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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.

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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

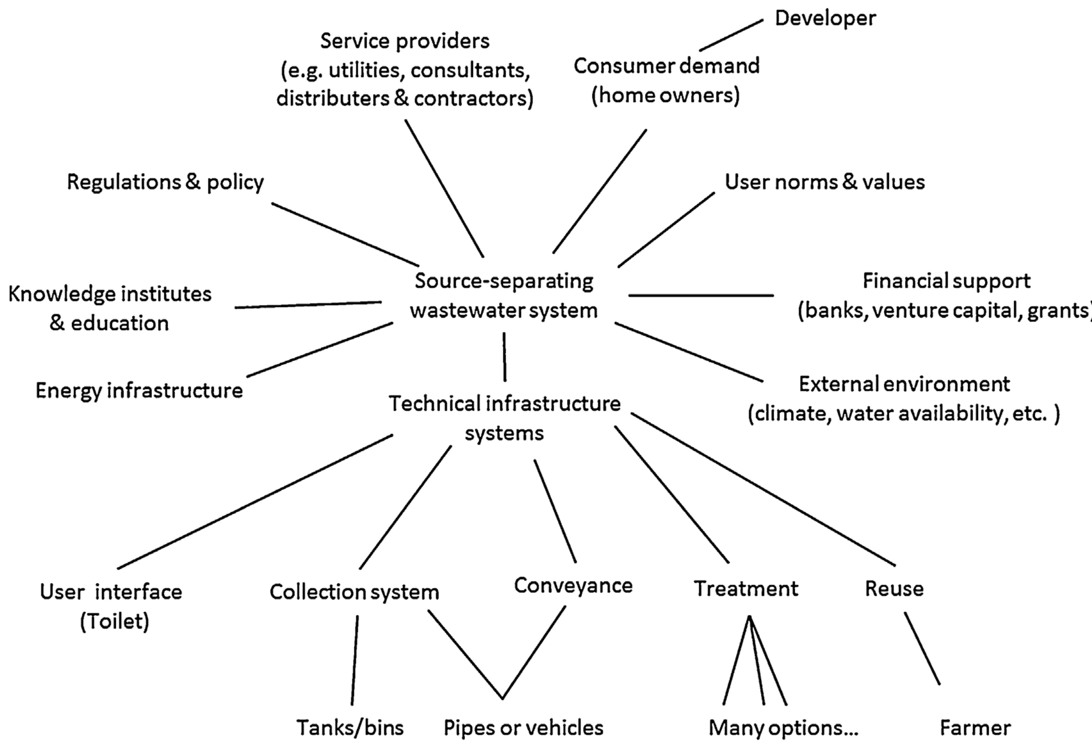

Fig. 1. Structural components of the sociotechnical system of source-separating wastewater systems.

this study is thus, to fill this knowledge gap by assessing the status of source-separating technologies in Sweden based on a transition theory perspective and identify where there may be "windows of opportunity" to scale-up implementation and where there may be blocking mechanisms hindering expansion.

2. Methods

This study uses methodology from Technological Innovation Systems (TIS) for analyzing the development of source-separating wastewater treatment technologies in Sweden which return nutrients to agriculture. TIS studies are part of a growing field of research concerned with sustainability, innovations and transitions, which aim to better understand the forces that shape changes within socio-technical systems. A TIS analysis focuses on dynamic functions which control the performance of the innovation system (Bergek et al., 2008; Hekkert et al., 2011).

As a first step in this process the structure of the TIS system in question and its current stage in development needs to be defined. The structural components of the system are the actors, institutions, networks and technologies that make up the system (Fig. 1). In this case, the technical system is composed of collection, transport, treatment and reuse technologies for urine and blackwater (e.g. human excreta and flushing water). The actors, institutions and networks are composed of users who interact directly with the technical system, service providers, regulators, and the various institutional structures through which they interact, e.g. policy, cultural norms, and knowledge. Geographically the study has been limited to Sweden. Data has been gathered from national and municipal-based sources depending on the TIS function in question.

It is important to understand that a TIS develops and changes over time and that certain functions are more relevant than others depending on the level of maturity. For example, knowledge development is critical in the beginning while market formation may yet be underdeveloped. Therefore, evaluation of the TIS functions needs to first determine the phase of development. Development and diffusion of a technology generally follows an S-curve where early development phases are marked by low growth rates, followed by large market growth in take-off and acceleration phase until saturation occurs (Rogers, 2003). Based on the low rate of dissemination, it can be assumed that source-separation of wastewater in Sweden is in the development or niche-market phase. During this phase the technology is launched in naturally occurring or politically constructed niche markets where they are connected to paying customers and users (Swedish Energy Agency, 2014). In Sweden, the niche-market is generally on-site wastewater treatment in areas outside municipal wastewater jurisdictions.

A number of studies have identified critical functions which affect how innovations develop (Bergek et al., 2008; Hekkert et al., 2007; Markard and Truffer, 2008). This study is based on the functions identified in Bergek et al., 2008; although the diagnostic questions and indicators have been adapted for the case in study. Since previous sociotechnical studies of wastewater systems have highlighted the need for communication channels and participatory arenas between stakeholders (Fam and Mitchell, 2013; Storbjörk and Söderberg, 2003), the function "*development of social capital*" was added to this analysis. The functions cover a range of processes through which knowledge related to the TIS is gained, different stakeholders are involved, markets are formed and incentives created (Table 1). Each of the indicators was evaluated at an appropriate local or national scale in order to identify weaknesses and opportunities for the TIS.

Evaluation of the functionality of source-separation systems with nutrient recovery in Sweden was performed at several levels: local cases, national perspectives and global comparisons depending on the nature of the indicator (Table 1). Case study methodology was used as an appropriate method for the study of contemporary phenomenon within a real-life context (Yin, 2003); in this case the implementation and operation of source-separating systems in eight Swedish municipalities (Table 2). With the exception of Kullön in Vaxholm municipality, all of the systems are still operating as designed. It should be noted that there are currently no source

Table 1
Evaluation criteria for assessing the functionality of TIS for source-separated wastewater in Sweden. During evaluation indicators were rated on a scale from 1-weak to 3-strong, see Table A.1.

Function	Definition (adapted from Swedish Energy Agency, 2014)	Diagnostic questions (adapted from Hekkert et al., 2011)	Indicators	Scale
Knowledge development	Process with which knowledge related to the system is gained and spread.	Is the quality and quantity of knowledge sufficient for development of the TIS? Is there sufficient exchange of knowledge between actors?	Bibliometrics analysis of publications Analysis of national knowledge exchange forums	Global National
Development of social capital	Process through which social relationships are built and maintained	Does an arena exist for participation and conflict management? Do stakeholders have common norms, mutual understanding, and trust?	Existence of communication mechanisms between actors Quality of relationship between stakeholders	Local Local
Entrepreneurial activities	Iterative and social learning through which uncertainty in the system is reduced	Are the most relevant actors active in experimenting? Does the division of responsibilities & risks between actors form a barrier to innovation?	Diversity and accountability of actors involved # companies involved Clarity of division of roles & responsibilities	Local National Local
Legitimation	Process through which social acceptance is created – both technically & socially	Are advocacy and lobbying activities for the TIS sufficient? Are there accepted technical advantages of the TIS relative to alternatives?	Assessment of advocacy activities Level of user satisfaction & acceptance	Local Local
Market formation	Process through which the market emerges for system services	Is the current and expected future market size sufficient?	% of residents connected Growth rate (%)	Local Local
Resource mobilization	Process through which stakeholders develop a resource base	Are there sufficient financial and human resources available?	Financial resources mobilized (% of costs) Human resources required	Local Local
Guidance of the search	Processes which shapes stakeholder decisions about how they will use their resources	Is there a clear vision on how the industry and market should develop? Are there clear policy goals regarding growth of the TIS?	Local political support Alignment with national policy & legislation	Local National

separation systems at scale within existing wastewater jurisdictions in Sweden, hence the necessity to use cases within municipal boundaries but outside their respective wastewater jurisdictions (e.g. outside of sewerage networks). Selection criteria for cases included (i) active participation of the municipality in the system, (ii) greater than 50 households connected to the system, and (iii) the existence of detailed project reports. This means that demonstration projects, privately operated eco-villages, and public buildings such as schools were excluded from the case study. Information for the case studies was collected through interviews, focus groups, questionnaires, and literature reviews. In all cases, multiple data sources were used in order to triangulate and confirm data. The results have been reviewed and confirmed by municipal actors. Evaluation of the TIS functions within each case were rated on a scale from weak to strong based on fixed criteria (Table 3). It should be noted that evaluation of the TIS functions is based on the current situation in the municipalities, although several have been in operation since the 1990s and indicators such as political support and local human capital have changed over time. These changing dynamics are noted in the discussion. At the national and global

Table 2
Summary of the Swedish municipalities used in the case study.

Case	System (treatment)	Approx. # households	Policy initiation	Housing type	Data sources
Tanum	Urine diversion (storage)	500	1992	Individual houses (on-site systems)	(Andersson, 2008; Tanum Municipality, personal communication, Jan. 29, 2016)
Västervik	Urine diversion (storage) & Blackwater (urea)	230 (urine) 750 (blackwater)	1995 (urine) & 2013 (blackwater)	Individual houses (on-site systems)	(Fröberg and Lindberg, 2005; Västervik Municipality, 2013; Västervik Municipality, personal communication Nov. 26, 2013 and Dec. 16, 2015)
Linköping	Urine diversion (storage)	275	1999	Individual houses (on-site systems)	(Kärrman et al., 2005; Nilsson, 2014, Linköping Municipality personal communication Dec. 1, 2015)
Norrtälje	Blackwater (wet composting)	1000	1999 (plant opened 2004, nonoperational 2010–2013)	Individual houses (on-site systems)	(Eveborn et al., 2007; Norrtälje kommun, 2007; Norrtälje Municipality personal communication Dec. 11, 2013 and Feb. 22, 2016)
Vaxholm (Kullön)	Urine diversion (storage)	250	2001 (urine reused 2008–2013)	Housing collective (decentralized wwtp)	(Stintzing et al., 2006; Visscher and Verhagen, 2010)
Norrköping	Urine diversion (storage)	300	2003	Individual houses (on-site systems)	(Nilsson, 2014; Norrköping personal communication, Nov. 17, 2015)
Södertälje	Blackwater (urea & wet composting)	500	2009	Individual houses (on-site systems)	(Calo, 2013; Södertälje Kommun, 2010; TelgeNät personal communication Dec 2, 2015)
Uddevalla	Blackwater (urea)	650	2011	Individual houses (on-site systems)	(Andersson, 2011; Uddevalla Municipality personal communication Nov 12, 2013 and Dec 3, 2015)

Table 3
Evaluation criteria used for rating the TIS indicators from weak to strong. Indicators marked with an asterisk (*) are assessed on a national scale.

Function	Indicator	Weak	Moderate	strong	Source
Knowledge development	Bibliometrics analysis of publications (global)*	TIS is <3% of sector publications	TIS is 3–16% of sector publications	TIS is>16% of sector publications	Scopus, expert interviews
	Analysis of national knowledge exchange forums*	TIS is <3% of sector communications	TIS is 3–16% of sector communications	TIS is>16% of sector communications	National conference material
Development of social capital	Existence of communication mechanisms between actors	Informal mechanisms & ad hoc problem solving	Formal mechanisms, generally with one-way communication with little follow-up	Formal mechanisms, empowering dialogue with regular feedback	Interviews
	Quality of relationship between stakeholders	Lack trust, divergence of goals, feeling that actors not working towards common vision	Trusting and practical working relations, know and work with each other's' bureaucratic norms	Close partnership working towards common vision	Interviews
Entrepreneurial activities	Diversity and accountability of actors involved	Missing one or more key local actor	All local actors on-board, but limited outreach beyond municipality	All local actors on-board as well as regional/national actors	Project documents, interviews
	# of companies involved*	<5 companies	5–10 companies	>10 companies	Avloppsguiden.se, Internet search
	Clarity of division of roles & responsibilities	Lack of clarity and confusion over roles	Functional division of roles/responsibility without regard to shifting of risks/costs due to TIS	New standards and roles clarified for working with TIS	Interviews
Legitimation	Assessment of advocacy activities	Lack of advocacy activities for TIS	Passive advocacy –e.g. information on internet	Active advocacy – information campaigns, media events, etc.	Websites, reports, interview
	Level of user satisfaction & acceptance	<60% of users satisfied	60–85% of users satisfied	>85% of users satisfied	Reports from user surveys, interviews
Market formation	% of residents connected	<3% of user (Innovators)	3–16% (Early Adopters)	>16% (mainstream markets)	Municipal documents, interviews
	Growth rate (%)	<10% growth rate	10–50% growth rate	>50% growth rate	Municipal documents, interviews
Resource mobilization	Financial resources mobilized (% of costs)	External funding <25%	External funding for 25–50% of costs	External funding for >50% of costs	Project documents, email survey to municipalities
	Human resources required	Requires resources equivalent to more than a full-time employee	Requires equivalent of a full-time employee	Requires little (<10%) additional manpower	Project documents, email survey to municipalities
Guidance of the search	Local political support	Weak or non-existent	Supportive rhetoric but no action	Strong support backed by political decisions & policy	Interviews and municipal documents
	Alignment with national policy & legislation*	Legislation is ambivalent or prohibitive to TIS	Legislation is supportive, but lacking incentives for change	Legislation is supportive and backed by incentives	Legislative documents, interviews

level, data was gathered through a variety of sources, depending on the indicator of interest. Global knowledge development was assessed using Scopus to determine knowledge trends regarding source-separation both nationally and internationally. A review of Swedish wastewater policy and regulations was the basis for assessing the alignment of these systems with current legislation. A market analysis of toilet companies active in Sweden (based largely on a sector website Avloppsguiden.se where over 760 companies advertise their wastewater services) was used in the assessment of market formation. Interviews with sector experts from ministries (Swedish EPA, Swedish Agency for Marine and Water Management) and national professional organizations (Swedish Water & Wastewater Association, Federation of Swedish Farmers) were used to confirm trends.

3. Results

When interpreting the results of this study, the scale of observation and phase of development need to be kept in mind. In particular, the fact that this study is focusing on a socio-technical system which is primarily evolving in niche-markets outside existing wastewater jurisdictions. Hence, results focus on performance of the TIS within a niche-market, while at the same time trying to judge the readiness of the system to break into new markets, e.g. application within wastewater jurisdictions. The majority of indicators focused on local practice in municipalities working with source separation, or niche-markets. The results cannot therefore be scaled up and generalized nationally. For example, market formation are moderately strong in the niche-market, however, in the whole of Sweden the number of people using for source-separation systems in quite low. On the other hand, it can be noted that on average the niche-markets function reasonably well (Fig. 2). Looking more closely at results in the studied municipalities highlights a number of differences between them, with the most recent cases in Södertälje and Uddevalla performing best (Fig. 3). Detailed scoring of the case studies can be found in Table A.2. The following sections present the results for each function.

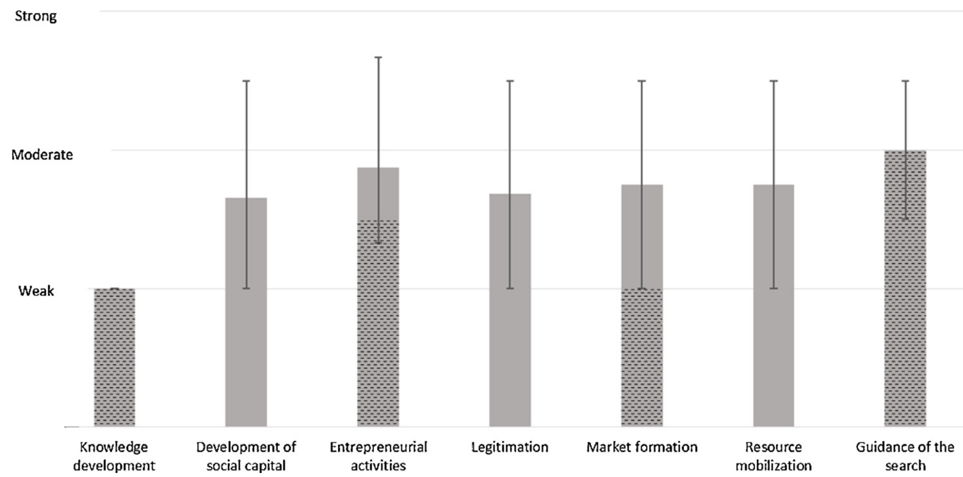

Fig. 2. Average TIS functional performance of source-separation wastewater systems in Swedish municipalities. The dashed bars show how the indicators perform at a national level (when measured). The error bars show that performance varies widely between different municipalities.

3.1. Knowledge development

Evaluation of the function knowledge development is based on assessment of global knowledge trends and national dissemination of knowledge related to the TIS. A keyword search in Scopus was used to assess the global production of knowledge related to source-separation in wastewater and sanitation; including nutrient recovery; urine diversion & urine separation; and blackwater (excluding hits related to other fields of research). Global knowledge availability regarding source separation remains low compared to overall knowledge creation in the wastewater sector (less than 1% of total publications; Fig. 4a). For comparison; 23% of wastewater publications in Sweden were related to "activated sludge" during this same time period. However; it is worth noting that Sweden is the leading country in knowledge production related to urine diversion (16% from Sweden) and among the top 10 countries regarding nutrient recovery and source separation (Fig. 4b). It is also worth noting that only a fraction (10%) of the publications related to nutrient recovery also address source separation. This survey only captures publications available on the internet and thus does not represent all knowledge available; such as grey literature in form of municipal documents; reports; etc.

The other important part of this function is the dissemination of knowledge. Sector experts agree that there are strong national forums in Sweden for sharing information related to wastewater, including new technologies. The Swedish Water & Wastewater Association (SWWA) is active in knowledge exchange and there are other forums such as the national water & wastewater conference (VAK), and a web-based knowledge bank for on-site sanitation systems (www.avloppsguiden.se) with over 220 municipalities as members. Nutrient-recovery is a common topic within these forums; however knowledge related to source separation is less frequent. Evaluation of the sessions presented at the VAK conference 2000–2015 found that topics related to nutrient-recovery averaged at 17% of the program material and 6% specifically addressed source separation. However, there is a decreasing trend in both topics with significantly less coverage of these topics since 2008 (6% and 1% for nutrient-recovery and source separation, respectively).

In summary, knowledge development and dissemination of source-separation systems is regarded as weak, both globally and nationally. Based on the publication indicator it is deemed that global knowledge production regarding source-separation is currently insufficient for wide-spread development of the TIS. This is supported by experts SWWA who feel that source-separating systems are not fully developed and further research is needed (personal communication Nov. 29, 2013). For example, many urine-diversion toilets have been criticized for being difficult to clean or inappropriately dimensioned for children. Many interviewees were also concerned about the robustness of these systems, both with regards to the technical toilet and collections systems, but also the organizational structures which would ensure proper management and guarantee reuse. All Swedish experience with source

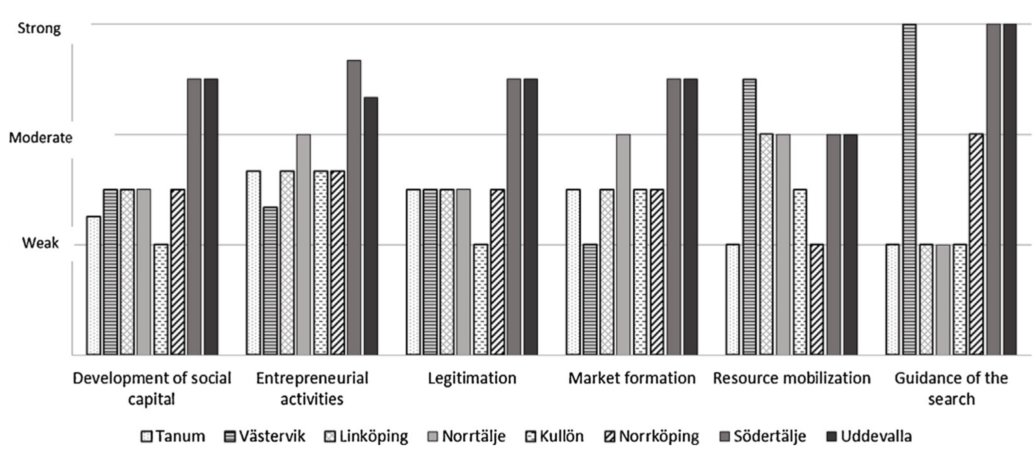

Fig. 3. Local-based evaluation of TIS functions for source-separation wastewater in eight Swedish municipalities. Note that only locally evaluated indicators are presented here. Patterned bars indicate urine diversion systems, while solid bars indicate blackwater systems (Västervik has both).

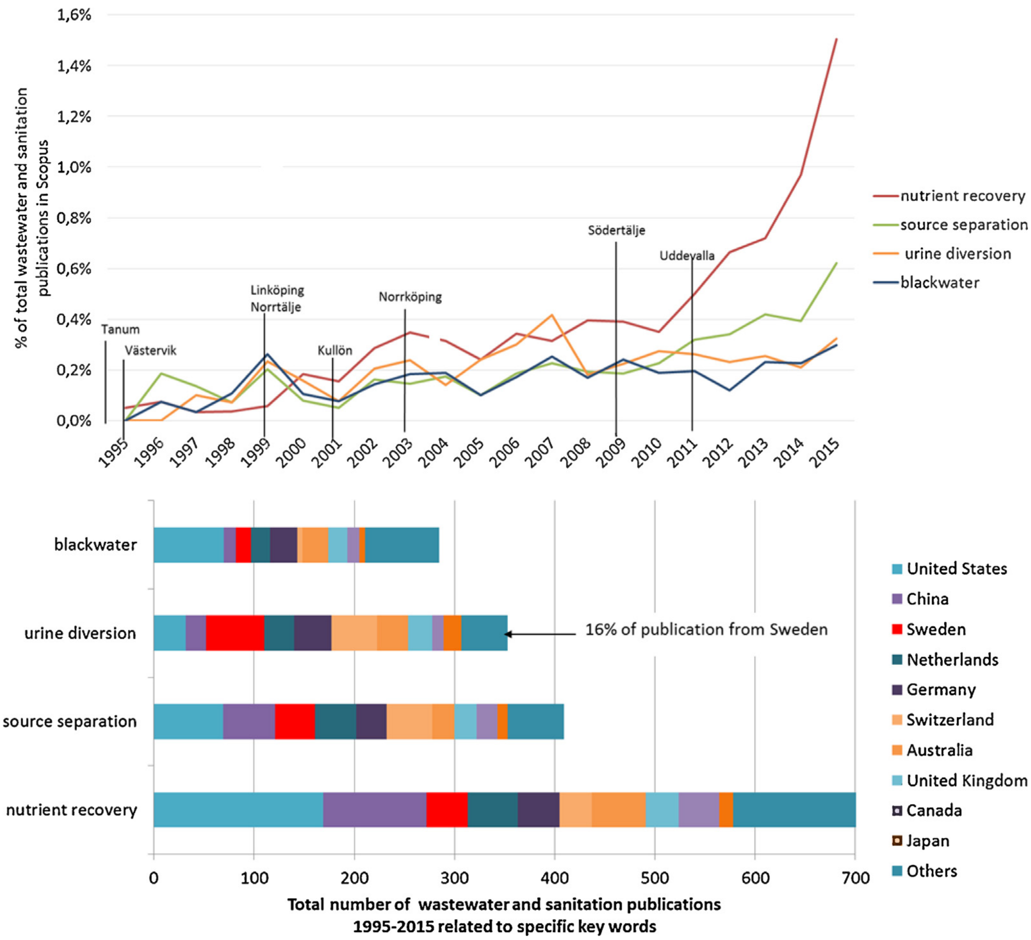

Fig. 4. Global knowledge trends in the wastewater and sanitation sector (source Scopus). a) The percent of total publications relating to themes of nutrient recovery and source separation. Years when projects used as case studies were started is also indicated. b) Distribution of knowledge creation related to nutrient recovery and source separation between countries, Sweden indicated in red.

separation stems from use of beta version of products and small locally developed pilots, so it should not be surprising that the TIS is immature. Further research is needed regarding toilet technology and treatment processes for source-separated waste fractions in order to identify standards and control measures for efficiency and quality control. Farmers also require better information regarding the nutrient content of these waste fractions if they are to use them as chemical fertilizer replacements. On the other hand, Sweden is one of the key centers for producing this knowledge and the amount of knowledge available is growing. Sweden has a well-established forum for knowledge dissemination in the sector, but as yet knowledge exchange related to the TIS is low.

3.2. Development of social capital

Development of social capital is critical for strengthening emerging networks and collaboration in innovations. Evaluation was based on the existence of communication mechanisms for participation and conflict resolution, as well as, the quality of the relationships between stakeholders. This second indicator captured an assessment of common values, enthusiasm, working relationships and trust. Assessment of this function is based mainly on stakeholder interviews supported by written documents (e.g. vision statements, internal/external communications). On average this function is judged as weak-moderate with the quality of stakeholder relationships scoring stronger than communication mechanisms.

Assessment of communication mechanisms for participation and conflict resolution is based on the existence and level of formality of communication mechanisms between actors. Many cases started as projects with regular communication and outreach to users. However, many of these communication strategies and actions decreased or disappeared after the system was established. This is particularly the case for communication strategies between household users and the municipality where initial information campaigns fade into passive information posted on, e.g. websites. The exceptions here are the moderate efforts by Tanum who holds yearly meetings with farmers; and the most recent initiatives (Uddevalla, Södertälje) who have formal arenas for participation or communication strategies (project meetings, information campaigns, etc.). All others were deemed to work basically with informal or ad hoc communication methods. However, it is worth noting that weak communication platforms and strategies is generally not seen as a problem by stakeholders and the majority of interviewees felt that they have good collaboration with others stakeholders and problems get solved ad hoc. This is likely due to the well-established roles and networks within Swedish society in general, so that communication is not seen as an obstacle. Considering that there are also established national knowledge dissemination forums in the sector it can be concluded that an arena for communication exists, but that it is not very well-used with respect to source-separation.

Assessment of the quality of the relationships between stakeholders attempted to judge the degree to which mutual understanding, norms and values bring stakeholders together, thus strengthen social networks. Assessment of this indicator captures the enthusiasm of the actors involved and how well it is shared with others stakeholders. Enthusiasm includes a measure of the main actors' belief in the potential and positive value of the system. Assessment of these factors also found that they appear to be time dependent, being often stronger in the beginning than after several years of operating a source-separating system. For example, project initiation in several cases was driven by local champions with enough influence to bring together a broad array of actors for consultations and awareness-raising. However, once routines have been set only the actors involved in operation of the system remain active and enthusiasm dwindled as local champions (generally a small group of people) retire or change jobs. Again, it is the two most recent cases where strong enthusiasm is shared with a broader group of active stakeholders. In a majority of the other cases, the fire of enthusiasm has stagnated and actors fulfill their roles in the system, but lack a sense of ownership (rated as moderate). In two municipalities the quality of relationships is deemed weak since there is a divergence of goals and lack of cooperation within the system. This is the case in Kullön where there is currently no one taking responsibility for the functionality of the system, and in Tanum where the municipal council voted in January of 2016 to remove the requirement for nutrient recovery systems for on-site sanitation, thus undermining the work of the municipal Environmental and Health Department to establish source-separating system. It is worth noting that the informant in Tanum felt that part of the reason for the decline of support was that the feeling that national interest had not grown and they were tired of struggling alone with their "different" system. There is also the feeling that the lack of a national goal for reuse undermines the local examples with new reuse systems, since they lack a standard in which they can perform better than the conventional systems. In this respect, strengthening national and regional networks and goal-setting may well play a role in maintaining and strengthening the development of social capital.

3.3. Entrepreneurial activities

Entrepreneurial activity is an iterative process of social learning, experimenting and fixing of problems. This development process needs a critical mass of different actors from different sectors actively working with the TIS. In later phases of development this activity will lead to the establishment of standards, norms, and operational models which reduce uncertainty and risk. Evaluation of this function looked at the diversity and accountability of the actors involved, as well as, the diversity of technologies applied. It also looked at the emergence of operational models, standards and division of responsibilities specific for source-separation, thus for frameworks to guide entrepreneurial activity.

Within source-separating systems for wastewater in Sweden there is a critical difference between systems which separate only urine or those which separate blackwater. Urine diversion systems all use storage as the main treatment option, thus the diversity of technologies applied in these systems is quite low. In contrast, there are a number of different treatment technologies applied in blackwater systems (Table 2), increasing the diversity of entrepreneurial activities and the number of companies involved.

A market analysis of companies providing flush toilets adapted to source-separating systems was conducted at a national level. The study found two companies providing urine-diversion toilets (Wostman EcoFlush, Dubbletten), two selling extremely low-flush toilets (BioLoo, Thetford Aqua Magic), and four companies selling vacuum toilets (Wostman EkoVac, Fann VA-teknik AB, Jets, Dometic SeaLand) in Sweden. It should be noted that the market is more diverse for dry toilet solutions with 17 companies in Sweden offering a variety of toilet system, including urine-diversion, composting and incineration options, which are primarily designed for vacation homes. This analysis used the numbers related to waterborne toilets since these are most likely to be used in permanent dwellings, and most likely to be used within existing wastewater jurisdictions. The majority of companies selling toilets for source-separating system have only one model. This is compared to the market for conventional WC toilets in Sweden where consumers can chose between 14 companies and over 300 toilet models. This indicator was rated differently depending on whether the system was designed for urine or blackwater separation. There are only two urine-diversion flush toilets on the market today in Sweden, this in combination with the low diversity of treatment methods applied to urine mean that urine-diversion is rated as weak. In fact, the lack of well-designed urine-diversion toilets has often been pointed out as a problem for expansion of urine-diversion systems. If it is assumed that blackwater separating systems should have extremely low-flush toilets (Norrtälje and Södertälje require this in new buildings), then there are six companies offering such toilets, thus entrepreneurial activity for blackwater systems is considered as moderate (see Table A.1).

This assessment also looked for the presence for all relevant actors in local activities, e.g. users, service providers, and farmers. In the weakest cases, there are key stakeholders who are not involved in the system, e.g. the water utility in Västervik and farmers in Kullön. It should be noted that since on-site systems are outside the wastewater jurisdiction, water utilities are not required to be involved. In all the other cases the most relevant local actors are present to some degree in the system. However, only in Norrtälje, Södertälje and Uddevalla is there a broader diversity of national organizations and research institutes supporting experimentation and learning.

Then there is the question of frameworks to guide participation in entrepreneurial activities, e.g. clarity of areas of responsibilities. Legally, there are national regulations stating which entities have responsibility for managing specific waste fractions; i.e. in Sweden source-separated toilet waste fractions are classified as household waste and are thus the responsibility of the Municipality and its solid waste service provider (Swedish Environmental Code 1998:808). However, for most municipalities the source separated toilet fractions are new and the application of the Environmental Code on these fractions is rather untested. They have no handling system for them and putting operational systems into practice is challenging. Many actors feel that there is a grey area of responsibility regarding these source-separated waste fractions. This is the case in Västervik and Norrtälje where actors feel that it is not clear who has responsibility for nutrient recovery and thus who should act (rated weak). In other cases division of responsibility worked moderately well, but actors still experienced coordination difficulties (Tanum, Linköping, Norrköping, Uddevalla). On the other hand, in Kullön, and Södertälje this indicator scored strongly since there have been studies and steering documents developed specifically for organizing roles with source-separating systems. It should be noted that in the case of Kullön, these documents were part of a research project connected to the system, but in practice they were non-functional since actors did not fulfill them. In Södertälje a project also contributed to the development of a nationally adopted certification standards for nutrient-rich wastewater flows from small treatment systems (SP Technical Research Institute of Sweden, 2012), thus clarifying the playing field for potential new actors in the TIS system.

3.4. Legitimation

Establishing legitimacy is not only a matter of proving technical advantages, but a process of creating social acceptance through advocacy and outreach. The indicators assessed considered the strength of advocacy activities linked to the TIS and level of user acceptance. Of course, the degree to which homeowners choose to implement TIS systems is also an indicator that the system has accepted technical advantages. However, as that indicator is captured in market formation, only advocacy and acceptance are used here.

Advocacy and lobbying appear to be another time and resource dependent indicator. In a majority of the municipalities, advocacy was strongest during launching of the TIS system when there was external funding to pay for communication activities. For example, Västervik, Norrtälje, Norrköping, Södertälje and Uddevalla have all carried out information campaigns with public meetings, demonstration sites, mass mailings and media events. However, Södertalje and Uddevalla are the only municipalities still actively lobbying for the system, as both still have external funding. The problem in most municipalities is that activities for development of their source separation systems have not become integrated into municipal budgets and planning. It should be noted that Södertälje is the only system with a quality certification for the fertilizer produced, which can be seen as an active form of legitimizing the system. Linköping and Norrköping appear to practice passive advocacy for the TIS by providing information on their webpage of the advantages of urine diversion, but they are no longer actively seeking to expand or promote the system. In the other four municipalities, there seems to be a lack of an advocacy for source-separating systems. In these cases, source separation may be mentioned in information provided to homeowners, but no reasons are given as to why one should implement such a system. In Tanum, urine diversion is no longer even included in municipal documents regarding on-site sanitation.

Social acceptance was evaluated based on the level of user satisfaction reported in surveys or estimated by municipal officers working with source separation. This indicator was rated as weak in Linköping and Norrköping as only about half of users were positive to the system, and then only as long as the urine was used (Nilsson, 2014). Similarly, acceptance in Kullön has decreased since the urine is not being used and is also rated as weak. User surveys in the other municipalities generally found that 70–80% were satisfied with their source separating system: 70% in Tanum (Andersson, 2008), 83% in Västervik (Fröberg and Lindberg, 2005), approximately 82% in Norrtälje and 70% in Södertälje (Petersens and Granath, 2015). Uddevalla has not conducted any formal user surveys, but municipal officers feel that the system is well received and it is assumed that acceptance there is in line with other municipalities. This level of acceptance is rated as moderate since there are still relatively large groups which are not satisfied with the system. As a municipal officer in Tanum commented, it is the few who are unsatisfied who speak the loudest. In general, it was found that social acceptance in the blackwater separation systems is higher than the urine-diversion systems. For example, in both Tanum and Västervik there are few households choosing urine-diversion today, in part due to technical problems and inconvenience, but also due to the lack of well-functioning toilets on the market. Factors limiting user acceptance appear to be extra investment costs, inconveniences with e.g. cleaning, and worries about chemicals and pharmaceuticals being returned to agriculture. Yet, as the case of Kullön demonstrates, acceptance is also affected by whether reuse is occurring or not.

3.5. Market formation

Evaluation of market formation is based on the market share and growth rate of these systems. Assessment of the strength of this function is based on Rogers (2003) concept of the diffusion of technology; assuming that approximately 3% of the population are innovators (weak market), the following 13% are early adopters (moderate market), and innovation within greater than 16% of the population is reaching mainstream markets (strong). First, it should be noted that with the exception of Kullön in Vaxholm municipality, the cases used in this study are focused on on-site systems. Therefore, market share has been evaluated as the percentage of on-site systems in the municipality using source-separation (for Kullön it was compared to the municipal population). Secondly, this assessment is focused on market formation at the local level. At the national level the market formation of source separation is quite low.

In general, the market share of these systems is between 5 and 7% of on-site systems, which is deemed as moderate. The exception is Västervik with 2% connected to urine-diversion and 2.5% connected to the blackwater system. Tanum and Norrtälje have the highest market shares of source-separating systems, account for approximately 15% and 12% of on-site systems respectively, and thus come close to reaching mainstream markets. In both of these municipalities, a large percentage of the total population is served by on-site systems. Assessment of growth rate highlights a strong contrast between urine and blackwater systems, with the blackwater separation increasing and urine diversion remaining stagnant. In Norrtälje the blackwater system is estimated to moderate and growing about 20% per year. While in Södertälje and Uddevalla the growth rate is strong at over 100% and 60%, respectively. Market formation for urine diversion is currently insufficient and is limiting innovation in Sweden. However, the on-site market does not appear to be a barrier for growth of the blackwater system and particularly the most recent cases have a moderately functional market.

3.6. Resource mobilization

As a TIS evolves it will need to mobilize a range of resources such as human resources, financial capital and complementary assets in the form of supporting products, service and infrastructure (Bergek et al., 2008). Part of these resource measures are captured in assessment of knowledge availability and market formation (e.g. availability of source-separation toilets). Therefore this assessment focuses more on the ability of the TIS to mobilize financial capital and human resource capacity for system management within the niche-markets. While not all systems studied required mobilization of large financial capital, the ability to mobilize financial resource is also an indicator of belief in the system by external funders and thus an indicator of its potential to break into other markets.

In general, there is a moderate level of financial and human resources available to municipalities working with source separation in Sweden. While source separation is judged to cost more, a majority of the cases studies found them able to mobilize sufficient financial and human resources. Evaluation of resource mobilization focuses on the amount of financial and human resources needed to build and operate the source-separating systems. With the exception of Uddevalla, all municipalities see that investment costs for source-separating systems are slightly more than for conventional systems. Investment costs are divided between households and municipalities. In Sweden, homeowners are responsible for the investment costs for on-site wastewater treatment systems, although some municipalities (Västervik, Linköping, Norrtälje, and Södertälje) originally offered subsidies to households installing these systems. Municipalities provide the supporting infrastructure for collection and treatment of the sludge from these systems and charge users fees to cover operational costs. However, with the exception of Norrtälje and Södertälje, investment costs for source-separating systems by the municipalities, e.g. for urine storage and farm-based blackwater treatment, have been minimal. Tanum, Kullön and Norrköping financed the investment with internal funding, rated as weak resource mobilization, while Västervik, Linköping, and Uddevalla received moderate external funding which covered 25–50% of investment. The exceptions here are Norrtälje and Södertälje which have built special treatment plants to handle source-separated blackwater and are thus the two municipalities who have mobilized the most financial resources. Norrtälje mobilized 5.5 million SEK (∼657 000 USD) or 85% of investment, and Södertälje received 8.3 million SEK (992 000 USD) or 70% of investment.

Human resources are generally available in Sweden, but the learning curve for these systems can be steep, requiring additional time input (cost) from the actors involved. Thus, this analysis estimated the demand for additional human resources needed. In scoring this function, cases which required less additional manpower were given a stronger score, assuming that the threshold for implementing these systems from a human resource perceptive was thus lower. Many of the municipalities felt that initiating a source-separating system was a time-consuming process, either requiring the equivalent additional manpower of a full-time employee (rated as moderate – Kullön and Uddevalla), or more than that (rated as weak – Tanum, Norrtälje, Södertälje). In contrast, Västervik, Linköping and Norrköping felt that the additional workload could be accomplished with a little extra effort from all parties (e.g. 10% extra); these cases were rated as strong. However, actors in these cases also pointed out that the amount of work required depends on the size of the municipality or system and the level of agreement between stakeholders. For example, it would take more time with larger economic investments, or if there was more resistance.

It was found that municipalities had difficulty separating out operational costs for source separation from the rest of the waste management system, thus these numbers were not included in the rating of resource mobilization. However, the ways in which operational costs are divided between different actors which can have ramifications for system acceptance and growth. From the household perspective operational costs for source-separation are often similar or higher to conventional systems, e.g. households pay the costs of emptying the additional collection tanks (Tanum, Västervik, and Norrköping from 2016). However, the municipalities argue that household operational costs are comparable to mini-wastewater treatment plants which meet the same effluent standards. In other municipalities, the additional emptying costs are distributed among all paying customers (Linköping, Norrtälje, current situation in Kullön), or internalized between municipal utilities (Södertälje), since source separation is deemed to lower loading at the wastewater treatment plant, which leads to operational cost savings for the wastewater utility. While the wastewater utility may see savings in source separation, the solid waste departments in charge of emptying tanks and operating storage/treatment facilities often see operational costs as significantly higher than "normal" operations. For example, Linköping estimates that urine separation, which serves 4% of their customers, costs 310 000 SEK/year (37 000 USD/yr), or 5% of the total budget for on-site sanitation services (personal communication Linköping Municipality). The farm-based blackwater treatment systems used in Uddevalla is the only one with lower operational costs than conventional systems (Uddevalla Municipality, communication Jan. 20, 2016).

3.7. Guidance of the search

Assessment of this function attempts to understand the processes which shape stakeholder decisions about how they will use their resources. Specifically, it is looking for clear policy goals and visions with regard to how the TIS should develop. Evaluation of this was done based on assessment of both national and local policy, as well as, levels of political support.

At a national level Swedish legislation supports the idea of nutrient reuse. The Environmental Code, dating from 1998, contains several objectives for recycling and efficient use of natural resources. In parallel to the Environmental Code, sixteen National Environmental Quality Objectives were established in 1999. Recirculation of natural resources (including nutrients) is also part of these objectives and one of the targets stated that at by 2015 at least 60% of phosphorus compounds present in wastewater should be recovered for use on productive land. However, this target has been removed so that there is no longer a national target for nutrient recirculation. A representative of the Swedish EPA feels that existing legislation does nothing to either support or hinder recycling of nutrients from wastewater (personal communication Jan. 16, 2014). Similarly, experts at the Swedish EPA and Swedish Agency for Marine and Water Management feel that there is generally low political support for nutrient recycling, with perhaps the exception of phosphorus which has attracted a relative large amount of political attention. In general, sector experts in Sweden feel that the transition to nutrient-recycling systems (including source separation) will go slowly. In summary, it seems that national policy is more enabling than driving and those municipalities interested in applying national policy struggle to integrate them in local policy and decision-making. Thus, national guidance of the search is ranked as moderate.

Political support within the municipalities studied varies considerably. In all of the cases, local policy refers to the national Environmental Code and Environmental Quality Objectives as enabling for their source separating systems. However, to date legal precedents do not make use of these laws and interpretation of the Code is up to every municipality. In addition, support from local politicians and in local policy documents is not always present. Similar to the development of social capital there appears to be a time correlation with the most recent initiative performing better. For example, in Uddevalla and Södertälje the actors feel that they have strong support from the local politicians and this is backed up in local policy documents supporting source separation and nutrient recovery. An interesting exception is Västervik where political support remains strong and they have launched a new initiative for blackwater separation and policy for recovering phosphorous (Västervik Municipality, 2013). Of the other older cases, it is only Norrköping where actors still feel that they have support from local politicians. The other municipalities have weak support and only national policy for guidance.

4. Discussion

This analysis has focused on the functionality of source-separation wastewater systems within niche markets (on-site sanitation) in Sweden. Based on the results of this study, these systems function moderately well within this niche. In general, the blackwater systems studied function better than UD systems. This could be because of the backlash against urine diversion in the early 2000s, due to technical malfunctioning and lack of UD toilet manufactures in Scandinavia, which reduced the legitimacy of UD; or because UD toilets are less socially acceptable than the low-flush/vacuum toilets used in blackwater systems.

Interpretation of the results from the above analysis needs to keep in mind that source-separation systems for wastewater are still in a development phase. During the development phase, entrepreneurial activity and knowledge development are key functions for exploring uncertainties in technologies and markets (Bergek et al., 2008; Hekkert et al., 2011). At the same time the development of social capital, guidance of the search, and resource mobilization must stimulate the entry of new actors and experimentation in many directions. The process of legitimation and

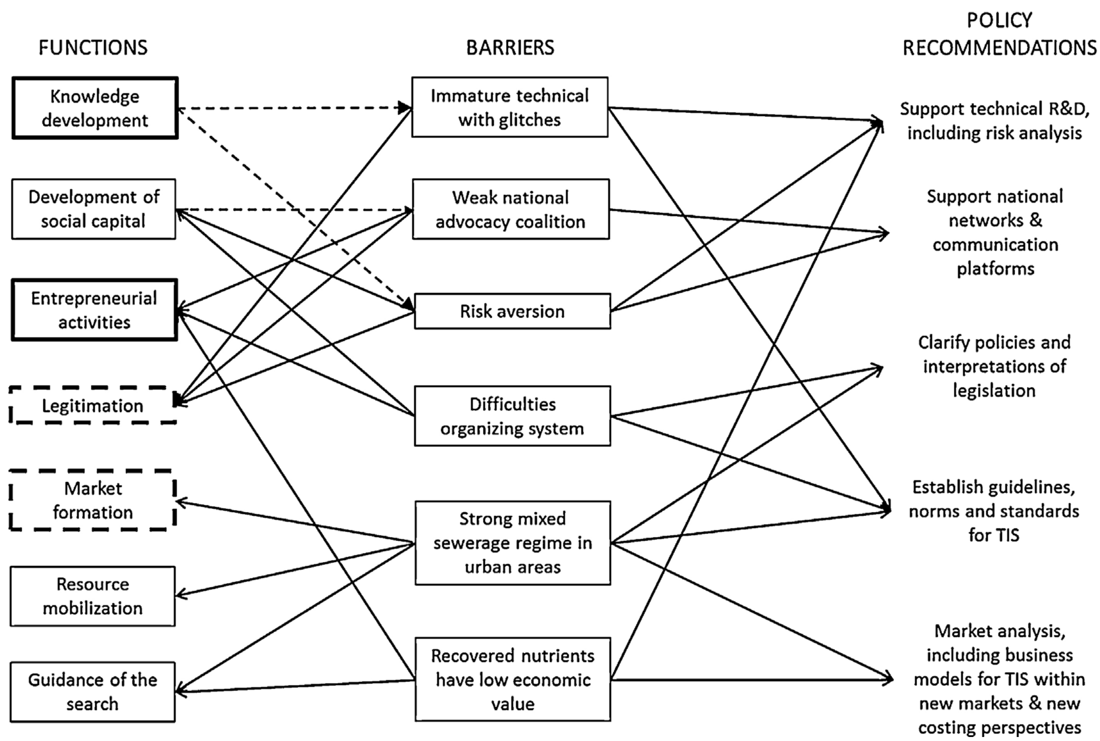

Fig. 5. Mapping barriers and potential policy recommendations for source-separation in Sweden. Note that key functions for the development phase are outlined in bold and those needed to shift into a growth phase in a dashed-bold line. Dashed arrows show where the function itself is causing barriers.

market formation start during the development phase and must grow stronger if the system is to shift into a growth phase. Instead of discussing the strengths and weaknesses of each function, the rest of this discussion will focus on identifying relationships between functions and mechanisms that are blocking the TIS from moving to the growth stage of development. Data from the case studies and interviews from sector experts reveals a number of barriers that are mentioned by multiple stakeholders in multiple case studies and can often be seen as blocking one or more of the system functions (Fig. 5). This figure is an attempt to summarize the results of the TIS analysis, including commentary from expert interviews, and structure the discussion.

It should be noted that there is strong interplay between the functions which mean that barriers can have ripple effects in multiple functions. For example, a major barrier for urine diversion has been technical problems with the toilets which have led to a decreased level of acceptance (legitimation) of the system. These technical problems are a result of immature technology and are a function of weak knowledge development, but also inadequate entrepreneurial activity for ironing out uncertainties; both of which are of course influenced by resource mobilization and guidance of the search. This analysis attempts to map the strongest relationships and blocking mechanisms.

It should be worrisome that the weakest function is knowledge development when this is one of the most important functions at this development stage. Entrepreneurial activity is also critical, but based on this study it is functioning better than knowledge development, at least for blackwater systems. This was also the only function that was primarily assessed at a national and global level, indicating that the TIS is still far from mainstream outside the niche markets. Although there has been an uptick of knowledge related to the TIS during the last five years, the majority of informants in this study feel that there is a lack of information regarding roles and responsibilities in system management; standardization of technologies and implementation practices; and quantification of risks and benefits, e.g. fate of medical residues and nutrient recovery. Weak knowledge development means that source-separation systems are often regarded as immature and risky by decision-makers.

Aside from technical challenges with immature technology, all of the studied cases have struggled with difficulties organizing the entire system from collection to reuse. It should be stressed that achieving reuse is critical for success of the system. One of the main reasons in Sweden for urine diversion systems reverting back to conventional systems has been that people lost motivation when there was no reuse in the system (Vinnerås and Jönsson, 2013). Organizational difficulties include establishing logistical systems for e.g. collection and transport, but also discrepancies in policy interpretation and division of responsibility between stakeholders. These difficulties are rooted in a lack of guidelines, standards and norms for management of the TIS, but are also linked to weaknesses in the social relationships (social capital) and social learning (entrepreneurial activity) that support development of these systems. For example, cross-sectoral collaboration has been difficult in some municipalities, e.g. between the wastewater utility, the solid waste utility, and the environmental health department, which has hindered experimentation and system expansion. If source separation is to expand beyond niche markets these actors need to come together to explore opportunities for new technical applications, as well as, new interpretations of regulations, tariff setting and zoning. Supporting national networks and communication platforms will also strengthen the social capital and entrepreneurial functions of the TIS which can contribute to technological development.

In addition, many municipalities struggle to attract farmers to accept the treated waste fractions, in part due to counter advocacy from risk aversion groups, including major players in the food industry, users, farmers and politicians. These groups worry about chemicals and medical residues in human waste being returned to agriculture. Risk aversion thus creates a barrier for both acceptance (legitimation) and strengthening social capital since several stakeholder groups are in opposition. Risk aversion is also a function of weak knowledge regarding risks with source separation systems.

Closely linked to this is the absence of a strong national advocacy coalition which could strengthen social capital, encourage entrepreneurs and also argue for the legitimacy of source separation beyond niche markets. Unfortunately, the trend in source separation projects has been that enthusiasm, advocacy and social capital decrease over time, thus leading to a weak national advocacy coalition.

Of course, the establishment of such a coalition is hindered by another barrier – the strongly entrenched regime of mixed sewerage in wastewater jurisdictions. In Sweden, there is a clear preference for municipal wastewater services and flush toilets (Wallin et al., 2013). An alternative toilet may be acceptable in a vacation house, but at home people want the convenience of a flush toilet. A major challenge for innovative wastewater systems is offering a competitive alternative to the regime standard. Changing pipes and treatment systems presents a significant economic barrier (resource mobilization), which also limits possibilities for expanding the market for new TIS systems. Further innovation, research and dialogue are needed to explore possible gaps within the centralized wastewater regime which source-separation could fill. On the other hand, there are one million on-site wastewater systems in Sweden which is not an insignificant market, especially considering the export potential to billions of on-site sanitation users around the world. Spinning the market formation of source-separation to meet the needs of this market would be one possibility for growth.

Finally, despite their significance from an environmental perspective, the nutrients in wastewater currently have a low economic value as a fertilizer which makes it difficult to motivate higher capital investments (Ishii and Boyer, 2015; Jönsson et al., 2010). This limits possibilities for attracting new entrepreneurs and mobilizing resources. Within the existing niche markets the level of resource mobilization is fine. However, moving the TIS into a growth phase will mean increasing it by orders of magnitude and that feels unlikely with the existing market and support network. Similar to many actions linked to environmental protection, the value of nutrient recycling is not fully reflected in conventional cost-benefit calculations. Overcoming this barrier may require new methods for calculating costs, such as life-cycle costing. For example, source separation can be a viable strategy to source control influent to wastewater treatment plants, thus enabling them to meet stricter regulation on eutrophication and pharmaceuticals. Source separation may well be less costly than treatment plant expansion/upgrading to meet stricter regulations or resource recovery goals. In addition, urine diversion can provide significant water savings. Further work is needed to clarify the context and scale in which source-separation can be an economically and environmentally viable alternative.

5. Conclusions

A major blocking mechanism for source separation in Sweden is the weakness of the interchange between knowledge development and entrepreneurial activity. There is limited experimentation, few pilot projects and limited actors experimenting, especially in areas outside of the niche markets. This study suggests the following policy recommendations for overcoming barriers to source-separation systems, based on identified weaknesses in TIS functions and needs described by case study informants and expert interviews. However it recognizes that prioritization of policy actions will be dictated by local policy goals.

- Support technical R&D, including risk analysis.
- Support national networks & communication platforms for reuse.
- Clarify policies and interpretations of legislation related to resource efficiency.
- Establish guidelines, norms and standards for source separation and application of recovered products in agriculture.
- Market analysis, including business models for innovations within markets & new costing perspectives.

The global environmental challenges that we are facing today demand changes in the systems we use to manage waste and resources. We need policy actions that stimulate the entry of new entrepreneurs and experimentation in many directions. Source separation as it is known today may not be the solution of the future, but by stimulating new ideas, new collaborations and experimentation with new systems we may succeed in transitioning to a sustainable system.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resconrec.2016.12.004.

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