of contaminants, allowing the digestate to be applied on land (corresponding to the "good" slurry quality). For the less efficient pre-treatment – scenario 70–10% more of initial waste TS was refused assuming the slurry composition did not change and the quality was still "good". For improved pre-treatment effi-