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Source separation: Challenges & opportunities for transition in the swedish wastewater sector

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ABSTRACT

A paradigm shift to waste reuse has started in the wastewater sector with many experts calling for greater resource recovery, often facilitated by alternative solutions such as source separation. Source separation has been shown to be advantageous for improving treatment capacity, food security, and efficiency; yet these systems are still immature, considered risky by professionals and scarcely implemented. This study attempts to answer the question of why source separation is still marginalized by examining the Swedish experience with source separated wastewater from the perspective of Technology Innovation Systems (TIS) in order to identify obstacles and policy recommendations. Considering that source-separation is still in a development phase, the study found that source separation works moderately well within the on-site niche and that blackwater systems in general perform better than urine diversion. Knowledge development is found to be the weakest function. A major blocking mechanism is the weakness of interchange between knowledge development and entrepreneurial activity. Policy recommendations include: increased R&D; building networks and communication platforms; and establishing guidelines for technologies, legislation interpretation and organizational models.

1. Introduction

Given the global environmental crisis with extensive pollution from natural and anthropogenic substances there is an ever increasing need to consider all waste products as potential resources. Particularly with regard to nutrients, there is a growing shift away from discharge management to holistic resource management. The biogeochemical flows for nitrogen (N) and phosphorous (P), which lead to eutrophication, have been identified by scientists as part of the critical planetary boundaries, which define a safe operating space for keeping Earth's environmental system processes in a hospitable balance (Steffen et al., 2015). While overuse of agricultural fertilizers is primarily responsible for this imbalance, N and P flows in wastewater are significant. A study of phosphorus flows in Sweden found wastewater to be the second largest internal phosphorous flow after manure (Swedish EPA, 2013), making wastewater management a critical part of maintaining balance in the planetary boundaries. In addition, wastewater treatment (or lack of it) also contributes to chemical pollution and climate change, through energy consumption, two other planetary boundaries under threat. For example, the majority of commercial nitrogen fertilizers are produced through the energy- intensive Haber-Bosch process (Galloway et al., 2008). This nitrogen ends up in food products and eventually in wastewater flows where conventional wastewater treatment plants consume large amounts of energy to remove it. Recovery of these nutrients from wastewater could significantly offset the need for chemical fertilizer use, reduce nutrient loading on the environment and reduce climate change impacts.

The paradigm shift to waste reuse has started with many experts calling for greater resource recovery (Guest et al., 2009), often facilitated by alternative solutions such as source separation (Larsen et al., 2009). While separate collection and processing of different solid waste fractions (e.g. glass, metals, biodegradables) in order to enable recycling has become standard practice in solid waste management, it is less common for liquid waste fractions (i.e. wastewater). The majority of nitrogen, phosphorus, and other

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nutrients found in wastewater come from human urine and feces. Human excreta also contain a majority of the pathogens, pharmaceuticals and organic micro-pollutants which need to be removed from wastewater. Source separation of wastewater flows, such as blackwater (i.e. wastewater from toilets) and urine, captures concentrated nutrient-rich waste which makes nutrient recovery and pollutant removal more efficient (Larsen et al., 2004, 2009). When these nutrient-rich flows, after appropriate treatment, are recycled into crop production the eutrophication risk is also decreased, since the nutrient-rich flows of the wastewater are kept out of water courses (Jönsson, 2001). In addition, source separation has been shown to be advantageous for contributing to food security (Cordell et al., 2011), and improving the capacity and efficiency of treatment plants, e.g. through peak shaving (Borsuk et al., 2008). At the same time, there are significant limitations to promoting resource recovery within conventional wastewater systems. Difficulties for reuse from conventional centralized wastewater system include: loss of nitrogen in current nitrogen removal processes; sludge that only captures a fraction of the total nutrients, with the exception of phosphorus (if P precipitation is used); and difficulty in maintaining high quality sludge due to contamination of mixed wastewater with heavy metals, organics and other pollutants (Batstone et al., 2015). Conventional methods are optimized for nutrient removal from wastewater and not for nutrient recycling. In addition, large sunk costs in infrastructure make it difficult to introduce new technological improvements as they become available (Cordell et al., 2011). Despite their potential advantage source separating systems are thus, often ignored or dismissed in planning processes within wastewater jurisdictions and are only marginally applied in the world today (Etnier et al., 2007). This study attempts to answer the question of why this is the case.

Sweden has, over the years, developed extensive experience with source separation, mainly from on-site systems in areas outside existing wastewater jurisdictions. In Sweden, approximately 9% of the population have permanent dwellings with on-site systems (SCB Statistics Sweden, 2014) and around 2% (>20% of one-site market) source-separate urine and/or blackwater (Ek et al., 2011). Source-separation systems serving multiple households do exist, but are mainly found in a few eco-villages and demonstration sites. Source-separation systems are also common in summer houses, most often as part of dry toilet systems. In 2006, it was estimated that there were at least 120 000 urine-diversion (UD) systems in Sweden; the vast majority found in summer houses and involving dry fecal handling, and an estimated 15 000 of them using flushing toilets (Kvarnström et al., 2006). In addition, it is estimated that there are several tens of thousands of blackwater separation systems today, mostly in densely populated rural areas (Vinnerås and Jönsson, 2013).

The modern Swedish experience with source separation started in the early 1990s, with a grassroots' movement towards urine diversion systems in eco-villages. The main actors during this time were environmentalists, local eco-village cooperatives, innovators, and a few interested farmers. By 1997, housing companies, researchers and politicians had become interested in source separation technology. The national political party in power at the time, the Social Democrats, introduced the idea of "The Green People's Home", playing on the concept of The People's Home ("Folkhemmet") which was fundamental for the development of the Swedish welfare state after the Second World War. This high-level political support resulted in several investment programs in green technology and approaches, as well as, the formulation of a number of Environmental Quality Objectives. Housing companies tried out urine diversion systems in apartment complexes/row houses within existing wastewater jurisdiction in pilot projects, and several interdisciplinary research projects generated important knowledge on source separation systems and reuse of urine in agriculture (e.g. Johansson et al., 2000; Kvarnström et al., 2006; Schönning et al., 2004).

Yet the beginning of the 2000s saw a backlash for source separation in Sweden. Not enough emphasis had been put on ensuring a functional system from collection to reuse in the pilots during the 1990s. Another challenge was that the lack of emphasis on technological development to address technical problems revealed in the pilot projects' first generation of water-flushed urine diversion toilets. A study of two pilot project installing urine-diversion toilets in apartment building (Stångåstaden in Linköping and Ekoporten in Norrköping), for example, found that the housing companies operating the systems had problems finding ways to reuse the urine and struggled to organize management of the systems (Nilsson, 2014). In both cases, the toilets were changed to conventional flush ones after a few years. The fate of these cases is similar to many urine diversion projects in Sweden. Systems which failed to organize recycling of the urine ended up lacking an incentive (environmental benefits) to provide the extra maintenance required and thus, a majority were converted to conventional flush systems after 5–10 years (Vinnerås and Jönsson, 2013). It is worth noting that the only systems that are still in use are the ones that actually used the urine as a fertilizer.

Attempts to implement source separation in urban areas have also proven difficult, particularly when it is compared with existing infrastructure systems. For example, evaluation of a pilot blackwater separation system with decentralized membrane treatment in Gothenburg found that the system recovered a significantly higher grade of nutrients than sewerage sludge, however, due to the calculated high costs it was recommended not to continue with blackwater separation systems in Gothenburg (Karlsson et al., 2008). A comparative study of alternative systems for wastewater management in Gothenburg also concluded that high investment costs and energy consumption in blackwater systems made it less attractive compared to source-control efforts to improve sludge quality at the central wastewater treatment, particularly if the main goal is to recover phosphorus but not the other nutrients (Göteborg Stad, 2007). There are also uncertainties regarding the advantages of source separation since life-cycle assessments show that source separation is advantageous in certain impact categories, but performs worse than advanced WWTPs in others (Spångberg et al., 2014; Tidåker et al., 2007). In general, the major challenges with implementing source-separation systems at scale within wastewater jurisdictions have initially been the additional capital costs, but more recent literature also show that legal and institutional uncertainties (e.g. lack of national objectives regarding reuse of nutrients), lack of capacity and organizational challenges are also major barriers (Christensen, 2013; Nilsson, 2014).

Despite the backlash and difficulties implementing urban source separation systems, interest in and the number of source-separating systems in Sweden is still growing, although at a slower rate than in the 1990s (Vinnerås and Jönsson, 2013). During the last decade there has been a renewed interest in source separation in Sweden, backed by changing regulation for on-site sanitation systems which has shifted the focus to function rather than being technology prescriptive. That fact that one of these functions is nutrient recycling has opened up the on-site sanitation market in Sweden for new alternatives. Several municipalities today offer collection, treatment and reuse of nutrient-rich fractions such as blackwater or urine. There are also municipalities, such as Helsingborg and Stockholm, where source separation with new technologies are being investigated and explored within existing wastewater jurisdictions in planned development areas.

Given the continuing interest and environmental motivations for source separation, there is a need for a more holistic understanding of the relative strength of this innovation and its potential for integration within the existing wastewater regimes. The aim of