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Decentralized utilization of wasted organic material in urban areas: A case study in Hong Kong

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ABSTRACT

Urban areas, characterized as areas with a high population density, generate large amounts of liquid and solid waste streams. Without proper treatment, these waste streams accumulate in the environment of urban areas and may lead to serious environmental problems. Contrarily, waste streams and particularly wasted organic materials contain valuable compounds, which can be biologically and/or chemically converted into products to cover the economic needs of urban areas. In this study, a concept is presented that contributes to treatment and utilization of wasted organic material in a way to (1) avoid environmental problems, (2) exploit its potential and (3) establish a recycling. In this context, technical aspects, such as hydrolysis, waste reduction, integration in urban structures and recycling of wasted organic matter, were discussed. An example of waste utilization is given based on the organic waste stream generated by a common building in Hong Kong with 640 residents. The 640 residents would generate more than 250 kg of wet organic waste per day, which can be biologically hydrolyzed using decentralized processes on site. The hydrolysis of 250 kg wet organic waste would result in the production of 33 kg glucose, 15 kg lipids, 0.6 kg free amino nitrogen and 0.2 kg phosphate, which can be used as nutrients in biotechnological processes or feedstocks in chemical reactions for the production of food, feed, chemicals and materials. Recycling of organic matter is not only a sustainable waste treatment, but contributes to the economy and self-sufficiency of urban areas in resource supply.

1. Introduction

Urban areas are characterized as areas with a high population density and strong nutrient inputs in form of food, feed and fertilizer (Faerge et al., 2001). Most of the introduced nutrients appear in form of solid and liquid waste streams. Without proper treatment, these waste streams accumulate in the environment of urban areas and may lead to serious environmental problems. Waste streams and particularly wasted organic materials, however, contain valuable compounds, which can be biologically and/or chemically converted into products to cover the demand of urban areas for food, chemicals, materials, fuels, power and heat (Gajdoš, 1998; Zhang et al., 2007; Leung et al., 2012; Arancon et al., 2013; Luque and Clark, 2013; Pfaltzgraff et al., 2013; Pleissner et al., 2013, 2014b; Zhang et al., 2013; Karmee and Lin, 2014).

By weight, 70% of municipal solid waste, which originates from households, institutions and commercials such as offices, schools and hotels, consists of organic material (Albanna, 2013). In Hong Kong, 40% of municipal solid waste is food waste, containing all kinds of food, such as cereals, roots and tubers, oilseed and pulses, fruits and vegetables, meat, seafood, milk and eggs (Hong Kong SAR Environment Bureau, 2013). The total global amount of food waste produced between agricultural production level and consumer level corresponds to more than 1.3 billion t per year (FAO, 2011; Gustavsson et al., 2011, 2013). Half of the global population lives in urban areas, and thus urban areas produce large amounts of unused food, which needs to be treated and/or disposed. Furthermore, the population of megacities, defined as cities with more than 7 million inhabitants, is estimated to increase by 280,000 people per day (OECD, 2006). Therefore, innovative treatment strategies are needed to minimize the environmental impact of waste streams, make use of the potential of waste material and increase the life quality of citizen in urban areas.

Treatment processes of organic municipal solid waste include mainly deposition, composting, anaerobic digestion or incineration (Crowe et al., 2002). These processes lead to heat or fertilizer (Gajdoš, 1998; Takata et al., 2013). However, the treatment of wasted organic material might be problematic in areas with limited space for waste disposal and composting, or limited public acceptance of waste incineration. Furthermore, in Germany untreated biologically degradable waste is banned from being disposed in

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landfill sites since 2005 (Hempen, 2005). Prior to disposal, organic material needs to be deactivated in order to avoid uncontrollable biological activities resulting in the production of gases and contaminated leachates in landfill sites (Białowiec, 2011). The large amount of organic material wasted in urban areas and elsewhere, however, should not be considered as unwanted, but as valuable source of carbon, nitrogen and phosphorus compounds. This means in the perspective of waste management that conventional waste treatments should be substituted by effective waste utilization processes. Utilization in this aspect may include the hydrolysis of wasted organic materials and utilization of the hydrolysate. By this approach, organic compounds can be recycled in products to partly cover the economic needs of urban areas (IEA, 2008; Lehmann, 2011).

In order to make organic compounds in waste streams available, concepts are required to treat and utilize wasted organic materials in a way to (1) avoid environmental problems, (2) exploit their potentials and (3) establish a recycling. Therefore, the aim of the present study was an identification of technical aspects of processes for an effective utilization of wasted organic material in densely populated areas for the recovery and recycling of nutrients in products. The focus was particularly on decentralized processes, which can be integrated in urban structures.

In this study, the term "food waste" refers to industrial, commercial and domestic mixed food residues, bread and other bakery wastes meant for human consumption. Contrarily, the term "organic waste" refers to those waste matters generated by households and containing edible and inedible materials. "Yard waste" describes plant biomass (e.g. grass clippings, leaves and bushes) and the term "wasted organic material" refers to food, organic and yard wastes.

2. The potential of wasted organic material as nutrient and energy source

Due to the great demand for fertilizers, water and energy of food production, transportation and processing, it is suggested here that wasted food should not be considered as a sustainable renewable resource. Cuéllar and Webber (2010) estimated the energy demand for food production, transportation, processing and handling in the United States (U.S.) at 8080 trillion BTU in 2007. Gunders (2012) summarized the demand of land, energy and water for food production in a short and impressive sentence. "Getting food from the farm to our fork eats up 10 percent of the U.S. energy budget, uses 50 percent of U.S. land, and swallows 80% of all freshwater consumed in the United States". This statement may not only apply for the U.S., but for many countries worldwide. Cuéllar and Webber (2010) considered in their estimation that 27% of the energy initially spent on food production, accounting for 2030 trillion BTU, was wasted in U.S. in 2007. This value corresponds to 43.7 million t of food waste. The heating value of food wastes was estimated at 5.9 million BTU t^{-1} (Melikoglu et al., 2013). By applying this value it can be calculated that 257.8 trillion BTU or maximal 3.2% of the energy initially spent on food production can be recovered by incineration. The net-energy output, however, is lower as process efficiency and energy required for waste handling and processing need to be considered and subtracted. Due to the potential of wasted organic materials to serve as feedstocks in the production of food, feed, materials and chemicals, a utilization strategy should follow the cascading principle and an energetic use should, if wanted, occur at the end of the utilization chain.

Pleissner et al. (2014a, 2014c) reported a variable composition of mixed restaurant food waste of 450–750 mg g^{-1} total carbohydrates, 300–600 starch mg g^{-1}, 50–100 protein mg g^{-1} and 70–400 mg g^{-1} lipids. Those compounds are particularly important when it comes to a utilization of food waste in fermentation processes. Carbohydrates and proteins can be hydrolyzed to glucose and amino acids, respectively, and together with phosphate metabolized by many microbes (Leung et al., 2012; Pleissner et al., 2013; Zhang et al., 2013; Lau et al., 2014; Pleissner et al., 2014b). Furthermore, the hydrolysis of food waste contributes to waste reduction. This approach is certainly more effective in the sense of sustainable waste treatment than disposal in landfill sites, where the potential of the material remains unused.

In agriculture, nutrients such as phosphorus are urgently needed to maintain and increase the productivity of arable land. Pleissner et al. (2014c) quantified 1.9 mg phosphorus in 1 g (dry weight) of mixed food waste collected from restaurants in Hong Kong. The urban area Hong Kong is known for the daily production of large amounts of food waste. Around 3600 t wet food waste was daily produced in 2011 (Hong Kong SAR Environment Bureau, 2014). Assuming a dry matter of food waste of 50% (unpublished result) and applying the phosphorus content of mixed restaurant food waste, around 3.0 t of phosphorus is daily dumped in Hong Kong in form of unused food. This value corresponds to more than 1000 t phosphorus dumped every year. This large amount sounds reasonable if one compares it to the 125 t of phosphorus dumped in form of food waste in Gothenburg (Sweden) per year, a city that is in terms of its population approximately 14 times smaller than Hong Kong (Kalmykova et al., 2012). Hong Kong and Sweden, however, are comparable in terms of their organic waste generation rate (Hong Kong SAR Environment Bureau, 2014; Swedish Environmental Protection Agency, 2014).

Food waste in urban areas is generated by restaurants, institutions, schools and domestic sources. Contrarily to the quantified composition of mixed restaurant food waste by Pleissner et al. (2014a, 2014c), which contains only edible material, organic waste generated by households may contain edible and inedible material (e.g. peels). In Taipei City and Seoul, 0.2 kg of organic waste is generated per capita and day, while in Hong Kong, 0.4 kg organic waste is produced per capita and day (Hong Kong SAR Environment Bureau, 2014). Due to its variable composition, the weight specific contents of carbohydrates, starch, proteins, lipids and phosphorus in organic waste are difficult to estimate. In order to illustrate the potential of organic waste generated by households a dry weight composition of 550 mg g^{-1} carbohydrates (including 400 mg g^{-1} starch), 119.1 mg g^{-1} lipids, 54 mg g^{-1} proteins and 110.3 mg g^{-1} minerals (including 1.9 mg g^{-1} phosphorus) was assumed under consideration of the composition of food and organic wastes reported by Pleissner et al. (2014a, 2014c) and Matsakas et al. (2014), respectively. In Fig. 1, the generation of organic waste by a common apartment building with 640 residents in Hong Kong per day is shown. The 640 residents would generate 256 kg wet organic waste per day, which possesses a large amount of carbohydrates, starch, lipids, proteins, minerals and phosphorus. Thus, there is a potential demand of decentralized organic waste treatment and utilization processes, which are integrated in urban structures and contribute to waste reduction and recycling.

Organic waste collection and storage in densely populated areas may result in odor pollution, negatively affecting the life quality of citizen. Therefore, a collection system and appropriate logistics need to be implemented preventing this problem. Odor pollution might be prevented when storage time of organic waste is minimized by immediate hydrolysis. After hydrolysis, the hydrolysate and remaining solids are separately stored in airtight containers. This would make the development of an efficiently, effectively and continuously working hydrolytic process necessary.

Furthermore, in Hong Kong 127 t of yard waste, including grass clippings, leaves, bushes, shrubs, woods, etc., is produced per day, which additionally could be utilized (Hong Kong SAR Environment Bureau, 2014).