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Efficiency of a novel "Food to waste to food" system including anaerobic digestion of food waste and cultivation of vegetables on digestate in a bubble-insulated greenhouse

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ABSTRACT

At urban locations certain challenges are concentrated: organic waste production, the need for waste treatment, energy demand, food demand, the need for circular economy and limited area for food production. Based on these factors the project presented here developed a novel technological approach for processing organic waste into new food. In this system, organic waste is converted into biogas and digester residue. The digester residue is being used successfully as a stand-alone fertilizer as well as main substrate component for vegetables and mushrooms for the first time - a "digeponics" system - in a closed new low energy greenhouse system with dynamic soap bubble insulation. Biogas production provides energy for the process and CO_2 for the greenhouse. With very limited land use highly efficient resource recycling was established at pilot scale.

In the research project it was proven that a low energy dynamic bubble insulated greenhouse can be operated continuously with 80% energy demand reduction compared to conventional greenhouses. Commercial crop yields were achieved based on fertilization with digestate; in individual cases they were even higher than the control yields of vegetables such as tomatoes, cucumber and lettuce among others. For the first time an efficient direct use of digestate as substrate and fertilizer has been developed and demonstrated.

1. Introduction

Roughly one third (approximately 1.3 billion tons) of the food production in the world for human consumption gets lost or wasted (Gustavsson et al., 2011). This accounts for 6–10% of human-generated greenhouse gas emissions (Vermeulen et al., 2012). In Europe and North America alone 95–115 kg of food per person each year (Gustavsson et al., 2011) are wasted. More and more political action is being taken to reduce this amount; 15 the European Union has addressed this topic thoroughly in the Circular Economy Package 16 Action Plan (EU, 2016).

Aside from avoidance measures for organic waste generation anaerobic digestion is a favorable way of utilizing organic waste including food waste. This treatment reduces CO_2 emissions from composting or landfills and the biogas can be used for fossil fuel 20 substitution (Appels et al., 2011; Mata-Alvarez et al., 2000). However, anaerobic digestion still generates some emissions: an evaluation of anaerobic digestion and related carbon footprint Life Cycle Analysis (LCA) shows that treatment and handling of digestate are responsible for a large share of the CO_2 equivalent emissions (mainly as methane and nitrous oxide) (Chiew et al., 2015; Rehl and Müller, 2011). According to LUBW (2010) in the case of anaerobic municipal organic waste treatment plants storage, treatment and land application are responsible for about 50% of the total CO_2 equivalent emissions related to the whole organic waste collection and treatment chain. Making use of the digestate directly and locally in a more closed system can therefore potentially improve the footprint of the anaerobic digestion value chain. Moreover, substituting fertilizers and peat with digestate and compost, and applying CO_2 and excess heat in the greenhouse, will add to the overall environmental performance (Halmann and Steinberg, 1998).

For future urban sustainability it is necessary to develop integrated processes, which can be part of a circular bio-economy. It

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has been proven in projects worldwide that we can generate energy from waste (Tuck et al., 2012). However the challenge still remains of simultaneously recycling the nutrients from the waste. A controlled horticulture environment could do this without losses. The greenhouse horticulture sector is the ideal sector for improving the conversion rate of organic waste into food. The output of greenhouse horticulture per hectare is higher than open farming; the climate and growing conditions are protected and controlled (Heuvelink et al., 2008). This higher and controlled output is very well suited for local production - independent of the availability of agricultural land, additional fertilizers and challenges resulting from an unpredictably changing climate (Kulak et al., 2013).

Fresh and untreated digestate is anaerobic liquid slurry containing plant toxic substances, a very high electrical conductivity (EC) and chemical oxygen demand (COD). Garden waste compost may provide the necessary structure for a plant growth medium, as well as necessary nutrients in the first stage of cultivation (Hernández et al., 2016).

Subsequently, digestate could provide the additional demand of nutrients in the later stages of cultivation. Thus, digestate could be a perfect complement for garden waste compost, but its properties would have to be modified. The greenhouse system described here was developed based on knowledge from existing hydroponic/aquaponic growing systems and organic fertigation. In hydroponic systems plants are cultivated in water without a soil based substrate (Thiyagarajan et al., 2007). In aquaponics this is combined with aquaculture where aquatic animals are grown in the water and their excrements are used directly as fertilizer for the plants (Diver, 2006). Based on the fact that only digestate is used as a nutrient supply in a similar system we have termed this "digeponics".

However, greenhouses often have poor energy and water performance as well as a high carbon footprint. According to a study from Verheul and Thorsen (2010), which monitored more than 10 typical up-to-date greenhouses in Norway, CO_2 equivalent emissions were 53–92% (cucumber) and 93% (tomato) from the energy supply (mainly heat) and 4% (cucumber) and 5–8% (tomato) from peat application. For potted plants production emissions of the CO_2 equivalents is up to 50% from the energy supply and about 30% from peat utilization. Energy and peat utilization alone are mainly responsible for the high carbon footprint of horticultural products.

Moreover an additional important factor for the carbon footprint of greenhouse grown vegetables is caused by transportation and cooled storage (Garnett, 2006). When vegetables are grown centrally in large greenhouse complexes transport results in about 300 g/ton km CO_2 equivalent emissions. Therefore the reduction of transportation needs has a substantial impact on the overall environmental performance. Thus, the presented project focuses on a solution with very short transport distances within a town by creating the direct loop from food to waste to food.

The "Food to Waste to Food" project (F2W2F) has developed an integrated system aimed at greatly improving this situation and addressing the challenges described above. It focuses on peat and fertilizer substitution and largely reduced energy consumption. The project demonstrates a closed cycle organic waste to energy and food system, which is the integration of food waste treatment, biogas digestion, growing crops with the digester residue and a new closed dynamic bubble-insulated greenhouse technology. The complete system has been built at small scale in Drammen, Norway and is the basis for the results presented. Some initial insights were given in previous research by Stoknes et al. (2013). An up-scaled commercial size bubble-insulated greenhouse is now in operation in Poznan, Poland.

2. Materials and methods

2.1. Overall concept

The overall concept followed in the F2W2F project is illustrated in Fig. 1.

A full cycle of organic material is demonstrated. Source separated organic waste from municipalities (food waste) and organic residues from horticulture (garden waste) are processed to digestate and compost. In different investigated process steps such as vermicomposting, conditioning and mixing, substrates and nutrient solutions for vegetable and mushroom growth were developed and applied in the novel bubble insulated greenhouse using a digeponics system. Energy from the anaerobic digestion process and exhaust from biogas utilization can be used for greenhouse energy and CO_2 supply.

Fig. 1. Visualization of the overall concept for the F2W2F project.