*Desalination and Water Treatment*
www.deswater.com
doi: 10.5004/dwt.2017.20881
(2017) 1–9

# Is the Swedish wastewater sector ready for a transition to source separation?

J.R. McConville[a,c,*], E. Kvarnström[b], H. Jönsson[c], E. Kärrman[b], M. Johansson[d]

[a]*Department of Architecture, Chalmers University of Technology, SE-41296 Göteborg, Sweden, email: jennifer.mcconville@slu.se*
[b]*SP Technical Research Institute of Sweden, Drottning Kristinas Väg 67, SE-11486 Stockholm, Sweden, emails: elisabeth.kvarnstrom@sp.se (E. Kvarnström), erik.karrman@sp.se (E. Kärrman)*
[c]*Department of Energy and Technology, Swedish University of Agricultural Sciences, Box 7032, SE-75007 Uppsala, Sweden, email: hakan.jonsson@slu.se*
[d]*Ecoloop, Mosebacke Torg 4, SE-11646 Stockholm, Sweden, email: mats.johansson@ecoloop.se*

Received 20 December 2016; Accepted 2 May 2017

**ABSTRACT**

Source separation of urine for recycling has been applied in small-scale and decentralized wastewater systems in Sweden for the past 25 years and for blackwater for pollution control even longer. The Swedish experience with source separating nutrient recycling systems is relatively well documented; however, few reports have specifically studied the potential for expansion of this practice. The aim of this study is to fill this knowledge gap by assessing the status of source-separating technologies in Sweden based on transition theory. This study uses a multi-level perspective to determine how ready the Swedish wastewater sector is for transitioning to alternative systems. Given the stability of the existing sewage wastewater regime, it seems unlikely that changes within the regime will lead to a quick and large-scale transition to source separation. Instead, the initiative must come from the niche itself, exploiting institutional cracks in the regime and opportunities from shifting trends in the landscape. If source separation is to be mainstreamed in Sweden, it will need to break into markets within the wastewater jurisdictions. In order to do so, further knowledge needs to be developed that will overcome glitches with immature technologies, uncertain legal conditions/status, investigate potential risks, and clearly define complementary system advantages. This may require the use of new perspectives that focus on holistic sustainable use of resources, including other nutrients than phosphorous, and taking into account global issues such as planetary boundaries and effects from climate change, such as water scarcity. This knowledge can then be used to establish guidelines, norms, and standards, as well as clarify the legislative structures that can support such a transition. There is also a strong need to improve knowledge dissemination regarding best-practices for implementing source-separation technologies and supporting organizational structures. Similarly, support for entrepreneurial activities within the niche needs to increase, not least through strengthening social networks and communication platforms.

*Keywords:* Innovation; Resource recovery; Source separation; Transition; Wastewater

## 1. Introduction

Given the global environmental crisis and resource crunch there is an increasing need to consider all waste products as potential resources. The paradigm shift to waste reuse has started with many experts calling for greater resource recovery [1,2]. Within the municipal and on-site wastewater treatment sector, recovery of nitrogen, phosphorus, and organic matter for use as resources is of increasing interest. Since the majority of nitrogen, phosphorus, and organic matter in wastewater, and a minority of the heavy metals, originates in human excreta [3], source separation of excreta

* Corresponding author.

*Presented at the 13th IWA Specialized Conference on Small Water and Wastewater Systems & 5th IWA Specialized Conference on Resources-Oriented Sanitation, 14–16 September, 2016, Athens, Greece.*

from the rest of the wastewater stream would allow for simplified resource recovery. Source separation of urine, faeces, or mixed excreta (blackwater), has been shown to be advantageous for contributing to food security through recovery and reuse of fertilizing nutrients in agriculture [4,5], improving the capacity and efficiency of wastewater treatment plants by reducing nutrient loading at the plants [6,7], and improving biogas production [8]. At the same time, there are significant limitations to promoting reuse within conventional waste and wastewater systems at the global scale. For example, existing infrastructure lock-in and difficulties to optimize recovery from systems designed with a different purpose, i.e., for reduction of water emissions of organic matter and nutrients from the wastewater. Thus, systems designed for resource recovery are often ignored or dismissed in urban planning processes and are not widely applied in urban settings today.

In Sweden, about 90% of the population is connected to conventional wastewater treatment plants, many with tertiary denitrification processes which release nitrogen to the atmosphere and accumulate phosphorus in the sludge. Twenty-five percentage of the sludge is used on agriculture [9], which allows for some agricultural phosphorus reuse but very limited nitrogen reuse. Increasing the recycling rate is hampered by concerns about undesired chemicals in the sludge. Source separation of the nutrient-rich excreta fractions has been promoted as a means of achieving a cleaner reuse product in Sweden for the past 25 years. For example, since the 1990s source-separated urine has been recycled in Tanum municipality, as well as, from apartments with urine diversion in Stockholm. However, nearly all application of source separation has been outside existing wastewater jurisdictions, i.e., in on-site systems. The Swedish experience with source-separating systems for nutrient recycling is relatively well documented, both from national synthesizes [10,11] and reports from specific cases. However, few reports have studied the relative strength of this innovation and its potential for integration within the existing urban wastewater jurisdiction.

The aim of this study is thus, to fill this knowledge gap by assessing the status of source-separating technologies in Sweden based on a multi-level perspective to technology transition and identify where there may be “windows of opportunity” to scale-up implementation and potential transformation pathways for improving resource management on a larger scale in urban areas. The study is based on the assessment of niche cases where source separation has been implemented within Swedish municipalities outside the urban wastewater jurisdiction, a rapid assessment of the existing Swedish wastewater regime, and critical macro-environmental factors affecting both the niche and the regime.

## 2. Methods

This study uses a multi-level perspective (MLP) [12] to technological transition theory to assess the status of source-separating technologies for municipal wastewater treatment in Sweden. Technological transitions research uses an interdisciplinary approach to understand the processes through which technological systems change. These systems must be understood as sociotechnical systems in which technical infrastructure and legal framework interact with users and organizations. Therefore, the assessment includes aspects which relate to both hardware (e.g., toilets, tanks, and trucks) and software (e.g., organizational structure, user attitudes, and regulations). Since one of the aims of a source-separating wastewater system is to return nutrients to agriculture, the system boundaries are set to include the user interface, collection system, transportation, treatment, and reuse. The geographical boundaries of each system generally correspond with municipal boundaries since Swedish municipalities have a monopoly and mandated responsibility for managing household waste, including wastewater fractions.

The multi-level perspective highlights three layers, the micro-, meso- and macro-level of technological systems. The meso-level is called the regime and is represented by the existing dominate system of waterborne sewers within existing wastewater jurisdictions, i.e., pipe wastewater networks. Analysis of the regime brings in institutional issues [13] and certain aspects from a technology innovation system (TIS) approach [14]. The micro-level or niches represent areas of new development and radical innovation, in this case source-separation systems. The niche is assessed through applying a TIS lens to case studies of eight Swedish municipalities with existing on-site source-separation systems outside existing municipal wastewater jurisdictions. The aim of these systems is to improve the recovery and reuse of fertilizing nutrients from excreta while also minimizing eutrophication. The macro-level is the background landscape and consists of slow-changing trends which influence the other level. It is analyzed using a STEEPLED approach [15].

## 3. Results

The results presented here build on previous research by the authors on source separation in Sweden [16], which provides an in-depth study of source separation as a niche technology in Swedish municipalities. The results of the niche study are summarized here and more details provided on the regime and landscape analysis.

### 3.1. Niche analysis

The performance of source-separation wastewater systems as a technical niche in Sweden was assessed using a TIS methodology in a parallel study based on eight Swedish municipalities using these technologies. In general, it should be noted that the niche market for source separation in Sweden is on-site systems which are used in individual housing areas, outside the urban wastewater jurisdiction. There are a few cases of functional systems for urine diversion within urban wastewater jurisdictions, but these are mainly within schools or “eco-villages”. The analysis assessed critical functions which affect how innovations develop [14,17]: knowledge development, entrepreneurial activities, legitimation, market formation, resource mobilization, and guidance of the search. Since previous sociotechnical studies of wastewater systems have highlighted the need for communication channels and participatory arenas between stakeholders [18,19], the function “development of social capital” was added to this analysis.

Considering that source separation is still in a development phase and not yet widely applied, the study found that source-separation works moderately well within the on-site sanitation niche and that blackwater systems in general perform better than urine diversion. Although Sweden has been the leading country in knowledge production related to urine diversion, and among the top 10 countries regarding nutrient recovery and source separation, knowledge development is still a major barrier for expansion of the practice of source separation. For example, stakeholders often cite lack of knowledge on risk assessments, regulations, and technical standards as barriers for expanding use of this technology. Lack of knowledge development has ripple effects in multiple other critical functions. For example, a major barrier for urine diversion has been, and still is, 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 products (e.g., separating toilets and components) which can be directly related to the knowledge development, described above, but also inadequate entrepreneurial activity (e.g., a few small-size entrepreneurs) for ironing out uncertainties. All of these barriers are of course influenced by resource mobilization (e.g., funding for R&D) and guidance of the search (e.g., supportive policy). Consequently, market formation for source-separating systems is weak, although not unreasonably so considering that these technologies have not reached a growth phase for development. There are few toilet models available, especially for urine diversion, and financing for infrastructure development has been limited.

Aside from technical challenges with immature products, all of the studied cases have struggled with difficulties organizing the entire system from collection to reuse. These difficulties include establishing logistical systems, e.g., collection and transport, but also discrepancies in policy interpretation in the different municipalities and division of responsibility between stakeholders. Establishing an effective organizational structure is also made difficult as the recycling chain includes many actors that normally are not involved in wastewater systems. In addition, several key actors (e.g., farmers and politicians) tend to be risk adverse, thus creating a barrier for both acceptance (legitimation) and development of social capital. There is some evidence that this may be changing as social capital, legitimation, and guidance of the search are moderately strong functions in the more recent cases described in this study. Several correspondents in the study suggested that strengthening the currently weak advocacy coalitions could increase social capital, encourage entrepreneurs, and also argue for the legitimacy of source separation beyond niche markets.

### *3.2. Regime analysis*

Sociotechnical regimes are characterized by inertia and self-stabilizing effects, thus representing significant barriers to the diffusion of alternative technologies [20]. The methodology used in this analysis is based on the premise that opportunities for innovation and change are greatest when the existing regime is destabilized [21] or weakly institutionalized [13]. Assessment of each dimension thus attempts to determine how stable and institutionalized it is. For example, the existence of one dominant organizational form would indicate that this particular dimension is highly institutionalized and thus has a strong resistance to change. On the other hand, a diversity of sectoral values could indicate tension and the potential for changing interpretations. The analysis covers six dimensions of sociotechnical regimes which have been identified by other researchers [13,22]: technological infrastructure, organization and financing, technoscientific knowledge, user preferences and norms, and sector values and legislation (Fig. 1). Information to evaluate these dimensions was collected from a variety of sources, including national statistics, national policy documents, literature, and expert interviews.

#### *3.2.1. Infrastructure*

Approximately 91% of the Swedish population is connected to a municipal wastewater treatment plant and a majority of them (85%) are connected to large treatment plants serving >2,000 person equivalents [23]. Smaller treatment plants for between 25 and 2,000 pe are estimated to treat 6% of wastewater [23]. About 9% of the population is connected to on-site systems for single households or community systems for <5 households. Of these the most common systems are combinations of septic tanks and infiltration (approximately 5% of population), while around 2% of the population have permanent dwellings with on-site systems which source-separated urine and/or blackwater (calculated from data in [24]). Source-separation systems serving multiple households do exist, but are quite rare. Existing centralized and conventional waterborne infrastructure are thus highly institutionalized. Since wastewater infrastructure tends to have long service lifetimes, this creates a significant rigidity in the regime.

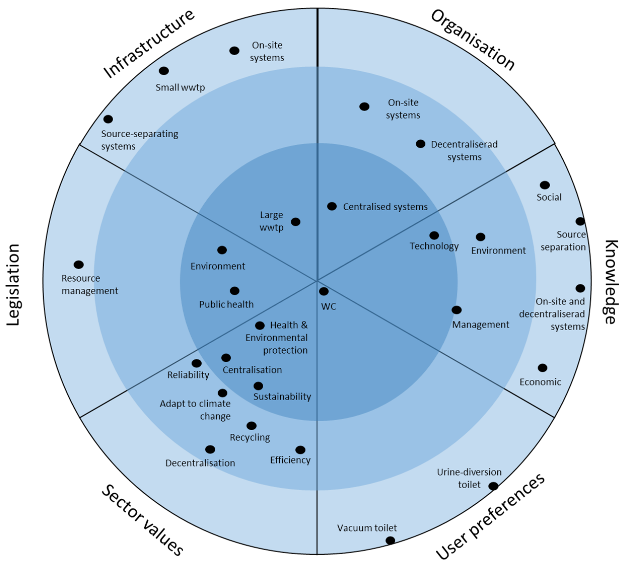


Fig. 1. Structuration of the wastewater and sanitation regime in Sweden in 2016. Positions of the symbols represent the degree of institutionalization: the closer to the centre of the circle, the stronger its institutionalization.

#### *3.2.2. Organization and financing*

Organizational structures for wastewater management in Sweden are closely related to infrastructure and are highly regulated within the wastewater jurisdictions. The Public Water Services Act (LAV: lag om allmänna vattentjänster in Swedish, 2006) requires that municipalities provide municipal water and wastewater service in areas where it is needed to protect public health and/or the environment. In these cases, the municipal council defines the area as part of the wastewater jurisdiction and thus it falls under the responsibility of the wastewater utility. The utility is responsible by law for building and assuring proper operation and maintenance of wastewater infrastructure. Utility operations are required by LAV to be self-financing through user fees. The large and small municipal wastewater treatment plants which serve over 90% of the population are all within defined urban wastewater jurisdictions and thus subject to LAV. Wastewater utilities in Sweden are normally operated by the municipality or a municipal-owned company. In either case, they are regulated by the same legislation regarding service provision. Residents within the jurisdiction are required to pay the service fees and follow the utility's requirements for water and wastewater installations.

Outside the wastewater jurisdiction, it is the responsibility of the individual household to assure that they meet the requirements set in legislation for the management of water and wastewater. All discharge of wastewater requires a permit, thus households are required to obtain a permit from the environmental authority at the municipality and regularly control that their wastewater system meets code. Correspondingly, the municipality is required to inspect and regulate wastewater systems outside the urban wastewater jurisdiction. All costs for implementation and operation of on-site systems are the responsibility of the household. However, municipalities have sometimes been known to subsidize upgrading of on-site systems, including source separation. This has generally been done when municipalities have received money from county or national level for specific projects focusing on reuse of nutrients. Decentralized systems, where several households together build and operate a wastewater treatment system, is also fairly common. Legally, these community systems have the same obligations as individual households to meet legislative requirements and obtain a discharge permit. However, the management organizations of these community systems can differ depending on how the individuals involved decide to organize themselves; ranging from informal collaboration to formal association management.

In general, organizational forms regarding centralized systems within the wastewater jurisdiction are highly institutionalized with legislation governing roles and responsibility of the actors involved. On-site systems and decentralized systems with multiple households outside the jurisdiction are subject to the same environmental legislation, but there is greater flexibility for structuring the management organization as LAV does not apply. The role of the municipality within these systems is more adaptable and several municipalities are currently exploring alternative management structures for areas with on-site and decentralized systems.

#### *3.2.3. Knowledge*

Knowledge trends in the Swedish wastewater and sanitation sector were mapped based on an evaluation of publications produced in Sweden during the period 1995–2015 (source Scopus). Of course, a large amount of knowledge is found in grey literature and in Swedish reports which are not reflected in this study. Themes related to centralized vs. decentralized treatment, source separation, and different sustainability factors were chosen to try to capture the diversity of knowledge that may be produced in the sector. These key word searches were then compared with the total number of publications in the sector. The majority of publications were related to technologies (77%). However, management (66%) and environment (60%) were also dominant trends in Swedish publications. Publications related to decentralized and on-site systems represented 3% and 5%, respectively, for total knowledge produced. Economic and social issues were relatively common at 20%, respectively, 15% of the publications. However, publications related to source separation and urine-diversion represented just 2% and 3% of publications, respectively (blackwater had even less). The small amount of knowledge being produced for source-separated systems indicates that the majority of knowledge production is still related to conventional wastewater treatment processes and plants. However, since 2012 there has been a trend in Sweden, as well as globally, with an increasing number of publications related to resource and nutrient recovery. While, this may support the production of more knowledge related to source-separated systems, it could also drive more end-of-pipe solutions that support the centralized wastewater regime.

#### *3.2.4. User preferences and norms*

Positive user attitudes and acceptance is a prerequisite for widespread diffusion of technologies [25]. However, a major challenge for source-separation systems is offering a competitive alternative to the regime standard of a water closet (WC), or flush toilet. In Sweden, there is a clear preference for flush toilets, with approximately 99% of the population connected to a WC [23,26]. The number of urine-diversion toilets has been estimated at 135,000, mainly in summer homes and mostly dry urine-diverting systems [27]. For blackwater, there are tens of thousands of low-flush toilets connected to tanks and approximately 1,000 systems with vacuum toilets, a number which is rapidly growing. Many consider that urine-diversion or dry toilets may be acceptable in a vacation house, but at home people want the convenience of a classic WC [26,28].

Management of human excreta is an issue that evokes strong emotions and avoidance reactions in all cultures. Conventional flush-and-forget technologies have achieved widespread acceptance because they allow for the physical and mental avoidance of this subject [29]. Alternatives to the standard WC system will need to provide an equivalent level of comfort, convenience, and cleanliness if they are to gain widespread acceptance. This is predominantly an engineering and design challenge; however, it will need to be coupled with good arguments and motivators for changing user habits and preferences. Sociological research on source-separation technologies indicates that users are surprisingly open to these new technologies, especially if they are well-informed of the benefits [30]. Understanding the reasons for the success of the WC and including users in the design process is likely the key to developing successful alternatives. This is exemplified in the most enduring urine diversion systems in Sweden, which have been collectively designed, implemented, and organized by the users [18].

#### 3.2.5. Sector values

Assessment of dominant values in the Swedish wastewater sector was done based on analysis of policy documents from a selected number of municipalities. Municipal water and wastewater policies in Sweden are non-binding documents which clarify strategic choices, priority issues and set guidelines; thus representative documents for assessing the values driving decisions. A sample of 35 municipalities was chosen, representing 29% of the total Swedish population, 12% of total municipalities, and including municipalities from 20 of the 21 counties. The documents were coded in an iterative process in which stated values were streamlined and aggregated into common themes. Protection of health and environment are the most dominant values with all policies referring to one or both of these goals (83% refer to both). Sustainability (71% of policies), adaptation to climate change (66%), and closed-loop systems for water and nutrients (63%) are also popular values coming from an environmental good logic.

Approximately 50% of the wastewater produced in Sweden is treated in wastewater treatment plants which are certified according to the REVAQ system [31]. This certification ensures that the wastewater treatment plant is actively working with upstream activities to reduce the inflow of pollutants to the wastewater treatment plant so that the quality is improved for both the sludge produced and the effluent. The intention is to increase the reuse of sewage sludge, and hence provide possibilities for recycling phosphorus and organic matter to agriculture. Agricultural reuse of sewage sludge, even from REVAQ certified wastewater treatment plants is, however, still controversial, probably due to the complexity of wastewater in terms of its pollutant load as it is a reflection of the general consumption patterns in society. According to official national statistics, approximately 23% of the sewage sludge produced was used in agriculture in 2012 [23]. If it is assumed that only REVAQ certified sludge is reused, it can be assumed that <50% of the REVAQ-certified sludge is actually reused in agriculture. This can be seen as a barrier against efficient reuse of nutrients from the conventional wastewater systems. Moreover, the reuse of sewage sludge in Sweden captures only mainly phosphorus, which is another weakness with the agricultural recycling from conventional wastewater systems.

Aside from environmental values and recycling, there are also strong values which are more representative of public and economic good logics which can be in conflict with environmental good, e.g., system reliability (66%) and resource efficiency (60%). A potential conflict also exists between valuing expansion of the centralized wastewater system (71%) and support for decentralized solutions (51%). This analysis indicates strong environmental values within the regime and a willingness within half of the municipalities to explore alternative options to centralization. However, there are also strong values driving decisions based on economic efficiency, risk reduction, and maintenance of existing infrastructure (60%). There appears to be significant tension and room for debate within regime value structures.

#### 3.2.6. Legislation

Swedish legislation related to wastewater management covers three generations of regulatory development with different focuses: health protection, environmental protection, and resource management [32]. Regulations regarding wastewater management from a health perspective have existed in Sweden, since the 1860s with the primary aim to protect public health. The first environmental regulations related to wastewater came in 1942 and were strengthened in environmental protection laws in 1969 which were coupled to national support for construction of municipal wastewater treatment plants. The current Swedish Environmental Code (EC: Miljöbalken in Swedish) from 1999 is a compilation of 15 previous health and environmental acts, thus building on previous legislation and layering new laws in concord with the previous ones [32]. The EC also contains the first Swedish regulations requiring resource management, emphasizing recycling and efficient use of natural resources (EC chapter 1§1). Since 2006, the Swedish Environmental Protection Agency's EC guidelines for on-site sanitation are based on setting functional requirements, instead of prescribing specific technologies. However, the functional requirement principle is not valid when requiring specific actions from households and can only be applied towards actions by municipalities and companies. In parallel to the EC, 16 National Environmental Quality Objectives were established in 1999. Recirculation of natural resources (including plant nutrients) was part of these objectives and one of the targets stated that by 2015 at least 60% of phosphorus compounds present in wastewater would be recovered for use on productive land (this target was removed in 2012 when the structure of the objectives was revised and have not yet been replaced by new targets). In addition, as a member of the European Union, Sweden, follows European Water and Wastewater Directives and the non-binding policy goals of the EU 7th Environment Action programme (2013) which also specifies resource management as a goal for 2020.

The requirements for resource management set in the EC are worded to be on-par with the goals set for environmental and health protection with no difference in their degree of applicability. However, the regulations related for resource management are rarely applied today and there has been surprisingly little precedent related to this regulation after 17 years. The few precedents that exist highlight the difficulty of applying this legislation. For example, strictly speaking, recycling of nutrients from wastewater is not only a function of the system, for collection and treatment, which is directly regulated by permits according to EC. It is rather of the fact that a farmer uses them in agriculture to replace other fertilizers, which is an activity that cannot be directly steered by the municipality. However, there is a Catch-22 moment in the regulation where on one hand the courts have ruled that a municipality cannot make demands, e.g., source-separating systems, if there is no end-user for the collected nutrient-rich fractions, while on the other hand a farmer cannot legally be forced to use a specific product (e.g., source-separated urine). Municipalities are thus in the difficult position where they must manage a waste, but control neither the production stage (household toilet), nor the recycling stage (farmer). An additional complication is that source-separated wastewater fractions are classified as household waste and thus the responsibility of the municipal waste management department (often separate from the municipal wastewater department). This separation of legal responsibilities makes organization of the service chain difficult. On the other hand, the Planning and Building Act (2010) gives municipalities the ability to single-handedly decide on the spatial planning and infrastructure development in the local situation, especially when the municipality owns the land, but this is rarely used to enable closed-loop approaches for wastewater systems.

In addition, within wastewater jurisdictions, LAV applies. This specifies that the wastewater services should be self-financed by connection and user fees. However, it also specifies that only necessary costs may be taken on by the wastewater services. Resources such as nutrients should according to EC (chapter 1§1) be recovered, but on the other hand there are no precedents that this really is a necessary cost, thus it is still uncertain how large of a costs and how much effort, the wastewater services should, or may, put into resource recovery. Furthermore, LAV regulates that the utility should provide connection points to the household for tap water, wastewater, and storm water. However, LAV neither mentions source separation of excreta, nor any connection points for source-separated fractions such as urine or blackwater. Thus, LAV does not give any legal support for the wastewater utility to require source separation by the household, even if it would greatly simplify the provision of wastewater services.

In general, Swedish wastewater legislation can be seen as highly institutionalized, particularly with regards to health and environmental standards. However, the legislative system has been built up over more than 150 years in different legislatives based on the needs of society at the time. As a result, there is a certain lack of coordination between laws, resulting in gaps, overlaps, and sometimes contradictions. In particular, legislation related to resource management is relatively new and untested in the courts. While there are significant challenges to ironing out gaps, precedent, and contradiction in this third generation of legislation, there are also still, after 17 years, opportunities for new interpretations.

### 3.3. Landscape analysis

The landscape level is defined by a diverse set of macro-environmental factors such as, energy prices, economic growth, conflicts, demographic trends, politics, cultural and normative values, environmental conditions, etc. In this framework, mapping of this macro-level will be aided by use of a STEEPLED analysis (originally known as PEST (political, economic, social, technological) analysis [33]). It covers social, technological, economic, environmental, political, legal, ethical, and demographic factors that can influence the sociotechnical regimes and niches. The list is derived from previous studies [15,34] and adapted to the Swedish context based on the combined experiences of the authors (Table 1).

A number landscape factors represent potential opportunities for source separation to grow. Environmental awareness is already quite high in Sweden, which does not seem to have created more space for the niche. A recent survey found that 100% of Swedes feel that protecting the environment is personally important for them [35]. What may be more important than overall environmental awareness is the attitude of professionals in the sector. Here, the on-going generation shift in the Swedish wastewater sector from predominantly technically oriented men towards an increasing number of environmentally oriented women may create major opportunities for transition. In addition, changes in how individuals understand environmental impacts and their own role as consumers can change and potentially drive alternative system choices. For example, mainstreaming of the circular economy movement might have this affect. Knowledge dissemination channels such as formal media and other information and communication technology actors will play a crucial role here.

In addition, innovations in source-separation technologies, e.g., improved product design, or methods for concentrating fertilizers, would support the niche. Similar to environmental awareness, fertilizer shortages and the phosphorous crisis of 2008–2009 did not provide the expected boast to source separation. Again, however, this could change if the shortage is of longer duration or in relationship to other nutrients that are less easily extracted from mixed wastewater, such as nitrogen (N) or potassium (K). Stricter pollution and climate legislation, including reduced emissions of pharmaceuticals and pathogens, and perhaps coupled with tax/subsidy incentives could also support the niche. For example, taxes on high-energy processes like N-fixation or increased N-removal requirements could make source-separation economically competitive. The strong urbanization trend and accompanying housing shortage in Sweden also creates opportunities for innovation in new building stock; and several cities are currently experimenting with urban source-separating systems (Stockholm, Helsingborg).

Several landscape factors also represent threats to the expansion of source separation. For example, competing innovations which efficiently recover nutrients from WWTPs would reduce the need for source separation (this is already the case for P-recovery). Economic recessions or environmental disasters can lead to lack of funding for environmental projects or funds redirected to other needs. For example, flooding will likely distract resources away from sanitation in order to assure, e.g., drinking water quality and protect existing infrastructure. Existing fertilizer regulations also pose barriers to expanding the practice source separation, e.g., current EU regulations forbid the use of human excreta in organic farming which limits markets for reuse products. It is worth noting that the Swedish organic farming association (KRAV) allowed the use of human urine in organic farming before Sweden joined the EU in the mid-nineties and that many Swedish organic farmers still are in favour of such reuse. Similarly, ethical precautionary principles and risk aversion from key actors in closing the loop impede the spread of such technologies. For example, in spite of quality assurance large parts of the food industry in Sweden refuse to accept reuse from certified products, such as treated blackwater.

## 4. Discussion

The application of transition theory in this study helps to understand the diffusion of innovations such as source-separated wastewater systems. Transition processes generally follows an S-curve such as that shown in Fig. 2, with initial slow growth followed by rapid market growth [25]. According to Rogers [25], the acceleration part of the curve starts when 2.5% of the population has adopted a technology. According to the results of this study, source separation in Sweden is still within the innovator phase with just 2% of the population adopting such technologies. While, Swedish source separation in general is sitting at the bottom of the S-curve, certain municipalities and pockets of the Swedish market have already moved up the acceleration curve with greater than 10% of on-site sanitation systems connected to source separation [16]. Although source-separation works moderately well within on-site niche markets outside of wastewater jurisdictions in Sweden, there may be significant challenges mainstreaming these technologies for use within wastewater jurisdictions. It is estimated that there are 700,000 on-site wastewater systems in Sweden and that 30% of these are vacation homes [24]. Although this is not an insignificant market, especially considering the export potential to billions of on-site sanitation users around the world, it is a limited market compared with centralized systems. Using the MLP of this study, a number of windows of opportunity can be identified which could increase demand for source separation.

If the source-separation niche is to be expanded in Sweden, it will need to break into markets within the urban wastewater jurisdictions. In order to do so, further knowledge needs to be developed that will overcome glitches with immature technologies, clarify potential risks, and clearly define system advantages. This may require the use of new costing perspectives that focus on holistic sustainable use of resources, including water and other nutrients than phosphorous, and taking into account global issues such as planetary boundaries [36]. Increased water scarcity due to climate change may well support such costing models.

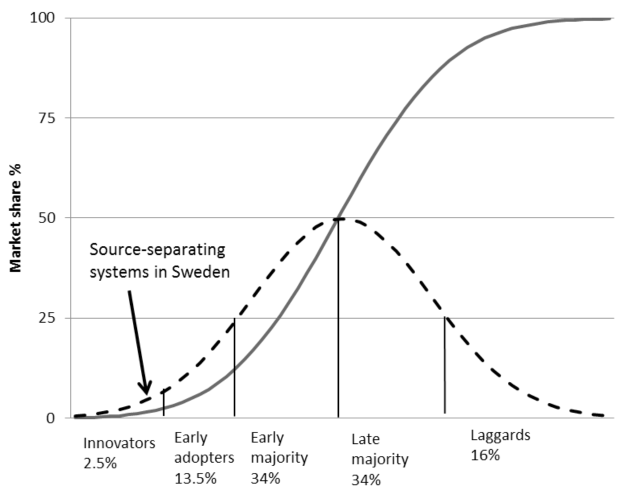


Fig. 2. Theoretical diffusion of innovations curve with consumers groups successively adopting the technology (dotted line) and thus increasing the market share of the technology until it reaches a saturation level (full line). Source separation in Sweden is theoretically at the base of the acceleration curve (adapted from [25]).

This knowledge can then be used to establish guidelines, norms, and standards, as well as clarify the legislative structures that can support such a transition. There is also a strong need for improved knowledge dissemination regarding best-practices for implementing source-separation technologies and supporting organizational structures, both outside and within wastewater jurisdictions. Source separation can offer more flexibility in the extension of municipal wastewater services, something that many municipalities are now looking for in high-density rural areas where LAV requires municipal service provision; but this requires developing new organizational models. Similarly, support for entrepreneurial activities within the niche needs to increase, not least through strengthening social networks and communication platforms.

At the regime level the dominance of centralized wastewater treatment plants is supported by the strong institutionalization of infrastructure, organizational structures, legislation, and user preferences. The strong degree of institutionalization in this system makes it resistant to change. These findings are in line with previous research [26] and perhaps unsurprising considering that the WC has been the dominant technology in urban Sweden for nearly a hundred years. An exception is on-site and decentralized systems where the regime is less rigid. There is also more variance in sectoral values and types of knowledge produced. These dimensions indicate potential tension within the sector about primary aim of the sector (e.g., public vs. environmental good) and a diversity of problem-solving approaches. In addition, the issue of resource management, both as a value and as a legal obligation, is very weakly institutionalized and subject to diverse interpretation. This analysis would therefore suggest that key opportunities for mainstreaming the niche lay in exploiting these weak points in the regime – that is alternative organizational structures (e.g., decentralization) and changing values regarding resource management, efficiency, and recycling. It should be noted that increasing importance of resource management is also a landscape trend and can be seen in areas outside the water and wastewater regime, e.g., the EU research emphasis on the bioeconomy. However, this will need to be done using technology that provides equivalent user convenience to the standard WC. Given good arguments for change people are willing to be environmentally friendly if it is not too complicated, too time-consuming, or too expensive [30].

It should be noted that there are municipalities, such as Helsingborg, where source separation is being investigated and explored within existing wastewater jurisdictions in planned urban development areas. Other municipalities are exploring expansion of wastewater jurisdictions using decentralized technologies and source separation (e.g., Västerås, Knivsta). If and when these projects are built they will provide valuable experience regarding possibilities for implementing niche technology within the regime. It seems likely that this type of niche–regime collaboration will be the most promising way for expanding the practice of source separation.

The landscape level does not appear to be applying strong pressure to the regime; however, there are a number of factors that may, if current trends continue, create pressure for change, e.g., increasing public environmental awareness;

Table 1
STEEPLED factors with the potential to impact on technology transitions in the Swedish wastewater sector

| Social | Technological | Economic | Environmental |
|---|---|---|---|
| **Changing environmental awareness** | *Innovation at WWTPs* | *Economic recession* | *Environmental disasters* |
| **Generation shift within professional fields** (e.g., young/more women) | **Innovation in source separation technologies** | **Fertilizer shortage** | Deteriorated agricultural conditions |
| Dietary trends (e.g., meat consumption) | | | |
| Waste handling practice (e.g., separation) | Parallel innovations in other sectors | **Tax/subsidy policies** | Impacts of nutrient emissions |
| Media influence | | Purchasing power | Water shortage |
| Political | Legal | Ethical | Demographic |
| Internal conflicts | *Fertilizer regulations* | *Precautionary principle* | **Urbanization** |
| Knowledge bias of decision-makers | **Stricter pollution legislation** | Sustainability ethic | Local population growth |
| International agreements | Green procurement | | Increasing immigration |
| Time frame of politicians | | | |

Note: Factors which are judged to be most likely opportunities (bold) or threats (italics).

fertilizers shortages; stricter environmental regulations and incentives, especially regarding medical residues, other micro-pollutants and pathogens; and urbanization. Many growing municipalities want to build in attractive areas near sensitive waterways, but water and wastewater services must first be solved. Thus, economic growth and expanding urban areas can push municipalities to try innovative solutions. However, based on the strength of the current regime, it is deemed unlikely that any of these factors alone will push regime actors to quickly adopt source separation. However, they are issues that niche actors could use to craft messages that would support expansion of the niche.

## 5. Conclusions

Given the stability of the existing wastewater regime it seems unlikely that internal changes will lead to a quick large-scale transition to source-separation systems. Instead, the initiative must come from the niche itself, exploiting institutional cracks in the regime and opportunities from shifting trends in the landscape. This paper has highlighted opportunities to strengthen the niche from within and advocacy arenas for expanding the use of source separation. In particular, this study highlights the following "windows of opportunity" for strengthening the competitiveness of source-separation systems and creating space for them within the urban wastewater regime. There are specific actions for both local and national level actors.

### *5.1. Municipal actors*

- Use and enforce environmental regulations requiring sustainable resource management (e.g., Swedish EC chapter 1§1 and EU policies for circular bioeconomy) in order to set precedent. Existing legislation is supportive but lacks clear definitions, particularly regarding roles and responsibilities of stakeholders.
- Explore options for decentralization and alternative organizational forms for providing municipal wastewater services.
- Pilot source-separated systems within the urban wastewater jurisdictions. This tests the technological and organizational possibilities and stretches the limits of regulations, standards, and norms.

### *5.2. National-level actors*

- Perform documented life-cycle based, cost-benefit analyses of complementary source-separating systems, including social and environmental risks. This knowledge is needed for informed decision-making.
- Support technology development and entrepreneurial activities within the niche in order to iron out glitches with immature technologies. This can lead to technical norms and standards which are necessary for expanding the market.
- Disseminate practical knowledge gained by current innovators in source-separation regarding best-practices for implementing technologies and supporting organizational structures. Establishment of a network of practitioners working with source-separation system can strengthen the confidence of network actors, increase knowledge exchange, and provide legitimacy.

An example of how these opportunities could be used would be to focus on the growing discontent by the municipalities in relation to the institutional cracks regarding the LAV legislation. The requirement that the municipality is fully responsible for service provision in all cases when "water and wastewater services ought to be provided in a larger context" is considered to be too expensive and too demanding a burden for the dynamic development of the municipalities. On top of this, environmental regulations for wastewater management are getting stricter. According to the 2016 decision by the Grand Chamber Court of the EU (case C-461/13), no permits will be issued for new wastewater treatment plants which negatively impact any of the chemical or ecological status indicators of the recipient of the effluent, which is a very strict requirement. Thus, an updated version of LAV which responds to: (1) stricter regulations regarding water pollution,

(2) increased pressure for resource recycling, e.g., EU circular and bioeconomy policies which strengthen the requirements already in the Swedish EC, and (3) municipal needs for flexible solutions, e.g., connection points for source-separated fractions, could open up new opportunities for source-separated systems. The use of several of these windows together might open for a regime transition and the rapid expansion of source separation wastewater systems in Sweden.

## References


[1] T.A. Larsen, A.C. Alder, R.I.L. Eggen, M. Maurer, J. Lienert, Source separation: will we see a paradigm shift in wastewater handling?, Environ. Sci. Technol., 43 (2009) 6121–6125.

[2] J.S. Guest, S.J. Skerlos, J.L. Barnard, Beck, M. Bruce, G.T. Daigger, H. Hilger, S.J. Jackson, K. Karvazy, L. Macpherson, J.R. Mihelcic, A. Pramanik, L. Raskin, M.C.M. van Lossdrecht, D. Yeh, N.G. Love, A new planning and design paradigm to achieve sustainable resource recovery from wastewater, Environ. Sci. Technol., 43(2009) 6126–6130.

[3] B. Vinnerås, H. Jönsson, The performance and potential of faecal separation and urine diversion to recycle plant nutrients in household wastewater, Bioresour. Technol., 84 (2002) 275–282.

[4] H. Jönsson, Urine separating sewage systems – environmental effects and resource usage, Water Sci. Technol., 46 (2001) 333–340.

[5] D. Cordell, A. Rosemarin, J.J. Schröder, A.L. Smit, Towards global phosphorus security: a systems framework for phosphorus recovery and reuse options, Chemosphere, 84 (2011) 747–758.

[6] M.E. Borsuk, M. Maurer, J. Lienert, T.A. Larsen, Charting a path for innovative toilet technology using multicriteria decision analysis, Environ. Sci. Technol., 42 (2008) 1855–1862.

[7] J.A. Wilsenach, Treatment of Source Separated Urine and Its Effects on Wastewater Systems, Delft University of Technology, Delft, The Netherlands, 2006.

[8] H. Kjerstadius, Å. Davidsson, J.C. Jansen, Sustainable systems for biogas production from sewage sludge and food waste (in Swedish). SGC Report 2012:271.

[9] Swedish EPA, Hållbar återföring av fosfor Naturvårdverkets redovisning av ett uppdrag från regeringen, Report No. 6580, Swedish Environmental Protection Agency, Stockholm, Sweden, 2013.

[10] M. Johansson, E. Kvarnström, A.R. Stintzing, Going to Scale with Urine Diversion in Sweden – From Individual Households to Municipal Systems in 15 Years, First IWA Development Congress, Mexico, 2009.

[11] B. Vinnerås, H. Jönsson, The Swedish Experience with Source Separation, T.A. Larsen, K.M. Udert, J. Lienert, Eds., Source Separation and Decentralization Wastewater Management, IWA Publishing, London, 2013, pp. 415–422.

[12] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Policy, 31 (2002) 1257–1274.

[13] L. Fuenfschilling, B. Truffer, The structuration of socio-technical regimes—conceptual foundations from institutional theory, Res. Policy, 43 (2014) 772–791.

[14] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: a scheme of analysis, Res. Policy, 37 (2008) 407–429.

[15] J.R. McConville, R. Künzle, U. Messmer, K.M. Udert, T.A. Larsen, Decision support for redesigning wastewater treatment technologies, Environ. Sci. Technol., 48 (2014) 12238–12246.

[16] J.R. McConville, E. Kvarnström, H. Jönsson, E. Kärrman, M. Johansson, Source separation: challenges & opportunities for transition in the Swedish wastewater sector, Resour. Conserv. Recycl., 120 (2017) 144–156.

[17] M.P. Hekkert, R.A.A. Suurs, S.O. Negro, S. Kuhlmann, R.E.H.M. Smits, Functions of innovation systems: a new approach for analysing technological change, Technol. Forecasting Social Change, 74 (2007) 413–432.

[18] D.M. Fam, C.A. Mitchell, Sustainable innovation in wastewater management: lessons for nutrient recovery and reuse, Local Environ., 18 (2013) 769–780.

[19] S. Storbjörk, H. Söderberg, Plötsligt händer det – Institutionella förutsättningar för uthålliga VA-system, Mistra Urban Water Program, Gothenburg, Sweden, 2003.

[20] C. Binz, B. Truffer, Leapfrogging in Infrastructure Identifying Transition Trajectories Towards Decentralized Urban Water Management Systems in China, DRUID Conference, Copenhagen, 2009.

[21] F.W. Geels, J. Schot, Typology of sociotechnical transition pathways, Res. Policy, 36 (2007) 399–417.

[22] F.W. Geels, Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective, Technol. Forecasting Social Change, 72 (2005) 681–696.

[23] SCB Statistics Sweden, Discharges to Water and Sewage Sludge Production in 2012 Municipal Wastewater Treatment Plants, Pulp and Paper Industry and Other Industry, Stockholm, Sweden, 2014.

[24] M. Ek, C. Junestedt, C. Larsson, M. Olshammar, M. Ericsson, Teknikenkät - enskilda avlopp 2009, Sveriges Meteorologiska och Hydrologiska Institut, Norrköping, Sweden, 2011.

[25] E.M. Rogers, Diffusion of Innovations, 5th ed., Free Press, New York, 2003.

[26] A. Wallin, M. Zannakis, S. Molander, On-site sewage systems from good to bad to...? Swedish experiences with institutional change and technological dependencies 1900 to 2010, Sustainability, 5 (2013) 4706–4727.

[27] E. Kvarnström, K. Emilsson, A.R. Stintzing, M. Johansson, H. Jönsson, E. af Petersens, C. Schönning, J. Christensen, D. Hellström, L. Qvarnström, P. Ridderstolpe, J.-O. Drangert, Urine Diversion : One Step Towards Sustainable Sanitation, EcoSanRes Publications Series, Stockholm Environment Institute, Stockholm, Sweden, 2006.

[28] Swedish EPA, Kretsloppsanpassade avloppssystem i befintlig bebyggelse, Report No. 4847, Swedish Environmental Protection Agency, Stockholm, Sweden, 1997.

[29] J. Lienert, High Acceptance of Source-Separating Technologies – but ..., T.A. Larsen, K.M. Udert, J. Lienert, Eds., Source Separation and Decentralization Wastewater Management, IWA Publishing, London, 2013, pp. 193–208.

[30] J. Lienert, T.A. Larsen, High acceptance of urine source separation in seven European countries: a review, Environ. Sci. Technol., 44 (2010) 556–566.

[31] Swedish EPA, Rening av avloppsvatten i Sverige, Swedish Environmental Protection Agency, Stockholm, Sweden, 2014.

[32] J. Christensen, Juridiken kring vatten och avlopp, Havs- och vattenmyndighetens rapport 2015:15, Göteborg, Sweden, 2015.

[33] S. Wall, A. Griffiths, Economics for Business and Management, 2nd ed., Financial Times/Prentice Hall, Harlow, England, 2008.

[34] T.A. Larsen, M. Maurer, R.I.L. Eggen, W. Pronk, J. Lienert, Decision support in urban water management based on generic scenarios: the example of NoMix technology, J. Environ. Manage., 91 (2010) 2676–2687.

[35] European Commission, Attitudes of European citizens towards the environment, Special Eurobaromere, 416, 2014.

[36] W. Steffen, K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs, S.R. Carpenter, W. de Vries, C.A. de Wit, C. Folke, D. Gerten, J. Heinke, G.M. Mace, L.M. Persson, V. Ramanathan, B. Reyers, S. Sörlin, Planetary boundaries: guiding human development on a changing planet, Science 347 (2015). doi:10.1126/science.1259855.