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Assessment of a combined dry anaerobic digestion and post-composting treatment facility for source-separated organic household waste, using material and substance flow analysis and life cycle inventory

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ABSTRACT

The fate of total solids, volatile solids, total organic carbon, fossil carbon, biogenic carbon and 17 substances (As, Ca, $CaCO_3$, Cd, Cl, Cr, Cu, H, Hg, K, Mg, N, Ni, O, P, Pb, S, Zn) in a combined dry anaerobic digestion and post-composting facility were assessed. Mass balances showed good results with low uncertainties for non-volatile substances, while balances for nitrogen, carbon, volatile solids and total organic carbon showed larger but reasonable uncertainties, due to volatilisation and emissions into the air. Material and substance flow analyses were performed in order to obtain transfer coefficients for a combined dry anaerobic digestion and post-composting facility. All metals passed through the facility and ended up in compost or residues, but all concentrations of metals in the compost complied with legislation. About 23% of the carbon content of the organic waste was transferred to the biogas, 24% to the compost, 13% to residues and 40% into the atmosphere. For nitrogen, 69% was transferred to the compost, 10% volatilised to the biofilter, 11% directly into the atmosphere and 10% to residues. Finally, a full life cycle inventory was conducted for the combined dry anaerobic digestion and post-composting facility, including waste received, fuel consumption, energy use, gaseous emissions, products, energy production and chemical composition of the compost produced.

1. Introduction

In recent years, organic household waste has gained increasingly more attention, and EU recycling targets of 50% (European Parliament, 2008) have only increased this awareness. The amount of biowaste produced annually in the EU is currently between 118 and 138 million tonnes, approximately 70% of which is found in municipal waste (European Commission, 2010). The treatment of this waste varies tremendously across member states, from 100% landfilling to 100% utilisation through waste-to-energy and recycling (Jensen et al., 2016). In the USA and Canada, 28.8 million tonnes of food waste was produced in 2007, 97% of which was landfilled (Levis et al., 2010). Treatment options for organic waste are manifold, including composting, anaerobic digestion, incineration and mechanical and biological treatment (MBT). To choose the best environmental treatment option, a life cycle assessment (LCA) can be a useful tool, and it has been used extensively within the field of waste management comparisons (e.g. Montejo et al. (2013), Kim and Kim (2010) and Jensen et al. (2016)). In order to conduct an LCA, large amounts of data are required, preferably in the form of a life cycle inventory (LCI). LCIs contain key information about direct emissions from processes (such as anaerobic digestion or transportation), products produced during these processes (such as compost or energy) and the use of materials or consumption of energy by the processes. Material flow analysis (MFA) and substance flow analysis (SFA) often form the base of an LCI.

MFAs and SFAs have a wide range of application options and have been used to map material flows on a single process (e.g. Andersen et al., 2010; Naroznova et al., 2016) up to regional (Schmid Neset et al., 2008), national (Bi et al., 2013) and international scale (Ott and Rechberger, 2012). When focusing on facility-specific MFAs and SFAs, both centralised biogas facilities and post-composting facilities have been assessed. Li et al. (2015) made a mass balance study of a full-scale biogas plant running on a rice-wine-pig system, and the study focused on overall wet weight flow and total solid (TS) flow. Additionally, de Araújo Morais et al. (2008) studied the mass balance of a MBT treatment facility and made SFAs for dry matter content (DM), volatile solids (VS) and oxidative organic matter. They used the results to study the efficiency of different treatment steps in the MBT and concluded that improvements could be made. Andersen et al. (2010) studied a

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windrow composting plant treating garden waste, and they used an MFA and an SFA to construct an LCI for the plant. In addition to the LCI, a recommendation for the plant operators to reduce the size of their windrows, in order to improve their environmental performance, was provided. Finally, Zhang and Matsuto (2010) made a comprehensive MFA and SFA study of 11 different composting facilities in Japan, focusing on overall mass flows (waste received, bulking agents, compost and residues), heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) and fertiliser compounds (Ca, K, Na, P). The conclusions were that the facilities' performances depended on the input material, and further research within the field should focus on facilities treating the same input material. Furthermore, material and substance balancing proved difficult, due to missing and unreliable data.

Combining an MFA and an SFA to produce an LCI was done by Andersen et al. (2011) for home composting, who then used the LCI to compare the home composting of organic household waste with incineration and landfilling using an LCA, concluding that home composting was a viable treatment option (Andersen et al., 2012). Naroznova et al. (2013) made an LCA based on an LCI (which was based on an MFA and an SFA) to compare two different pretreatment technologies for source-separated organic household waste, while Yoshida et al. (2013) made an SFA of a municipal wastewater and sludge treatment plant and used this as a basis for tracking the fate of the many different substances entering the treatment plant.

MFA, SFA, and LCI of a combined dry anaerobic digestion and post-composting facility have to the author's best knowledge not previously been carried out. However, the possibility of retrofitting existing MBT plants or composting facilities with a dry anaerobic digestion stage prior to the other treatment has been investigated (Di Maria et al., 2012a, 2012b). Di Maria et al. (2012a) investigated the possibility of retrofitting existing MBT's and composting facilities in Italy with dry anaerobic digestion and found that 52 MBT's and 36 composting facilities were eligible for retrofitting with dry anaerobic digestion as the first part of the treatment. The possibility of retrofitting the existing plants was based on the annual treatment capacities of the facilities (only facilities with a certain capacity was found relevant; >14,000 tonnes a year for composting plants and >25,000 tonnes a year for MBT plants) and did not encounter waste sampling and analysis or MFA/SFA. Di Maria et al. (2012b) investigated the effects of mixing fresh organic material (the organic fraction of municipal solid waste) with inoculum (digested organic material) and saw the highest biogas yields with a mixing ratio of one part fresh organic material with three parts inoculum. The investigation was based on performance of laboratory experiments of organic waste collected in an existing MBT plant in Italy. Pognani et al. (2012) established a complete mass balance of a combined anaerobic/aerobic treatment facility located in Spain. The facility receives source separated organic municipal solid waste and has a treatment capacity of about 25,000 tonnes a year. Pognani et al. (2012) did not undertake proper MFA, SFA and LCI but global mass balances (wet matter) and carbon (C), total nitrogen (N_{tot}), and phosphorous (P_2O_5) inputs and outputs were analysed and the efficiency of the facility assessed by measuring the evolution in respiration indices of the different treatment steps of the facility.

This paper aims at providing a full MFA, SFA and LCI of a combined dry anaerobic digestion and post-composting facility treating source-separated organic household waste. Substance transfer coefficients from the facility were established, making it possible to track substances throughout the facility. To the best knowledge of the authors this has not previously been done, and is highly relevant due to the increased focus on separate treatment of organic waste and division of organic waste from landfilling. The conducted MFA, SFA and LCI can be used to help optimise system performance and provide background information for an LCA.

2. Materials and method

2.1. Field site and system boundaries

This study focused on a combined dry anaerobic digestion and post-composting treatment facility located in the northern part of Germany. The facility treated 45,000 tonnes of source-separated organic household waste in 2014, the reference year for this study (Abfallwirtschaft Rendsburg-Eckernförde, 2015). Source-separated organic household waste is collected through a weekly collection scheme. The waste is received and stored in a receiving hall before it is fed into one of ten anaerobic digestion reactors (with an annual capacity of 30,000 tonnes) or to one of seven composting reactors (15,000 tonnes fresh organic waste annually). The latter is due to current under-capacity for the anaerobic digestion reactors at the facility. The anaerobic digestion reactors and the composting reactors are operated in a batch mode. The waste is in both cases not pre-treated before entering the reactors and no bulking agent is used due to presence of green waste in the received waste. The receiving hall is enclosed and excess air is vented to a biofilter. In the anaerobic reactor, waste material is sprinkled with water using a trickling filter, and any leachate from the waste material is recirculated. The temperature inside the anaerobic reactor is mesophilic at about 38 °C. The temperature is controlled by water recirculation, if the temperature gets too high more water is recirculated. The residence time in the anaerobic reactors is between four and six weeks, depending on different factors such as biogas production. The biogas is mainly produced inside the anaerobic reactors and is collected and burned in a biogas engine on-site to produce electricity and heat. After anaerobic digestion, the wet digestate is mixed with fresh organic waste (two parts digestate and one part fresh organic waste) before entering the composting reactors, inside which the mixture is force-aerated to ensure that aerobic conditions and fast composting are achieved over a residence time of five to seven days. Excess air from the composting reactors is collected and sent to a biofilter. After the composting reactors, the material is laid out in windrows (40 m long, 5 m wide at the bottom and 3 m high) for sanitation and maturation. The windrows are covered with a roof but all emissions are released to the atmosphere. The windrows are turned twice a week with a windrow compost turner until the compost is mature (about eight weeks), following which it is sieved into compost and residues. The turning procedure takes about 1½ hours. The process stability of the anaerobic digestion and post-composting is controlled throughout a range of measurements including temperature, recirculation of water, and ventilation.

The maturity of the compost is controlled during monthly mandatory sampling and analysis, which is used for the annual compost declaration providing information on C/N-ratio, growth of salmonella (no presence in 50 g sample), soluble nitrate (maximum 600 mg/L), and limits on seven metals in accordance with the German law (Prüfkriterien Ral, 2010). In 2012, the C/N-ratio of the final compost was 15, soluble nitrate was 129 mg/L fresh material, no salmonella was found, and all seven metals were below limits, and thus the compost fulfilled the national requirements for compost quality. The compost is sold to farmers as a substitute for conventional fertilisers and soil amendment. The compost is stored in an open hall until it is sold, and the residues are landfilled in accordance with German law (Bundesministerium der Justiz, 2013). Fig. 1 shows the layout of the facility.

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