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Quantification of greenhouse gas emissions from a biological waste treatment facility

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ABSTRACT

Whole-site emissions of methane and nitrous oxide, from a combined dry anaerobic digestion and composting facility treating biowaste, were quantified using a tracer dispersion technique that combines a controlled tracer gas release from the treatment facility with time-resolved concentration measurements downwind of the facility. Emission measurements were conducted over a period of three days, and in total, 80 plume traverses were obtained. On-site screening showed that important processes resulting in methane emissions were aerobic composting reactors, anaerobic digester reactors, composting windrows and the site's biofilter. Average whole-site methane emissions measured during the three days were 27.5 ± 7.4, 28.5 ± 6.1 and 30.1 ± 11.4 kg CH_4 h^{-1}, respectively. Turning the windrows resulted in an increase in methane emission from about 26.3–35.9 kg CH_4 h^{-1}. Lower emissions (21.5 kg CH_4 h^{-1}) were measured after work hours ended, in comparison to emissions measured during the facility's opening hours (30.2 kg CH_4 h^{-1}). Nitrous oxide emission was too small for a downwind quantification. Direct on-site measurements, however, suggested that the main part of the emitted nitrous oxide came from the biofilter (about 1.4 kg N_2O h^{-1}). Whole-site emissions were compared to emissions previously measured at different point sources on-site. Whole-site fugitive emissions were three to eight times higher than the sum of emissions measured at on-site sources. The magnitude of the emissions had a significant influence on the overall environmental impact of the treatment facility, assessed by consequential life cycle assessment. Including the higher whole-site fugitive emissions led to an increase in global warming potential, from a saving of 97 kg CO_2-eq. tonne^{-1} of treated waste (wet weight) to a loading of 71 kg CO_2-eq. tonne^{-1}, ultimately flipping the environmental profile of the treatment facility.

1. Introduction

According to current EU waste policy, as stated by the waste hierarchy, ideally waste generation should be prevented, and what cannot be prevented should be prepared for re-use, recycling, recovering (with priority given to material recovery followed by energy recovery) and as a final option landfilled (Directive 2008/98/EC, article 4, 2008). Diverting specific waste streams away from the waste hierarchy should be justified by life cycle thinking on the overall environmental impacts of the generation and management of such waste.

The European Waste Framework Directive sets the goal of recycling 50% of household waste by 2020 (Directive 2008/98/EC, article 11, 2008). Specifically concerning biowaste, EU member states must take measures to encourage: (a) the separate collection of bio-waste with a view to the composting and digestion of biowaste, (b) the treatment of biowaste in a way that fulfills a high level of environmental protection, and (c) the use of environmentally safe materials produced from biowaste (Directive 2008/98/EC, article 22, 2008). In Denmark, most biowaste is currently incinerated in "state-of-the-art" waste-to-energy plants, substituting the use of fossil fuels but losing important materials and substances, including nitrogen and phosphorous. However, in other European countries, such as Germany, a significant part of the biowaste is separately collected, treated and recycled. Common treatment options in the EU include aerobic composting, anaerobic digestion or a combination thereof. In composing, organic material is stabilised and sanitised to produce compost, which is beneficial to plant growth. Application of compost to soils improves the physical, chemical and biological characteristics of the soil by addition of nutrients and carbon and improvement of the soil structure. In anaerobic digestion, a part of the organic carbon is converted to biogas or biomethane, which can be used for electricity and heat production, or as a transport fuel. A digestate is also produced

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which, like compost, can be applied on land to support plant growth. In the future, the amount of biowaste treated by biological processes is expected to increase, in order to recycle carbon and nutrients contained in the waste material.

The biological treatment of organic waste, however, entails generating various gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO) and ammonia (NH_3). Some of these gases are classified as greenhouse gases (GHGs), thus contributing to global warming. Currently, only very few GHG emission data from biological treatment facilities are available. Recent emission measurements performed at a number of treatment facilities for biowaste (situated at landfill sites) have shown significant methane emissions from biowaste treatment, e.g. the treatment of garden/park waste in open windrows (Mønster et al., 2015; Andersen et al., 2010a). The magnitude of these GHG emissions may impact significantly the overall environmental performance of the treatment facility.

Gas emissions from biological treatment facilities are diffusive by nature and often occur through leakages, ventilated buildings, composting and material storage areas. The diffusive and dynamic nature, together with the large-scale challenge quantification of these emissions. On-site measurement which gauges emissions from various point sources at the facility is the most commonly applied approach (e.g. Daniel-Gromke et al., 2015; Liebetrau et al., 2013; Reinelt et al., 2015; Andersen et al., 2010a). An alternative approach to on-site point measurement is ground based remote sensing, which measures the emission from a distance away from facility and thus gives facility integrated emission numbers (e.g. Andersen et al., 2010a; Yoshida et al., 2014; Flesch et al., 2011; Groth et al., 2015; Hrad et al., 2014).

The main objective of this study was to quantify whole-site methane, nitrous oxide and ammonia emissions from a waste treatment facility in Northern Germany receiving biowaste, by using a mobile tracer dispersion method. Emission factors were estimated relating the measured emissions to the waste material treated and to the compost and methane gas generated. Finally, the contribution of the measured diffusive emissions to the overall environmental impact of the treatment facility was assessed by consequential life cycle assessment considering global warming potential. To the best of the author's knowledge, this is the first time that facility-integrated emission measurements of methane and nitrous dioxide from a biological treatment facility have been conducted using the tracer dispersion method.

2. Materials and methods

2.1. Description of the treatment facility

The biological treatment facility a combined dry anaerobic digestion and post-composting treatment facility located in the northern part of Germany. Fig. 1 provides an overview of the treatment facility, whereas the Fig. SI1 in the Supporting Information (SI) shows a mass flow diagram of the facility. In 2014, the facility treated 45,000 tonnes of wet source-separated organic household waste. The average moisture content of the received waste was 48%. In the remaining part of the paper, given material weights always refers to wet weight (ww). 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 ww) or to one of seven composting reactors (15,000 tonnes ww 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, and any percolate from the waste material is recirculated. The temperature inside the anaerobic reactor is mesophilic at about 38 °C. The residence time in the anaerobic reactors is between four and six weeks, depending on different factors such as biogas production. The biogas is 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 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. No further watering of the material in the composting reactor is needed as the digestate from the anaerobic reactor is sufficiently wet. 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 h. Apart from turning, there is no further regulation of the composting process. The stability of the anaerobic digestion and 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) and soluble nitrate (maximum 600 mg L^{-1}) in accordance with the German law (Prüfkriterien and Ralgz, 2010). The compost stability is measured using the Rottegrade Test, which showed a stability index of IV indicating that the compost is stable. In 2012, the C/N-ratio of the final compost was 15, soluble nitrate was 129 mg L^{-1} fresh material, and no salmonella were found, and thus the compost fulfilled the national requirements for compost quality. A substance flow analysis performed in 2014, showed that during treatment in the combined dry anaerobic digestion and post-composting facility the C/N ratio decreased from 18.4 in the input waste to 9.1 in the mature compost (Jensen et al., 2017). About 23% of the volatile solid (VS) content in the input waste was transferred to the compost, and the compost had a total organic carbon (TOC) content of 10% and a total nitrogen content of 1.5% (both based on the total solid (TS) content) (Jensen et al., 2017). The compost is sold to farmers as a substitute for conventional fertilizers 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 (Bundesministeriums der Justiz, 2013.

In 2014, the production capacity was 18,600 tonnes ww of compost, 4100 tonnes ww of residues, 4781 MWh of heat and 4550 MWh of electricity (Jensen et al., 2017). About 1018 MWh of the heat generated was used for district heating. The biogas production was 2.28 million m^3, with a methane content of 58% vol. About 86% of the generated electricity was sold to the international grid, whereas 21% of the heat generated was used in the local district heating network. The biogas production (50.7 Nm^3 $tonne^{-1}$ ww) of the combined dry anaerobic digestion and composting facility was much lower than typical biogas production plants (around 80 Nm^3 $tonne^{-1}$ ww incoming source separated organic household waste with a methane content of 65%) (Christensen, 2011). This is likely a result of that the facility was operated under under-capacity, which implied that 30% of the waste material

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