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Research article

Carbon footprint of urban source separation for nutrient recovery

H. Kjerstadius [a, *], A. Bernstad Saraiva [b, c], J. Spångberg [d], Å. Davidsson [a]

[a] *Water and Environmental Engineering, Department of Chemical Engineering, Lund University, P.O. Box 124, 221 00 Lund, Sweden*
[b] *SAGE/COPPE, UFRJ, Rio de Janeiro, Brazil*
[c] *SAGE/COPPE, UFRJ, Centro de Gestão Tecnológica - CT2, Rua Moniz de Aragão, no. 360 - Bloco 2, Ilha do Fundão – Cidade. Universitária, Rio de Janeiro, RJ 21.941-972, Brazil*
[d] *Swedish University of Agricultural Sciences, Department of Energy and Technology, Box 7032, 750 07 Uppsala, Sweden*

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ABSTRACT

Source separation systems for the management of domestic wastewater and food waste has been suggested as more sustainable sanitation systems for urban areas. The present study used an attributional life cycle assessment to investigate the carbon footprint and potential for nutrient recovery of two sanitation systems for a hypothetical urban area in Southern Sweden. The systems represented a typical Swedish conventional system and a possible source separation system with increased nutrient recovery. The assessment included the management chain from household collection, transport, treatment and final return of nutrients to agriculture or disposal of the residuals. The results for carbon footprint and nutrient recovery (phosphorus and nitrogen) concluded that the source separation system could increase nutrient recovery (0.30–0.38 kg P capita^{-1} year^{-1} and 3.10–3.28 kg N capita^{-1} year^{-1}), while decreasing the carbon footprint (−24 to −58 kg CO$_2$-eq. capita^{-1} year^{-1}), compared to the conventional system. The nutrient recovery was increased by the use of struvite precipitation and ammonium stripping at the wastewater treatment plant. The carbon footprint decreased, mainly due to the increased biogas production, increased replacement of mineral fertilizer in agriculture and less emissions of nitrous oxide from wastewater treatment. In conclusion, the study showed that source separation systems could potentially be used to increase nutrient recovery from urban areas, while decreasing the climate impact.

1. Introduction

The urban metabolism of materials and energy has received increased attention due to the global trend of urbanization. Therefore, the energy-water-food nexus is of increasing importance (Villarroel Walker et al., 2014), especially in regards to wastewater management, which is facing increased needs for efficiency and sustainability (Libralato et al., 2012). In Sweden, work to increase the sustainability of wastewater management includes the return of nutrients from wastewater back to agriculture to be used as fertilizer. Such a return would decrease the need for mineral fertilizer and the associated impact on climate change from its production and transportation (Brentrup and Pallière, 2008; IFA, 2009). Today, the main return of nutrients from urban wastewater is conducted via sludge from wastewater treatment plants. The Swedish environmental protection agency (SEPA) is working on a more stringent regulation for the handling of wastewater sludge (SEPA, 2013). Their latest regulation proposal includes targets for the return of 40% of the phosphorus and 10% of the nitrogen from wastewater to agriculture (SEPA, 2013). However, the use of sludge in agriculture is heavily debated (Bengtsson and Tillman, 2004), and only 25% of the produced sludge in Sweden is currently returned to agriculture (Statistics Sweden, 2016). Considering only approximately 20% of the nitrogen that enters wastewater treatment plants ends up in the sludge (Siegrist et al., 2008), reaching the proposed targets of nutrient recycling would be challenging with today's conventional system.

It has been suggested that source separation systems could be an alternative to the conventional sanitation management of domestic wastewater and food waste (Meinzinger, 2010; Hillenbrand, 2009; Otterpohl et al., 2003). In source separation systems, toilet wastewater (blackwater), other household wastewater (greywater) and food waste are separated from other urban waste and wastewater flows. Separated streams could potentially be treated more efficiently at a wastewater treatment plant and yield increased biogas production and nutrient recovery (Kjerstadius et al., 2015).

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* Corresponding author.
E-mail address: hamse.kjerstadius@chemeng.lth.se (H. Kjerstadius).

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Such an increase in nutrient recovery could make it possible to reach the proposed targets for phosphorus and nitrogen recovery in Sweden. Additionally, it could possibly decrease the carbon footprint (Weidema et al., 2008) of sanitation management, which would facilitate reaching the existing Swedish national environmental objectives for climate change (Nykvist et al., 2013). However, although several pilot areas with source separation systems are under construction in Europe (Skambraks et al., 2017) and international work on the corresponding climate impact exists (Thibodeau, 2014; Witteveenbos, 2014; Meinzinger, 2010; Remy, 2010; Hillenbrand, 2009), there is a lack of up to date research regarding the impact for an area with low emission energy generation, such as Sweden. The impact in Sweden, due to its hydropower and biofuel based electricity and heat production, could likely be different from more fossil fuel dependent European countries. Thus, an investigation of source separation systems in a Swedish context would generate useful results on the suitability of the source separation for urban areas with a higher degree of renewable energy generation. For this purpose, a Life Cycle Assessment (LCA), looking at the environmental impacts during the entire life cycle of the system, would be suitable. LCAs were previously used to identify the environmental impacts of wastewater management (Corominas et al., 2013; Lim and Park, 2009), as well as the carbon foot print of Swedish wastewater treatment plants (Gustavsson and Tumlin, 2013) and food waste management (Bernstad and la Cour Jansen, 2012). Thus, LCA methodology would be suitable to give further insight in to both the potential for nutrient recovery and the associated carbon foot print of source separation systems, as well as a comparison to a conventional management system of today.

The aim of the present study was to identify the carbon footprint of two studied sanitations systems, as well as their potentials for nutrient recovery to agriculture. The goal was to obtain conclusions in regards to what parts of the management chain are more important to decrease climate impact. Such information would be most beneficial to municipal water utilities and policy makers, who plan city infrastructure with a long-term perspective.

2. Methods

2.1. General method

The study considered a hypothetical development of a greenfield urban area in a city in southern Sweden. The entire infrastructure for food waste and wastewater management was considered to be built from scratch. The time span for the study was 50 years, as this was the longest technical life span of any infrastructure component included in the study (namely sewer systems); this time span was also used in similar studies (Thibodeau, 2014; Witteveenbos, 2014). The impacts from infrastructure were evenly divided over the time span. Attributional lifecycle inventory (LCI-modeling) was used based on the ILCD Handbook (EC, 2010) and a similar study (Remy, 2010), as the study was aimed at decision support, and no large-scale consequences on processes in the background system were expected from the decisions.

2.2. Scope and functional unit

The study scope was the management and recovery of energy and nutrients from household wastewaters (blackwater, greywater and food waste). The functional unit (FU) was the management of 1 capita yearly load of food waste (FW), blackwater (BW) and greywater (GW), according to Eq. (1). Similar FUs were also used in studies by Thibodeau (2014), Remy (2010) and Hillenbrand (2009). Management was defined as the collection, treatment and disposal in accordance with Swedish laws and regulations. Furthermore, discharge limits for wastewater treatments plants (WWTPs) were assumed to be 10 mg N L^{-1} and 0.5 mg P L^{-1}.

$$FU = \frac{Management\ of\ 1\ capita\ load\ of\ FW,\ BW\ and\ GW}{year} \tag{1}$$

2.3. System boundary and impact categories

The study included only domestic wastewaters (blackwater and greywater) and sorted food waste (the fraction of food waste collected separately from other waste). Other wastewaters, such as stormwater, industrial wastewater and other waste, were not included, due to the local variations of these streams (Remy, 2010). The assessment boundary for each system (Fig. 1) included the infrastructure and operation for collection, transport, treatment and nutrient recovery, as well as the spreading of sludge in agriculture or the use of sludge as a soil improver. The emissions to water or air were considered from several processes (striped clouds in Fig. 1). In general, all stationary infrastructure was included, whereas no infrastructure for transports was considered. Management services (such as needed personnel) were not included, and the end-of-life treatment of infrastructures was not included since its impacts were previously shown to be negligible (Hillenbrand, 2009). System expansion was used to investigate the potential climate benefits related to the use of biogas and nutrients recovered from waste fractions. The potential for reuse of treated greywater in the source separation systems was not included based on previous studies either not including it (Thibodeau, 2014; Witteveenbos, 2014; Hillenbrand, 2009), stating it to be of minor energetic importance (Remy, 2010) or not specifically calculating its benefit (Hillenbrand, 2009). However, it should be mentioned that reuse of treated greywater is considered for at least one of the currently planned pilot areas with source separation in Europe (Skambraks et al., 2017) and thus may be more important in the future. The details of the included and excluded processes are given as supplementary information (SI_2).

Results were considered for the parameters given in Table 1. These parameters covered nutrient recovery to agriculture or the carbon footprint, the latter being a parameter used to estimate climate impact (Weidema et al., 2008). The return of nutrients was calculated with the mass balances presented below. The carbon footprint was calculated through the lifecycle impact assessment (LCIA) method ReCiPe for climate change (ReCiPe, 2016). The characterization factors for the midpoint category global warming potential (GWP 100) in this method were based on Forster et al. (2007). The results for the additional parameters can be found elsewhere (Kjerstadius et al., 2016).

2.4. System description and data collection

The study covered two systems. The conventional system represented a typical Swedish sanitation system for food waste and wastewater, and the second system was a source separation system. Both systems were based on Kjerstadius et al. (2015), with minor updates to the mass balances presented in the supplementary information (SI_1), as well as in greater detail by Kjerstadius et al. (2016). The conventional system was 120 000 capita, and the source separation system was 12 000 capita. This represented a scenario in which the conventional system was given the benefit of scale, whereas the source separation system have to be gradually implemented in the urban area. All of the data are presented as supplementary information (SI_1 and SI_2).