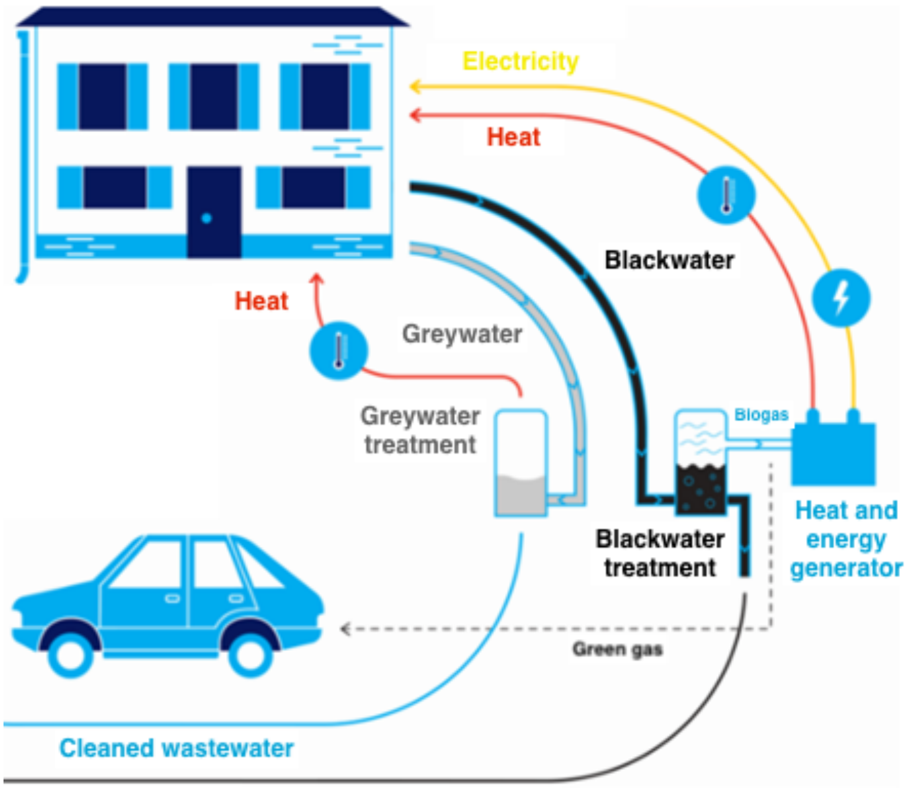
Master's Thesis – master Innovation Sciences

The development of DESAR technologies in the Netherlands

Student: Jorin de Mul; 3987884; j.j.demul@students.uu.nl; +31636188830



Supervisor: Prof.Dr. Bernhard Truffer; Bernhard.Truffer@eawag.ch
Second supervisor: MSc. Jonas Heiberg; Jonas.Heiberg@eawag.ch

Second reader: Dr. Wouter Boons; W.P.C.Boon@uu.nl

Universiteit Utrecht

Contents

Abstract

The Dutch government aims to have an economy that is completely circular by 2050. Resources need to be reused as much as possible in order to reach this. Current wastewater management has been criticized for being fundamentally unsustainable and it fails to close the resource cycles. Decentralized sanitation and reuse (DESAR for short) technologies are possible alternatives for parts of the current system. It is being acknowledged by the Dutch government that DESAR technologies are potential alternatives for parts of the current system, but there is no clarity on how these technologies can contribute to a sustainable transition in the Netherlands and what the conditions are for DESAR technologies to develop. The following research question has been composed: *"What barriers and drivers can be identified in the DESAR innovation system in the Netherlands and how may these technologies contribute to a sustainability transition in the Dutch urban water management sector?".* An innovation system includes all important factors that influence the development, diffusion and use of innovations. In this study, a qualitative research method has been used in which sixteen experts in the field have been interviewed.

The core structures and processes that are necessary for the development of DESAR technologies have been assessed. Various barriers and drivers have subsequently been identified that hamper or induce the development of DESAR technologies in the Netherlands. The main findings are: 1) There is no clear governmental policy how to develop a circular economy; 2) There is a lack of suppliers on the market that can deliver DESAR technologies; 3) Housing corporations and project developers lack the willingness to innovate; 4) Pilots are beneficial in the development of DESAR. However, a critical scale size of 2000 and 3000 housing or larger is required to make DESAR implementation profitable; 5) There is a lack of financial and human resources; 6) It has yet to be decided whether or not municipal heat companies are going to be included, creating uncertainty and slowing down the development.

DESAR technologies are believed to have the potential to contribute to a sustainability transition in the Dutch urban water management sector. A hybrid system (both centralized and decentralized sanitation) will likely exist in the future, meaning that the DESAR technologies will be mainly applied in new housing estates. There is no need to fundamentally restructure the Dutch urban water management sector in order for DESAR technologies to flourish.

1. Introduction

1.1 Societal background and problem definition

The Dutch government aims to have an economy that is completely circular by 2050 (Rijksoverheid, 2016). In order to reach this, resources need to be reused as much as possible, meaning that the resource cycles need to close. Urban water management builds upon a well-established socio-technical system that solved most of the water and hygiene-related problems in cities all over the world by providing safe drinking water, urban hygiene, and protection of flooding (Larsen et al., 2016). A part of urban water management is concerned with wastewater processing. Current wastewater management has been criticized for being fundamentally unsustainable because it depends strongly on large quantities of water, uses resources inefficiently and fails to close the resource cycles (Larsen et al., 2016; Lens et al., 2001, pp. 6–7; Mels, 2005). All wastewater streams (e.g. rainwater, grey water from the sink and shower, black water from the toilet) are mixed and subsequently transported via a single sewage pipe instead of being treated separately (Hegger et al., 2008, p. 24; Larsen et al., 2016; Lens et al., 2001, pp. 6–7; Mels, 2005). As a result, large amounts of energy are needed in order to treat the mixed wastewater while the treated water can only be reused partly because it still contains toxic materials (Hegger et al., 2008, p. 24; Lens et al., 2001). Decentralized sanitation and reuse (DESAR for short) technologies are possible alternatives for parts of the current system (Hegger et al., 2008, p. 24; Lens et al., 2001, pp. 6–9).

DESAR technologies can be defined as a group of innovations that provide technical solutions for collection and treatment of wastewater, focusing on reliability and minimum water wastage (Hegger et al., 2008). These DESAR technologies have the advantage that they separate water streams at the source (blackwater, greywater and rainwater) and allow for local treatment of water, which increases water productivity (Larsen et al., 2016). Examples of current DESAR technologies are vacuum toilets/sewers, local water treatment plants, dry toilets, thermal energy recovery technologies and technologies aimed at separating wastewater streams. It is being acknowledged by the Dutch government that DESAR technologies are potential alternatives for parts of the current system, but there is no policy dedicated to the application of DESAR technologies (Hegger et al., 2008; Moron et al., 2018). Research is needed that gives insight on how DESAR technologies are able to contribute to a sustainability transition in the Netherlands and what the conditions are for DESAR technologies to develop (Moron et al., 2018). The central aim of this study is to identify the conditions for DESAR technologies to contribute to a sustainability transition in the urban water management sector in the Netherlands.

The Netherlands is known for having innovative activity within the water management field (Hegger et al., 2008; OECD, 2014; Van Der Roest et al., 2002) and has over 10 pilots in which DESAR technologies are applied. The two most salient DESAR pilots in the Netherlands in terms of size and visibility (in terms of media attention) are Buiksloterham and Strandeiland, which are therefore used as main object of analyses for the data collection for this study. DESAR technologies used in these pilots are vacuum toilets, local water treatment plants and thermal energy extraction plus reuse technology. It is unknown how important these pilots are for a sustainability transition in the Netherlands and how they are executed so far.

1.2 Scientific background

To better understand the development conditions of DESAR we adopt a systemic perspective. The technological innovation system (TIS) framework provides an encompassing approach to analyze the core structures and processes that are necessary for developing a certain technology (Hekkert et al., 2007). An innovation system can be defined as *"All important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion, and use of innovations"* (Edquist, 2009, p. 182) and is composed of actors, networks and institutions that develop, diffuse and use innovation (Carlsson & Stankiewicz, 1991). These actors, networks and institutions are called structural components in the literature. In order to understand technological change and to be able to guide its direction, insight in the structural components of an innovation system is not enough. The processes of an innovation system (so called functions) need to be analyzed (Hekkert et al., 2007). By looking at the structural components and the functions, mechanisms can be identified that block or induce the development of the DESAR innovation system (Bergek et al., 2008).

A sectorial transition cannot be understood by only looking at the maturation and diffusion of single technologies (Markard & Truffer, 2008). Therefore, we also have to consider how the new technologies interact with broader sectorial structures. The TIS framework is known for not paying much attention to the system's environment (Bergek et al., 2015; Markard & Truffer, 2008). A framework that explains the broader transition process is the Multi-level perspective (or MLP) (Geels, 2002). Socio-technical transitions in the MLP are understood as resulting from the interplay of stabilizing mechanisms at the regime level and pressures that destabilize the regime from the landscape level in combination with emerging (radical) innovations (or niche technologies) at the niche level (Geels, 2002). A technical regime is defined as: *"The rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures that make up the totality of a technology"* (Rip & Kemp, 1998). The landscape level is defined as *"A set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems"* (Geels, 2002). Finally, a niche can be defined as a protected space that comes in the form of an application domain or an early market for some alternative socio-technical configuration (Kemp et al., 1998).

There has been little overlap in the use of these frameworks, although they are based on common theoretical roots and show promising complementarities (Markard & Truffer, 2008). Processes like niche forming, institutional alignment and the entry of actors are important for the growth of a TIS and may become a powerful model for the explanation of technological transformations or even sectorial transitions. According to Markard & Truffer (2008), further analysis is needed in order to explore the benefits and difficulties of such an integrated framework. It will be necessary to do empirical test cases (like this study) to demonstrate the actual usefulness of an integrated framework (Markard & Truffer, 2008). In the context of the DESAR innovation system, this would mean that niches are emerging and allow for development of a TIS to happen. One or more niches (which can be a configuration or an application domain related to one of these technologies or a combination of them) can span over several pilots and are expected to interact with one or more incumbent regimes (Markard

& Truffer, 2008). The pilots will be used to analyze the structural components and the functions so that mechanisms can be identified that block or induce the development of the DESAR innovation system. Subsequently, an answer will be given on how these DESAR technologies may contribute to a sustainability transition in the Dutch urban water management sector.

1.3 Research question

In order to identify the conditions for DESAR technologies to contribute to a sustainability transition in the urban water management sector in the Netherlands, the following research question has been defined: *"What barriers and drivers can be identified in the DESAR innovation system in the Netherlands and how may these technologies contribute to a sustainability transition in the Dutch urban water management sector?"*

At the beginning of this study, it is unknown whether vacuum toilets/sewers, local water treatment plants and thermal energy extraction and reuse technologies form a coherent innovation system. Structural components of the DESAR innovation system(s) need to be identified and compared in order to determine if the DESAR technological field is homogeneous or heterogeneous in nature *(sub question 1)*. Depending on the homogeneity of the DESAR field, one, two or three sub-TISs should be analyzed. Mechanisms will be identified that block or induce the development of the DESAR innovation system. Based on this, an answer will be given on how well suited the pilots are to promote further development of the Dutch DESAR TIS (*sub question 2*). Finally, prospects will be given for the transition in the Dutch water management sector based on the study (*sub question 3*).

SQ1: How can we delimit the Dutch DESAR innovation systems? What kinds of system weaknesses exist in the different sub-TISs in terms of structures and functions?
SQ2: How well are the pilots suited to promote the further development of the Dutch DESAR TIS?
SQ3: What are the prospects of the transition in the Dutch urban water management sector based on the outcomes of the study?

The theory that forms the basis for this study will be described in Chapter 2. Chapter 3 provides an overview of the followed research methods. The results will be divided into three Chapters. The way the system is delineated is explained in Chapter 4. A structural analysis is presented in Chapter 5. A functional analysis is covered in Chapter 6. The result section ends with Chapter 7 that explains how DESAR technologies contribute to a sustainable transition. The conclusions can be found in Chapter 8, followed by the discussion in Chapter 9.

2. Theory

2.1 Concepts for the analysis of technological change

Innovation scholars have approached the analysis of technological change from at least two different perspectives, being the transition perspective and the emerging technology perspective (Markard & Truffer, 2008). Study strands of conceptual and empirical works that contributed to the transition perspective are transition Management (Rotmans et al., 2001), Strategic Niche Management (Kemp et al., 1998) and ultimately the MLP (Geels, 2002). The MLP is mainly used to explain the broader transformation process (Wieczorek, 2014) but is less powerful in explaining the roles of actors, strategy making and the interaction between actors and institutions (Markard & Truffer, 2008). The TIS framework contributes to the emerging technology perspective and provides an encompassing approach to analyze the core structures and processes that are necessary for developing a certain technology (Hekkert et al., 2007).

The TIS is member of the family of innovation system approaches, which stems from a combination of the classical theory of Friedrich List and the modern evolutionary-institutional theories like those of Chris Freeman, Richard Nelson, Charles Edquist and Bengt-Ake Lundvall (Frederiksberg & Kastelle, 2009). An innovation system is primarily an analytical construct that is used to illustrate and understand innovation dynamics and performance (Bergek et al., 2008). Earlier innovation system studies discussed the importance of innovation and knowledge as drivers of economic growth (Rosenberg, 1971), while the later innovation system studies focused more on the support of institutions (Nelson & Rosenberg, 1993) and the relationships between firms and other organizations (Lundvall, 1992). Both Nelson & Rosenberg (1993) and Lundvall (1992) defined an innovation system as factors influencing the innovation processes. However, Nelson & Rosenberg (1993) did not provide a sharp guide on what should be included in an innovation system, and Lundvall (1992) insisted that a definition of an innovation system must be kept open and flexible. According to Edquist (2009), the distinction between what is inside and outside a system is crucial, meaning that the boundaries of an innovation system have to be defined explicitly. Multiple variants of innovation system approaches subsequently emerged (national, regional and sectorial), that complement rather than exclude each other (Edquist, 2009). Critics argued however, that these innovation system frameworks made it difficult to explain how the system operates and why varying specificities of similar systems made it hard to transfer learnings gained from applying one system concept to another (Wieczorek & Hekkert, 2012).

The TIS approach emerged in response of these critics. The TIS approach can be traced back to the studies of Carlsson & Stankiewicz (1991), that focused on the interplay of firms and actors under a particular institutional infrastructure as the essential driver behind the generation, diffusion and utilization of technological innovation (Markard et al., 2012). In a TIS, the starting point is not geographical or sectorial, but a technology or technological field (Bergek et al., 2015; Binz & Truffer, 2017; Hekkert et al., 2007; Wieczorek & Hekkert, 2012).

2.2 Understanding the emergence of new industries

Most of the innovation system approaches are focused on weaknesses in the structural composition of a system by evaluating a particular structural component and compare this to the structures of other innovation systems without referring to its effects on the innovation process (Bergek et al., 2008; Wieczorek & Hekkert, 2012). On the contrary, a TIS is based on structural components which are evaluated on their capacity to stimulate innovation by using so called functions (Bergek et al., 2008).

The structural components used in the TIS analysis are actors, networks and institutions (Bergek et al., 2008; Binz & Truffer, 2017; Carlsson & Stankiewicz, 1991; Hekkert et al., 2007). Actors are all the individuals and organizations that play a role in the innovation process (Wieczorek & Hekkert, 2012) and are categorized into civil societies, companies, knowledge institutes, governmental and non-governmental organizations, and other parties (Bergek et al., 2008; Wieczorek & Hekkert, 2012).

Networks can be explained as all the informal and formal interaction within an innovation system (Bergek et al., 2008). Formal networks are often easily identified (Bergek et al., 2008). Examples of formal networks are standardization networks, partnerships and supplier groups. Informal networks evolve in a less orchestrated fashion (Bergek et al., 2008). Examples of informal networks are buyer-seller relationships and university-industry links.

Institutions structure the relations and interactions between actors and are considered as the rules of the game (Edquist & Johnson, 1997). Actors may change/adapt existing institutions or create new ones (Markard & Truffer, 2008). The concept of institution can be distinguished as formal (regulative) or informal (normative and cognitive) institutions (North, 1994; Scott, 1995, 2008). Regulative institutions consist of explicit processes like laws, regulations and standards (Scott, 2008). Normative institutions can be described as norms, values, customs and ethical standards that structure choices, emphasizing how things should be done and defining legitimate means to accomplish them (Scott, 2008). Cognitive institutions reflect the manner in which actors understand their environment and guide individual or firm behavior like (shared) beliefs, visions and interpretations (Scott, 2008). The structural components and their subcategories can be found in *Table 2.1*.

Table 2.1 Structural elements and their subcategories

Structural components	Subcategories
Actors (Bergek et al., 2008; Wieczorek & Hekkert, 2012)	- Civil society - Companies (start-ups, small and medium sized enterprises, large firms, multinational companies) - Knowledge institutes (universities, technology institutes, research centers and schools) - Government - Non-governmental organizations - Other parties (legal organizations, financial organizations, intermediaries, brokers, consultants)
Networks (Bergek et al., 2008)	- Formal networks - Informal networks
Institutions (Bergek et al., 2008; Edquist & Johnson, 1997; North, 1994; Scott, 1995, 2008)	**Formal** - Regulative (laws, regulations and standards) **Informal** - Normative (norms, values, customs and ethical standards) - Cognitive (beliefs, visions, and interpretations)

Structural components and functions inside a focal TIS are generally well conceptualized in the literature. However, what happens outside and across the system boundary has been worked out in a less systematical way (Bergek et al., 2015). Bergek et al. (2015) proposed ways to identify different types of interactions that cross TIS boundaries and give rise to coupled dynamics between a TIS and various contextual structures. They distinguished two types of interactions. The first type of interaction is ‘external links’, meaning influences that have impact on the development of a TIS but not affected by internal TIS processes. These ‘external links’ can be conceptualized as landscape forces (for instance sudden price shifts and technical disasters) or as forces closer to the TIS (for instance national policies affecting the TIS). The second type of interaction is ‘structural couplings’, which is described as shared structural components between contextual structures (Bergek et al., 2015). Most TIS elements do not only exist for purposes aimed at promoting the related technology. Instead, they typically exist because they are embedded simultaneously in several different contexts. Meaning that the decisions and strategies of shared actors cannot be explained by their involvement in the focal TIS alone, but will depend on the interaction between internal decision processes aimed at balancing the tension and trade-offs among different goals the actor wants to achieve (Bergek et al., 2015). A shared structural component can therefore be seen as a coupling structure between a TIS and different contexts. An example of such a different context is a related or surrounding TIS. Horizontal interactions draw on the same inputs and complementary assets to provide similar outputs. If there are a lot of horizontal relationships, then a technological field can be considered to be one TIS. If there are not so many, they should rather be treated as separate sub-TISs.

The structural components are evaluated on their capacity to stimulate innovation by using functions. Functions have a direct impact on the development, diffusion and use of new technologies and will be analyzed in order to describe what is actually going on in the TIS (Bergek et al., 2008). The functions used in the TIS analysis for this study are those proposed by Hekkert et al. (2007) and can be found in *Table 2.2*. These functions are empirically tested and cover similar functions that are used in other studies like Bergek et al. (2008), Wieczorek & Hekkert (2012) and Binz & Truffer (2017). The seven functions within a TIS describe the functional pattern (Bergek et al., 2008).

Table 2.2 Elaboration on seven functions.

Function	Explanation	Definition
F1: Entrepreneurial activity	Entrepreneurial activity is a first and primary indication of the performance of an innovation system (Hekkert et al., 2007). Causes of a lack in entrepreneurial activity may be found in the other six functions. Entrepreneurial activity is essential for a well-functioning innovation system.	All activity of entrepreneurs and incumbent companies diversifying their portfolio that have the potential to convert new knowledge, networks and markets into concrete actions relevant for the innovation system.
F2: Knowledge development	Mechanisms of learning are crucial for any innovation process because knowledge is the most fundamental stock of the modern economy (Lundvall, 1992).	All activity of 'learning by searching' and 'learning by doing' that lead to the knowledge development relevant for the innovation system.
F3: Knowledge diffusion	In order for networks to function, the exchange of information is essential (Carlsson & Stankiewicz, 1991). The exchange of information can be regarded as a precondition to 'learning by interacting' and 'learning by using' (Hekkert et al., 2007).	All activity regarding the exchange of knowledge among actors that is relevant for the innovation system. A distinction can be made between coded and tacit (non-codified) knowledge. Tacit knowledge is defined as: *"non-codified, disembodied know-how that is acquired via the informal take-up of learned behavior and procedures"* (Howells, 1996).
F4: Guidance of the search	Various technological alternatives of centralized wastewater systems exist. A selection is needed because resources are almost always limited (Hekkert et al., 2007).	All activity within the innovation system that can positively affect the visibility and clarity of specific needs and expectations among technology users.
F5: Market formation	For an emerging TIS, markets may not yet exist or are underdeveloped (Carlsson & Stankiewicz, 1991). Inventions are often relatively crude and inefficient in the beginning and thus may have no or only small advantages (Rosenberg, 1972).	All activity that drives the formation of DESAR technologies.
F6: Mobilization of resources	The allocation of financial, physical and human capital resources are needed as basic input within the IS (Wieczorek, 2014).	All activity concerned with the input of resources (financial, physical and human capital) within the innovation system.
F7: Creation of legitimacy	New technologies need to become part of an incumbent regime by creating legitimacy (Sabatier, 1988). Lobby activists or interests groups take actions to create legitimacy and react on the opposed force of 'creative destruction' of parties with vested interests (Sabatier, 1988).	All activity related to the creation of legitimacy of the emerging technologies(s) within the innovation system and activity aimed at counteracting resistance of the incumbent system.

Reconstructing a functional pattern does not in itself explain if a TIS is well-functioning or not. The relative 'goodness' or 'badness' of particular functions, called functionality, needs to be evaluated. By using a functional analysis, this evaluation can systematically take place. Although such a functional analysis is considered to be helpful, two bases of assessment should be used in combination.

Firstly, an assessment can take place by comparing TISs. This is a powerful way of improving the understanding for decision makers. Comparing TISs might give information on what development is reasonable to expect and it can help identify critical functions.

Secondly, an assessment can take place in which functions are evaluated according to what is needed in a specific development phase. The development of a TIS can be categorized into two phases, which are a formative and a growth phase (Bergek et al., 2008). The required functionality might differ between phases (Bergek et al., 2008; Bergek & Jacobsson, 2003; Jacobsson & Bergek, 2004). Or put differently, the way functions are performing depend on the requirements of each phase (Bergek et al., 2008). A system in the formative phase is characterized by structural components that are just getting in place and by high uncertainty in terms of technologies and markets (Kemp et al., 1998; Van De Ven, 1993). At some point, a TIS may begin to behave in a more self-sustaining way as it moves into a growth phase. The focus changes to system expansion and large-scale technology diffusion through bridging markets end eventually reaching to mass markets. Identification of the phases can be found in *Table 2.3* and are based on Bergek et al. (2008).

Table 2.3 Identification phase of development of TIS according to Bergek et al. (2008).

Phase	Identification
Formative	- Large uncertainties regarding technologies, markets and applications; - Price/performance not well developed; - There is just a fraction of the potentially reachable volume of diffusion; - Demand is unarticulated; - Absence of positive feedbacks and weak positive externalities; - Structural elements getting in place.
Growth	- System is self-sustaining - Focus changes to expansion and large-scale technology diffusion - Diffusion through bridging markets and eventually mass markets

Policymakers and entrepreneurs may want to build-up and eventually take-off TIS(s) around emerging sustainable technologies. To do so, they should take into account how functions within a system reinforce each other over time. The performance of the functions (evaluated as relatively 'good' or 'bad') could result in a virtuous cycle, led by positive or negative feedback loops (Suurs, 2009). Suurs (2009) identified four different cumulative causation (or motors) of sustainable innovation, each characterized by particular interactions between system functions. Firstly, the Science and Technology Push Motor (STP), which is dominated by knowledge development (F2), Knowledge diffusion (F3), guidance of the search (F4) and resource mobilization (F6). The willingness of actors and investors to participate into pilots depend on the outcomes of studies. Secondly, the Entrepreneurial Motor, which is similar to the STP motor, but emphasizes more on the importance of entrepreneurial activity (F1). The outcome of pilots, positive or negative, feeds back into an incentive or barrier for actors to participate in new pilots. This motor may be strengthened through the existence of niches. In a formative phase, a STP or an Entrepreneurial Motor normally emerges as a result of a dedicated (but small) group of enactors. If enactors are able to improve the institutions and technologies, more enactors may be attracted (Suurs, 2009). Thirdly, the System Building Motor, which is similar to the Entrepreneurial Motor, but also includes a more important role of market formation (F5). Entrepreneurs organize themselves in networks and attract new actors. They subsequently lobby for policies to mobilize resources and change/development of regulations in favor of the TIS. Fourthly and lastly, the Market Motor, in which all functions are strongly fulfilled except for creation of legitimacy (F7), which is no longer needed. According to Suurs (2009), policymakers and entrepreneurs should strive for a System Building Motor or a Market motor to emerge. Motors typically arise during the development of TISs as a transformation of less powerful motors. A System Building Motor was in the study of Suurs (2009) observed as being a transformation of the Entrepreneurial Motor, while the Market Motor was typically observed as a transformation of the System Building Motor.

2.3 How new technologies can change entire economic sectors

The MLP framework can help to understand the broader transition process. A TIS analysis provides more analytical power, will help to identify barriers and drivers for the development of the DESAR innovation system and seems to be complementary to the MLP. Markard & Truffer (2008) made a comparison of the key concepts of innovation systems and socio-technical transitions in order to explore the relationship between the TIS and the MLP.

Geels (2002) explained that the stability of existing sociotechnical configurations are results from linkages between heterogenous elements. These elements and linkages are subsequently the result of activities of social groups which (re)produce them. The activities of these different groups are coordinated and aligned to each other. Geels (2002) built upon the concept of technological regimes by Nelson & Winter (1982), who conceptualized the coordination of socio-technical activities as the outcome of organizational and cognitive routines. Technological regimes result into technological trajectories because groups of engineers search in the same direction. Rip & Kemp (1998) expanded the concept by defining technological regimes with the sociological category of ‘rules’. Because the activities are also guided by rules, Geels (2002) proposed to use the term socio-technical regime. Other scholars in the field expanded the concept of regimes even more by including elements like artifacts and infrastructures (Hoogma et al., 2002; Raven, 2007; Smith et al., 2005), and actor groups (Konrad et al., 2006; Verbong & Geels, 2007), suggesting that a regime is very similar to that of innovation systems. Markard & Truffer (2008) concluded that there is a strong need to explicitly deal with actors, institutions and technological artifacts at the meso level.

At the niche level, technologies or socio-technical practices emerge and develop isolated from ‘normal’ markets or regimes (Markard & Truffer, 2008). Niches and regimes show similar textures but differ in level of aggregation and stability. The relation between niche and regime may determine the development of the niche. Niches that are in a way compatible with, or have an advantage over a regime may be more successful than others (Markard & Truffer, 2008). Smith & Raven (2012) explain two forms of niche empowerments that help to understand and analyze dynamics of protection in sustainability transitions. Fit and conform empowerment makes the niche innovation competitive with the mainstream socio-technical practices in an otherwise unchanged environment. The objective is to convince the wider world that the niche can be competitive to a conventional regime and be profitably in existing markets without radical changes to institutions, infrastructures, skills, knowledge bases etc. In the case of stretching and transforming, the aim is to undermine incumbent regimes and transmit institutional reforms (derived from niches) into restructured regimes. The objective is to convince the wider world that the rules of the game are in need for change. Regimes need to be transformed in order for niches to flourish. It is subsequently argued that the analysis of these properties needs to be complemented with attention for the politics involved in their construction. The landscape is an external context of processes and factors that influence regimes and niches. This external context is harder to change than that of regimes.

2.4. How these concepts help to address the research question

A TIS framework provides an approach in which core structures (structural components) and processes (functions) can be identified that are necessary for the development of DESAR technologies. The structural components of the DESAR TIS will first be identified (actors, institutions and networks). A shared structural component can be seen as a coupling structure between a TIS and different contexts. Horizontal interactions draw on the same inputs and complementary assets to provide similar outputs. If there are a lot of horizontal relationships, then the whole DESAR field can considered to be one TIS. If there are not so many, they should rather be treated as separate sub-TISs (SQ1). The interaction between these sub-TISs might give valuable information. Influences that have impact on the development of a TIS but not affected by internal TIS processes are called external links. These influences can be conceptualized as landscape forces or forces closer to the TIS.

The structural components are evaluated on their capacity to stimulate innovation by using the seven functions. The functionality can systematically be determined by using a functional analysis in combination with two bases of assessment (comparing with other TISs and taking into account the phase of development of the TIS). Mechanisms can subsequently be identified that block or induce the development of the DESAR innovation system. This can be linked to the main research question. Blocking mechanisms hinder the development of DESAR technologies in the Netherland and can be seen as barriers, while inducement mechanisms can be seen as drivers that promote development of DESAR technologies in the Netherlands. Eventually, weaknesses in a system may lead to system failure, meaning that a system fails to develop or does so in a stunted fashion (Bergek et al., 2008). Policymakers and entrepreneurs may want to build-up and eventually take-off the DESAR TIS. To do so, they should take into account how functions within a system reinforce each other over time. Policymakers and entrepreneurs should strive for a System Building Motor or a Market Motor to emerge.

Buiksloterham and Strandeiland represent space for experimenting were the alignment of technical and social elements can be tried out and tested (leading to niche dynamics) and also space were actors can establish new capabilities, build up new networks test the suitability of institutions (seen from a TIS perspective). For a TIS, there is no difference between radical and incremental innovations and it can therefore be applied to both the regime or niche like situations, depending on its maturity (Markard & Truffer, 2008). The DESAR TIS is expected to be immature and can therefore best be applied to a niche like situation. A niche refers to a single application context. Therefore, a TIS will typically span several niches and a niche can span several pilots (Markard & Truffer, 2008). The TIS (that include niche dynamics) is expected to interact with two incumbent regimes, being the urban water management and housing/building regime (see *Figure 2.1)*. These incumbent regimes can be challenged by the niche innovation(s) as they represent a potential substitute for (parts of) the established technologies. In later stages, when the TIS grows more mature, the niche dynamics within a TIS might become part of the regimes or transform the regimes (fit and conform or/and stretching and transforming), meaning that DESAR technologies might embody the rules and in which actors perform routines that make up the regime. Overlaps between TIS and regime in terms of institutions and actors will determine the ease or resistance to potential transformations and can therefore help explain how well suited the pilots are to promote the further development of the Dutch DESAR TIS (SQ2). The relation between niche and regime may determine the development of the niche. Findings that explain this relation will therefore be used to create prospects for the transition in the Dutch urban water management sector (Q3).

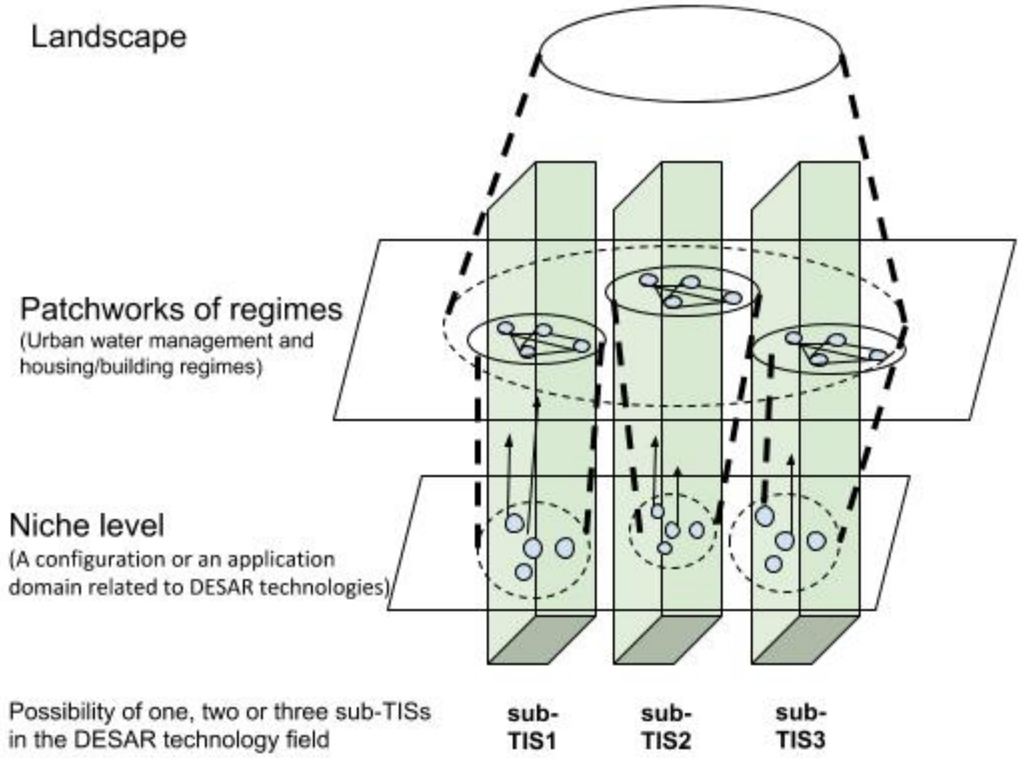


Figure 2.1 Interrelation between TIS and the MLP, based on Markard & Truffer (2008).

A combined approach will, according to Markard & Truffer (2008), be beneficial if it meets some (or all) of the following identified shortcomings of the individual frameworks. Firstly, there should be more focus on micro-level innovation processes at the level of organizations. Secondly, the mutual interdependencies between actors and institutions should be kept in mind. Thirdly, consistent performance comparisons need to be developed in order to recommend how to support the development of a particular innovation (not only by looking at the diffusion of the innovation). Fourthly and finally, the review of the environment is less systematic. The system perspective falls short in explaining technological transitions. The system perspective only partly takes aspects into account outside the system's environment. For example, external institutions that hinder the innovation process are just treated as blocking mechanisms, while they may be the result of strategic actions of incumbent actors. Furthermore, novel technologies in competing innovation systems might affect the focal TIS. Facilitation of systemic identification and assessment is needed for the broad range of factors that influence the innovation process. If this study meets some or all of the aspects identified as shortcomings of one of the frameworks, it can be argued that a combined framework might be beneficial, or at least beneficial for this specific case.

3. Method

3.1 Research design

The central aim of this study was to identify the conditions for DESAR technologies to contribute to a sustainability transition in the urban water management sector in the Netherlands. This study used a case study design which is useful for studying phenomena in the real world (Bryman, 2016, pp. 60–64). We adapted a systemic perspective that provides an encompassing approach (TIS) to analyze the core structures and processes that are necessary for developing a certain technology (Hekkert et al., 2007). The MLP framework has in addition been used to get a better understanding of the broader transition process. In this study, a qualitative research method was used.

3.2 Case description

The Netherlands is known for having innovative activity within the water management field which makes it an interesting national context to study the development of DESAR technologies. Furthermore, there is a demand for the development of a political strategy for a more effective water management system in the Netherlands. It is being acknowledged by the Dutch government that DESAR technologies are potential alternatives for parts of the current system, but there is research needed that gives insight on how DESAR technologies are able to contribute to a sustainability transition in the Netherlands. The two most salient DESAR pilots that are conducted in the Netherlands are Buiksloterham and Strandeiland and are used as main object of analyses for the data collection for this study. Due to their size and visibility (in terms of media attention) in the Netherlands, we assume that these pilots are important contexts for TIS(s) to develop. In the Netherlands, a centralized sewer system is in use. This centralized sewer system is connected to buildings. Therefore, a change of a sanitation system requires changes in and outside buildings. The TIS(s) are therefore expected to interact with two incumbent regimes, being the urban water management and housing/building regime.

3.3 System boundary

The three DESAR technologies that were being used in Buiksloterham and Strandeiland are vacuum toilets/sewer, local water treatment plants and thermal energy extraction/reuse technology. System delineation is challenging because different technologies are empirically intertwined and are often a technology continuum instead of separate fields (Markard & Truffer, 2008). The system boundary therefore depends on how heterogeneous or homogeneous the actors, networks and institutions were across these three technologies. This data was received from the (same) semi-structured interviews that served as main data for this study (*Paragraph 3.4*). These semi-structured interviews helped to identify and compare structural components of the DESAR innovation system so that it could be determined if the technological field was homogeneous or heterogeneous in nature and one or several system boundaries (or sub-TISs) needed to be specified. The sub-TISs cross geographic as well as sectoral boundaries. Although DESAR technologies are also developing in other countries, the geographic boundary of this study was set on the Netherlands. The study cannot be used for generalization purposes on cases of DESAR technologies in other countries. However, the results of the case study might serve as learnings that can be used for purposes within the Netherlands and for conceptual generalization that goes beyond a national context. The sectorial boundary was set on urban water management and housing/building sector.

3.4 Data collection and analysis

The interview questions were based concepts from the literature and were semi-structured. The questions were divided into three blocks. First, questions were asked about the development of DESAR technologies in the Netherlands. Secondly, the roles of the pilots were discussed, and in particularly the pilots “Buiksloterham” and “Strandeiland”. Thirdly and finally, the prospects of urban water management and the role of DESAR technologies in the future were discussed. Diagnostic questions in English and Dutch can be found in *Appendix A*. The interview questions became more specified as the interview campaign progressed and the system boundaries became clearer. Sixteen experts have been interviewed. Sixteen experts have been interviewed and can be found in *Table 3.1*. Due to Covid-19, the interviews were all held digitally using an online video and chat tool (Zoom).

Table 3.1 List of interviewees

Nr.	Category
1	Consultant
2	Governmental organization
3	Governmental organization
4	Consultant
5	Company
6	Governmental organization
7	Governmental organization/researcher
8	Governmental organization/researcher
9	Researcher at knowledge institute
10	Governmental organizations
11	Researcher at knowledge institute
12	Researcher at knowledge institute
13	Company
14	Researcher at knowledge institute
15	Company
16	Governmental organization

The number of interviewees depended on theoretical saturation and available time. Sampling was based on theoretical sampling in combination with snowball sampling: The analyst collects and analyzes the data and decides what data to collect next and where to find them and is controlled by the theory until new events do not occur (Bryman, 2016).

For the analysis, concept-driven coding was used. The data was approached by using existing developed concepts (see *Table 3.2*). Text (or events) were only coded if they could be related to the DESAR technologies in focus and on one or more concept(s). Similar codes within the categories were subsequently put together in order to create more clarity. For example, a sub-category was made as “Actors – Housing corporations – Alliantie”, in which all events were placed that included Alliantie as a subject.

Table 3.2 Coding processes that were used in NVivo, related to concepts.

Concepts	2. Categories	3. Subcategories
Structural components *Structural elements with their categories as explained in Table 2.1*	Actors, networks, institutions	Similar codes within the categories will be put together
Interaction *Events related to explanation of concepts as stated in Paragraph 2.2.*	External links, structural coupling	Similar codes within the categories will be put together
Functions *Functions as given in Table 2.2*	F1: Entrepreneurial activity F2: Knowledge development F3: Knowledge diffusion F4: Guidance of the search F5: Market formation F6: Mobilisation of resources F7: Creation of legitimacy	Similar codes within the categories will be put together
System development phase *Identification of development phase according to Table 2.3.*	Formative phase, growth phase	Similar codes within the categories will be put together
Role of Pilots	Based on findings	

Evaluation of the function knowledge development and knowledge diffusion is based on qualitative data of experts and a on a (limited) assessment of publications related to the sub-TISs. A keyword search in Scopus was used to gain insight in the overall publications. The search strings have been carefully selected in consultation with experts and supervisors and can be found in *Appendix B-1*. Subsequently, the following commands were used in Rstudio version 1.3.1093:

```
>Install.packages(bibliometrix)
>Library(Bibliometrix)
>Biblioshiny()
```

Biblioshiny is a web-interface for the package Bibliometrix which performs science mapping analysis using the main functions of the Bibliometrix package. The CSV files obtained from Scopus were uploaded on this webpage and analyzed. The significancy of the results of the assessment of publications via Bibliometric and Scopus are limited. Although the search strings have been carefully selected, it is still likely that the obtained database includes irrelevant publications or lacks publications that should have been included, but are not. Furthermore, the data has not been harmonized by hand, but via Bibliometrix. Sometimes, affiliations are just specific centers or institutes, which may belong to larger universities, but are counted as individual entities because the name does not suggest any semantic similarity. Still, we believe that Bibliometric did a decent job, resulting in interesting insights that can be used to strengthen the findings obtained from the interviews.

3.5 Results

The results are divided into three sections. First, a system delineation (*Chapter 4*), in which is explained how the system is delineated into one or more sub-TISs and how these sub-TISs are structured. Secondly, a structural analysis has taken place and can be found in *Chapter 5,* in which actors, institutions and networks have been identified. Thirdly, a functional analysis can be found in *Chapter 6.* The functionality has been determined by using a functional analysis in combination with two bases of assessment (comparing with other TISs and taking into account the phase of development of the TIS). Mechanisms have subsequently been identified that block or induce the development of the DESAR innovation system. Based on the functional pattern, the inducement and blocking mechanisms and taking into account the Motors of innovation, three types of system failures have been identified. The result section ends with *chapter 7* that explains how DESAR technologies contribute to a sustainable transition.

3.6 Quality of the study

The quality of this research can be presented by accessing the criteria of reliability, replicability and validity (Bryman, 2016). Reliability is a criterion that is concerned with the question whether a measure is stable or not (Bryman, 2016). Data in this study was extracted from the original sources (by coding) in an accurate and consistent way by using the concepts in the literature. The semi-structured interviews might have margins in terms of variability due to a different interpretation of questions among interviewees. This little margin is however more tolerated in qualitative research (Leung, 2015). Replicability is concerned with the possibility of replicating the findings by others (Bryman, 2016). All steps for gathering the data and analyzing data are spelled out in detail. Most of the procedures in this study are based on an existing framework. However, the coding of data might be exposed to a certain interpretation of the observer. This has been taken into account by discussing the codes with both my supervisors. The sampling method is based on theoretical sampling in combination with snowball sampling. Meaning that the obtained data is constantly being assessed and used as a guidance to decide what data is needed next and subsequently let participants propose other participants who have the experience or characteristics relevant to the research until new interviews do not result into new insights. This way of sampling likely reduces the number of interviews needed to reach theoretical saturation but should be similar in terms of outcome to other sampling methods under the condition that theoretical saturation is achieved. In order to avoid being caught in a closed circle of actors, different starting points have been used at the beginning to avoid capture (being interviewees 9, 10, 12 and 7). Validity is concerned with the conclusions that are generated from the results of this study (Bryman, 2016). Because this study used a case study research design, the study cannot be used for (statistical) generalization purposes on cases of DESAR technologies in other countries. However, the results can be used for conceptual generalization, since this is not bounded to a geographical boundary.

4. System delineation

Experts explain DESAR as one concept with different technological parts that can be applied depending on what is needed in a specific situation. DESAR technologies draw on the same inputs and complementary assets to provide similar outputs, namely to collect and treat water in a reliable way while focusing on the sustainable use of resources. All these technological parts reinforce each other (see *Figure 4.1)* and are related to mostly the same actors, institutions and networks because they are highly depended on each other. For example, black water from vacuum toilets can be used to produce bio-gas. Bio-gas can subsequently be used in combination with recovered thermal energy to warm up houses. This example is only one out of many that explains DESAR as a technology continuum instead of separate fields. Interviewee 11 (researcher at knowledge institute) noted: *"I always call it a concept in which multiple technological parts can be applied".* However, a well-formed TIS should have a certain coherence in terms of technologies and their structural components. Although the experts all agree with the idea of explaining it as one concept, some (small) differences in terms of actors and more differences in institutions have been found, which will be described in *Chapter 5*. Because of the structural heterogeneity in components within this DESAR technology field, three different sub-TISs haven been identified. The first sub-TIS contains the vacuum toilets/systems technology (vacuum sub-TIS). The second sub-TIS contains the decentralized treatment technology of both greywater and blackwater and the recovery of resources (wastewastewater treatment sub-TIS). The third sub-TIS contains the technology of thermal energy recovery from wastewater (thermal energy sub-TIS). The thermal energy recovery technology has been linked multiple times by the experts to thermal energy storage technologies for surface water, wastewater and drinking water. This appears to overlap with TIS(s) outside the boundaries of this study.

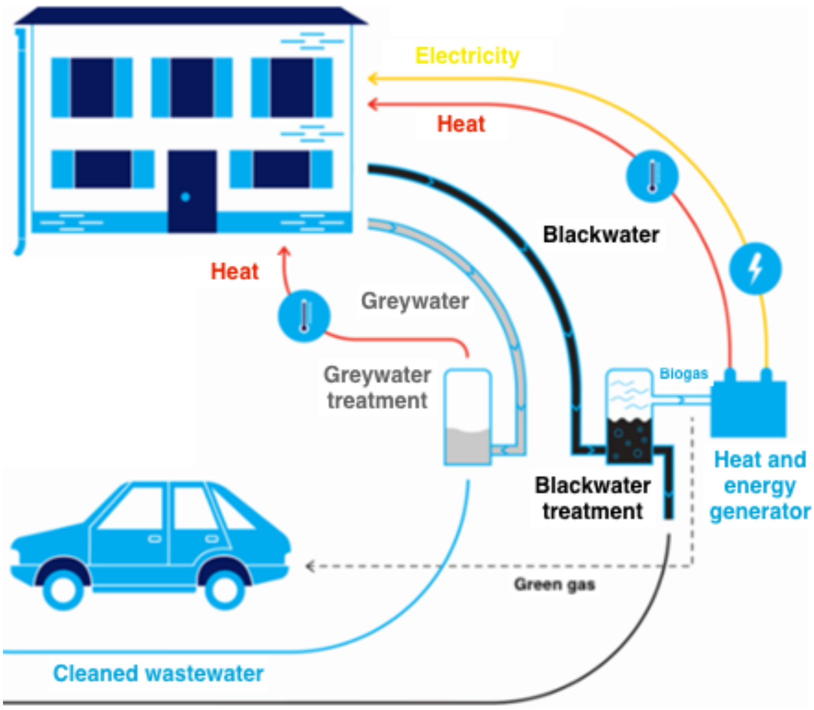


Figure 4.1 DESAR technologies combined.

Pilots in the Netherlands are used for experimenting in which the alignment of technical and social elements can be tried out and tested (leading to niche dynamics). The three described sub-TISs span across all of these pilots in which technical and social elements are tried out and tested. Interviewee 6 (employee at governmental organization) explained: *"Usually these pilots have some kind of link with policy that the municipality would like to implement in the future"*.

Buiksloterham and Strandeiland are, according to the experts, the most important pilots (details can be found in *Table 4.1*). The initial plan was to experiment with DESAR technologies at Buiksloterham, and subsequently apply it on a larger scale at Strandeiland. Unfortunately, due to delays at Buiksloterham, both pilots run more or less synchronously. Strandeiland contains 8000 households which makes it the largest scale project for DESAR technologies in the Netherlands, and one of the largest worldwide. Experts consider Strandeiland as an important, or even key pilot for the Dutch DESAR development. Interviewee 5 (an employee at a supplier of decentralized treatment technologies) stated that projects like Buiksloterham and Strandeiland are "fancy" examples that demonstrate that Dutch companies already participate in innovative projects of a substantial size, showing that DESAR technologies have large marketing value. Although the pilot Strandeiland has a lot of potential, there are some uncertainties that need to be adjusted. It is still unclear what technologies will be included and who is responsible for different aspects within the DESAR technology concept (according to interviewee 13, employee at a housing corporation). For example, decisions need to be made on whether or not vacuum toilets will be included and subsequently who is responsible (the housing corporations or the vacuum system/toilet supplier).

Table 4.1 Details about Buiksloterham and Strandeiland.

Characteristic	Buiksloterham (Plot C)	Strandeiland
Scale	550 houses (160-170 working with DESAR right now); Schoon Schip is connected and presumably Rapublika will be connected in the near future.	8000 houses.
Technologies	Vacuum toilets; Grey water treatment (no thermal energy reuse); Black water treatment (decentralized digesters, nutrient recovery).	Vacuum toilets; Grey water treatment and thermal energy recovery; Black water processing (decentralized digesters, nutrient recovery).
Status	Implementation phase. Started in 2015. Building in process. Estimated year of completion: 2024.	There already is an investment plan together with an urban construction plan. There is a go from the city council. Currently they are further developing the plan in a legal framework. A so called 'bestemmingsplan' or zoning plan. If the plan is in place, the building can start.
Structure	Bottom-up; Users are the main pushers.	Top down; Municipality of Amsterdam works with tenders. This way they can control to some extent what and how things happen.
Actors	• Municipality of Amsterdam • Waternet (waterboard) • Alliantie (housing corporation) • Syncrhoon (project developer) • Tauw • Jets – Biocompact at Plot C • Qua-Vac at Schoon schip • Users • DeSah	• Municipality of Amsterdam • Waternet • Alliantie, Ymere and Stadsgenoot • Tauw • No choice has been made about a vacuum toilet supplier • Users • Desah • Local energy cooperatives • Various actors within NAT*

**Netwerk AquaThermie or in english: Network Aqua Thermic*

Some of the technological parts within the DESAR technological continuum find their origin in other sectors. For instance, vacuum toilets are being used in maritime and aviation sector for many years and also heat exchangers (used in thermal energy recovery) have been used in other industries for centuries. However, the idea of DESAR in the urban water management sector is relatively new (around 15 years old). In 2005, the research institute in Leeuwarden called Wetsus, together with Wageningen university, and a company called Landustries in Sneek were exploring wastewater innovations. Together they created the idea to develop decentralized sanitation. This resulted in a first pilot called Sneek1 for 32 houses in 2006. This pilot was considered a success (in terms of functionality) and resulted in even more pilots. Other pilots in Sneek (Sneek2 Noorderhoek), Venlo, The Hague and also in Wageningen followed soon. In 2020, there are already over 10 pilots with various sizes working with DESAR in the Netherlands (*Table 4.2* includes all of them except for Buiksloterham and Strandeiland).

Table 4.2 Overview of Dutch DESAR pilots

Pilot	Size	Year	Technologies	Additional information
Den Haag	Building for 6000 people	2017	Vacuum toilets/systems, decentralized treatment of blackwater and greywater.	Ministry of infrastructure and water management
Kerkrade	130 households	2016	Vacuum toilets/systems, black, rain and greywater treatment.	Housing corporation: Synchroon
Oosterwold	1000+ households	2020	Choices about DESAR technologies have yet to be made.	Bottom-up structure
Sneek 1	32 households	2006	Vacuum toilets/systems; Decentralized treatment of blackwater (biogas production and sludge production).	First Dutch pilot
Sneek 2: Noorderhoek	250 households	2008	Thermal energy recovery reuse (from grey water). Biogas recovery, biogas usage for warming up houses from black water (including kitchen disposal separation and processing), vacuum toilets/systems, decentralized black and greywater treatment.	
Valkenburg	5000-5600 households	2020	Thermal energy recovery and reuse, vacuum toilets/systems, decentralized black and greywater treatment.	
Venlo	Unknown	2012	Vacuum toilets/systems. Decentralized sanitation of black and greywater.	Greenport Venlo – Villa Flora
Wageningen	Building for 300 people	2011	Vacuum toilets/systems, decentralized black water treatment.	NIOO (Dutch ecological institute)

5. Structural components

5.1 Actors & interactions

All the Dutch DESAR pilots (*Table 4.2*) have more or less the same structure of involved actors, including the municipality, waterboard, users, consultancies, knowledge institutes, project developers, housing corporations and technology suppliers. The actors identified in the sub-TISs of DESAR technologies are visualized in *Figure 5.1*.

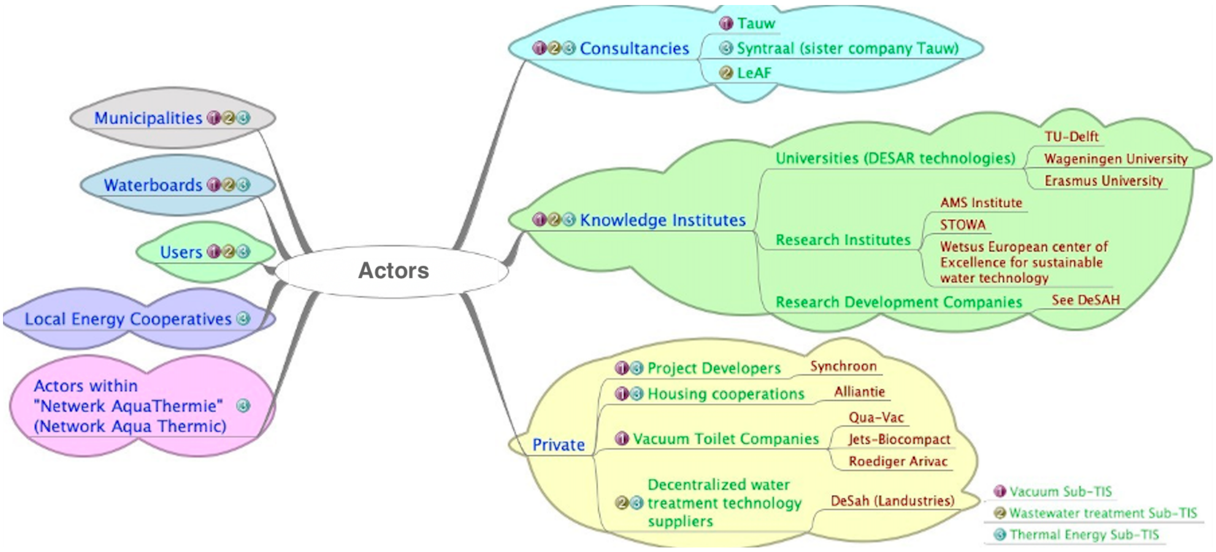


Figure 5.1 Actors of all DESAR sub-TISs visualized.

Some actors are involved in only one sub-TIS, while others are involved in multiple sub-TISs (*Table 5.1)*. Experts indicate that housing corporations or project developers do not play a significant role in the decentralized treatment process of the wastewater streams. Therefore, the role of the housing corporation and the project developer in the wastewater treatment sub-TIS is neglected.

Table 5.1 Overview of actors and related sub-TIS(s)

Paragraph	Actor	Vacuum sub-TIS	Wastewater treatment sub-TIS	Thermal energy sub-TIS
5.1.1	Municipalities	X	X	X
5.1.2	Waterboards	X	X	X
5.1.3	Consultancies	X	X	X
5.1.4	Knowledge institutes	X	X	X
5.1.5	Users	X	X	X
5.1.6	Decentralized water treatment technology supplier		X	X
5.1.7	Housing corporations	X		X
5.1.8	Project developers	X		X
5.1.9	Vacuum toilet companies	X		
5.1.10	Local energy cooperatives			X
5.1.11	Actors within NAT*			X

**Netwerk AquaThermie or in english: Network Aqua Thermic*

5.1.1 Municipalities

Municipalities are governmental actors that make the contracts and tenders for other actors and therefore are the client for most pilots. The municipality has all the data of underground infrastructure (for instance sewer infrastructure) and above ground objects and plans. Waternet (the local waterboard) develops the plans for the municipality of Amsterdam and the municipality facilitate implementation of the plans. The municipality of Amsterdam is very progressive and sustainable oriented (according to interviewee 3, 6, 7, 8 and 16).

A well-known struggle in public-private relationships is the dissimilar way their formal collaborations are structured. As explained by interviewee 10 (an employee at a governmental organization), the typical time horizon for a project of a public organization is 30 to 40 years and they have no incentive to make this a profitable exercise. On the other hand, the time horizon for a project of a private firm is much shorter (typically 5 years) and they are aiming at a commercial set-up with a reasonable time frame for return on investment. This illustrates how the different views of public and private actors may complicate the collaboration.

5.1.2 Waterboards

Waterboards are also governmental actors and considered to be a pusher of DESAR technologies. Interviewee 2, 7, 8, 9 and 16 explained that waterboards are driven to be innovative and consider alternative solutions. The interviewees explain that the demand for sustainable solutions and the need to close resource cycles are typical drivers for the waterboards to push DESAR technologies. The waterboards also have a few pioneers that follow the path developed through the first few pilots in the Netherlands, in which some of them were even involved (according to interviewee 7, an employee at a governmental organization). Furthermore, it is mentioned (interviewee 3, an employee at a governmental organization) that waterboards (Waternet) had access to (European) subsidies specifically distributed to organizations that experimented with DESAR technologies. This also might have been a driver for to push DESAR technologies. These subsidies have been used for the pilot Buiksloterham but no longer exist.

Waternet is the local waterboard in Amsterdam and has two parent organizations, being the municipality of Amsterdam and the combined municipality of Amstel, Gooi and Vegt (AGV). As a water authority, Waternet is responsible for the treatment and processing of wastewater. However, they are not responsible for the sewer infrastructure (the municipality is). They push the municipality towards vacuum systems and thus indirectly to a change of infrastructure (according to interviewee 2, 3, 6, 7, 8). The relationship between waterboards and public actors can be viscous. Interviewee 3 (an employee at governmental organization) replied that waterboards can be very active and enthusiastic and want to run fast. This often does not match with the speed a typical municipality is acting. Public processes are usually slow and it takes a lot of time to convince and find legitimacy for certain developments within the board. There is a separate department at Waternet working only on thermal energy. This department works on the sources surface water, wastewater and drinking water. Waterboards expect to deliver 25-40% of the total national heath demand with technologies related to these three sources.

5.1.3 Consultancies

Tauw is the largest new sanitation consultancy firm in the Netherlands which started 14 years ago with the consultancy related to sanitation. They mainly give advice on the vacuum toilets/systems (vacuum sub-TIS) to the waterboards. The sister company Syntraal gives advice on thermal energy recovery from wastewater (thermal energy sub-TIS). LeAF is another consultancy firm in the Netherlands. It is a small spin-off from Wageningen University and gives mainly advice on water treatment technologies (wastewater treatment sub-TIS).

5.1.4 Knowledge institutes

The development of knowledge is explained in further detail in *Paragraph 6.1.2*. The knowledge institutes can be divided into universities, research institutes and research and development companies (like DeSah, *Paragraph 5.1.8*).

TU Delft (in collaboration with Waternet), Wageningen university (in collaboration with AMS institute and TU Delft) and Erasmus university of Rotterdam are universities that develop knowledge for DESAR technologies. G. Zeeman is a former professor of Wageningen university and is considered to be the major pusher of DESAR technologies from the start (according to interviewee 5, 7 and 14).

The AMS institute is involved in knowledge development and diffusion in the DESAR technology field, mainly in Amsterdam. Another big knowledge institute is STOWA. STOWA was and is doing research on DESAR and also creates financial resources. STOWA therefore played a big role at the start of new sanitation in the Netherlands. They subsidized the first projects and carried out important research. At last, there is a major research institute in Leeuwarden called Wetsus, which is a European center of excellence for sustainable water technology.

5.1.5 Users

Pilots are mostly structured in a bottom-up way. Users (living in individual households) are considered as a pusher of DESAR technologies. For example, in Buiksloterham, users started with ideas for the application of DESAR technologies. Users also play a role in informal institutions, which will be explained in *Paragraph 5.2*.

5.1.6 Decentralized water treatment technology supplier

DeSah (Landustries works under the same holding as DeSah) is the main supplier of water treatment technologies of both the black water and grey water streams (wastewater treatment sub-TIS). In 2005 DeSah started the first pilots in Sneek1 as a spin-off from parties that were involved with the initial set-up of this pilot. There is a close collaboration with the vacuum toilet companies (according to interviewee 5, an employee at a technology supplier company). DeSah delivers machines for specific locations in collaboration with the local waterboards. DeSah also provides support with the application of thermal energy recovery systems.

5.1.7 Housing corporations

A housing corporation is a company engaged in building, managing and renting out houses. It is important that these houses are affordable for the tenant. The activities of the housing corporations are carried out on a non-profit basis. Alliantie is the housing corporation working at Buiksloterham, and is also tendering for the project of Strandeiland (together with Ymere and Stadsgenoot).

5.1.8 Project developers

Project developers invest in houses and sell them afterwards. Synchroon, the project developer at Buiksloterham, collaborates closely with Alliantie, but not so much with the municipality. Project developers in general find it hard to include DESAR technologies in their developing plans and it seems hard to get them interested. Investment costs to implement DESAR are higher while the rental price is fixed. Also, there were some problems with the noise level of the vacuum toilets being too loud in Buiksloterham (will be discussed in *Paragraph 5.2*). Some experts (interviewee 11, researcher at knowledge institute) indicated that these technical problems (teething problems) were used by the project developers as an excuse to exclude introduction of vacuum toilets.

5.1.9 Vacuum toilet companies

Vacuum toilet companies deliver the vacuum toilets and systems for the houses (vacuum sub-TIS). There are three main companies that compete with each other: Qua-Vac, Jets-Biocompact (Biocompact is the Dutch agency of Jets) and Roediger Arivac. Roediger Arivac toilets were applied for Sneek1, while Qua-Vac toilets were applied in Buiksloterham. However, because of noise issues, Roediger Arivac toilets in Sneek 1 were replaced with Jets-Biocompact toilets. Jets-Biocompact showed that the noise could be reduced, so they became the main partner in most pilots in the Netherlands. Jets-Biocompact has its own research subsidiary. Initially Jets-Biocompact was also active in producing treatment and processing technologies mainly for the blackwater sub-TIS. However, they have chosen to focus exclusively on vacuum toilets/systems since the spring of 2020. The vacuum toilet companies have a close collaboration with DeSah. It has been mentioned that problems occurred because housing corporations deviated from the guidelines on how to install vacuum toilets, resulting in problems (according to interviewee 3, an employee at a governmental organization).

5.1.10 Local energy cooperatives

Thermal energy has high potential when houses need to get off the gas grid (explained by interviewee 2, an employee at a governmental organization). About 20 years ago, only governmental energy companies existed in the Netherlands. However, they have been commercialized and sold to commercial parties. The Waterboards are currently conducting feasibility studies together with municipalities and local energy cooperatives to explore how thermal energy recovery could replace natural gas in the future. Local energy cooperatives are a group of people that (together) generate energy in a legal form. A cooperative (not to be confused with a corporation) is the most common construction to achieve this. Just like an association, a cooperative has a board and members. There are now 484 energy cooperatives in the Netherlands with a total of almost 70.000 members. For now, the idea of thermal energy recovery from wastewater is in the hands of the waterboards and is not yet available for private energy corporations or cooperatives.

Hydreco is a sister company of the water authority in Brabant (Water authority Brabantse Delta) and is specialized in cold and heath storage technologies. Although they are not specialized (yet) in thermal energy recovery from wastewater, they are an example of how waterboards were able to bring similar technologies to the market.

5.1.11 Actors within Netwerk Aquathermie

Netwerk Aquathermie (or NAT) is a network or coalition of partners working or specialized in thermal energy technologies (surface water, wastewater and drinking water). The purpose of the network is to bring actors together so that knowledge can be shared and partnerships can be made (according to interviewee 2, an employee at a governmental organization). Partners within this network are governmental organizations (ministries, municipalities and waterboards), knowledge institutes (STOWA and the university of Rotterdam), grid managers (Netbeheer Netherlands) funding organizations (the NWB bank and Invest-NL) and consultancy firms (Syntraal and others).

5.2 Institutions

The main findings of institutions are summarized in *Table 5.2*. The institutions are divided into formal, informal normative and informal cognitive. Differences between sub-TISs in terms of institutions are explained if needed.

Table 5.2 List of institutions divided over the sub-TISs.

Institutions	Vacuum sub-TIS	Wastewater treatment sub-TIS	Thermal energy sub-TIS
Formal	Obligation for municipalities to connect households to the central sewer;		
	Space for innovation is limited because of the national building regulation.	The law for reclaiming and reusing resources from wastewater is considered to be contradictory to what the government wants to achieve.	The way thermal energy should be recovered from wastewater is not clear or it is incomplete. It is not yet clear if any subsidies are going to be available for thermal energy recovery. The role of the decentralized authorities in thermal energy recovery has not yet been decided (the technology is currently in the hands of the waterboards).
Informal normative	Customs are aligned to the use of conventional technologies.		
Informal cognitive	Skepticism about vacuum toilets: noise and smell.	Taboo about human secretion.	

5.2.1 Formal institutions

Formal institutions that are related to all the three sub-TISs can roughly be divided into two main subjects. A first mutual formal institution is the obligation for municipalities to connect households to the central sewer. An advantage of DESAR technologies is that there is no need to connect to the central sewer infrastructure. The government regulations are in need for change in order for DESAR to be a worthy alternative for centralized systems. This also raises the question the government can obligate people to use DESAR technologies. As a government, you cannot simply connect a household to a conventional sewer system.

There is limited space for innovation in the vacuum sub-TIS due to the national building regulation (according to interviewee 3, 4, 6, 13, 16). A municipality cannot change a lot more than what the national building regulation allows for. The national building regulation is a law that regulates design standards. Interviewee 6 (an employee at a governmental organization) elaborated on this by explaining that the national building regulation is not progressive et all. The municipality of Amsterdam sees this as a bottleneck for further innovation. The only way they can push innovation is by ‘tendering’ for performance standards. The crisis and recovery law is sometimes used to deviate from the national building regulation. The use of the crisis and recovery law raises questions, because this sometimes leads to solutions that have a negative influence on the living comfort (for example by allowing toilets to make more sound than the current limit of 30DB).

Legislation has to be taken into account when an organization wants to recover nutrients from wastewater and subsequently wants to use them into the agricultural or in other sectors (formal institutions related to the wastewater treatment sub-TIS). Interviewee 5 (an employee at a supplier of decentralized treatment technologies) explains that there are differences in regulations between countries. In Germany the regulations for draining sludge is more relaxed compared to that in the Netherlands. For example, it is allowed to drain sludge on the field in Germany, however in the Netherlands the sludge has to be burned and cannot be put on the field. If it really is not possible to reuse them, then you should at least store them for later (according to interviewees 3, 4, 7, 8 and 10). Now they extract the resources and dispose them in the central sewer. Research shows that it is safe to reuse certain raw materials from wastewater without causing health issues. The law for reclaiming and reusing resources from wastewater is considered to be contradictory to what the government wants to achieve (an economy that is completely circular by 2050). Interviewee 5 (an employee at a supplier of decentralized treatment technologies) for example explains that legislation does not allow for reclaimed fertilizer to be sold. However, these legislations might change in the near future. Interviewee 5 continued: "*There was, I think two months ago… the European Union updated their legislation about recovered fertilizers and anything. So, I expect in the next years, that the local governments and the national governments will update their policies*"

Formal institutions for thermal energy sub-TIS can roughly be divided into three main subjects. Firstly, regulations are present that describe how thermal energy should be extracted from wastewater that has already been cleaned. However, thermal energy can also be recovered from untreated wastewater. Therefore, regulations for thermal energy recovery are not clear or they are incomplete. Secondly, subsidies are available for thermal energy recovered from surface water. However, there are no subsidies available for thermal energy recovery from wastewater and it is not yet clear whether this will be included in the (near) future. Thirdly and finally, it is not clear what role the decentralized authorities should play in thermal energy recovery. The idea of thermal energy recovery from wastewater is in the hands of the waterboards and is not yet available on the private market. STOWA is doing research on how aqua thermic (including thermal energy recovery from wastewater) should ideally be governed.

5.2.2 Informal normative institutions

The informal normative institutions are related to both the vacuum sub-TIS and the wastewater treatment sub-TIS because users need to change behavior/customs when using vacuum toilets. You cannot throw in weird materials like frying fat, clothing, sanitary pads and condoms. Of course, this should not be thrown in the conventional sewer either. However, the proportion of these materials in vacuum systems (that consist of more concentrated wastewater) is much higher and therefore easily can block a decentralized system. If the system is blocked it means that the whole neighborhood is affected and will not be able to use the toilet before the failure is fixed. The concept of DESAR is something that users do not have experience with and therefore there exist a lack of trust.

5.2.3 Informal cognitive institutions

There are misplaced arguments on why vacuum toilets are bad (vacuum sub-TIS). Interviewee 15 (an employee at a supplier of vacuum toilets/systems technologies) explained that there still is a lot of skepticism around the subject of DESAR technologies. Both authorities, but also a lot of potential users frequently argue that vacuum toilets are loud and smell much more. These kinds of arguments are not valid, according to this interviewee.

Secondly, there is a taboo about DESAR because it is related to poop, pee and waste. People react shocked if you say you will use human secretion for agricultural purposes (wastewater treatment sub-TIS). This is so much closer to the human body and therefor the cognitive institutions play a major role in this. Sanitation in that sense is not the same as energy or transport. Reused materials and resources can be so clean but still there is this taboo that it comes out of human bodies (according to interviewee 14, a researcher at a knowledge institute).

6. Functional analysis

6.1 Functions

A TIS is based on structural components (*Chapter 5*), which are evaluated on their capacity to stimulate innovation by using the seven functions. The two sub-TISs are very similar and show a lot of commonalities. When needed, a distinction between the three sub-TISs has been made during the functional analysis. The functional analyses of “Knowledge development” (F2) and “Knowledge diffusion” (F3) described in respectively *paragraph 6.1.2 and 6.1.3* are accompanied by a limited bibliometric analysis. The results of the bibliometric analyses for F2 and F3 are provided in Appendix B and C respectively.

6.1.1 Entrepreneurial activity (F1)

All activity of entrepreneurs and incumbent companies diversifying their portfolio that have the potential to convert knew knowledge, networks and markets into concrete actions relevant for the innovation system, is understood as entrepreneurial activity. To evaluate the entrepreneurial activity within the DESAR innovation system, the number and type of activities of involved actors were studied. Interviewee 9 (researcher at knowledge institute) explains that the positive attitude towards doing pilots is beneficial for the entrepreneurial environment in the Netherlands. Waterboards are willing to change their portfolio towards DESAR technologies and they are known to act fast. This is in conflict with (some) municipalities that prefer to have solid solutions in a structured way. Municipalities are considered to be the client in most of the pilots. This gives them the power to allow entrepreneurial activity to happen or not (by allowing or disallowing actors to get involved in a pilot). Most pilots (see *Table 4.1*) have a bottom-up structure in which users play an important role. In Buiksloterham for example, users came up with ideas and possible solutions for specific problems. Therefore, users encourage entrepreneurial activity to happen.

The structural analysis also shows some differences in entrepreneurial activity between the three sub-TISs. In the vacuum sub-TIS, there are three main suppliers of vacuum toilets, being Qua-Vac, Roediger and Jets-Biocompact. The entrepreneurial activity in the vacuum toilets/systems industry is considered to be sufficient according to the experts. For example, interviewee 15, an employee at a supplier of vacuum toilets/systems technologies, explained that vacuum toilets/systems are being applied for sanitary purposes in the maritime sector for almost 3 decades and is already a mature technology in which the market is saturated. The housing corporations and project developers (both vacuum sub-TIS and thermal energy sub-TIS) are known to have a harder time to diversify their portfolio. Investment costs are becoming too high, and they are therefore not enthusiastic to change their portfolio towards DESAR technology-oriented solutions. Interviewee 13 (an employee at a housing corporation) explains that investment costs keep increasing. Houses have to be energy neutral. Alternative energy systems are being introduced. Natural gas is gradually phased out, and DESAR comes on top of this. So, it is an accumulation of investment costs. The house rental price for consumers are fixed by government regulations so investment costs are difficult to recover.

DeSah is the only and major company in the market for decentralized wastewater treatment technologies (wastewater treatment sub-TIS). Municipalities work with tenders, in which it is not preferred to have only one supplier for decentralized water treatment technologies (according to interviewee 4, 5, 14 and 15). Also, for reasons of legitimacy and support, it is preferred to have more actors that can provide decentralized wastewater treatment technologies (*Paragraph 6.1.7*). DeSah is also an important player for DESAR technologies outside the Netherlands (according to interviewee 15, an employee at a supplier of vacuum toilets/systems technologies). This expert mentioned the drawback of having only one company that can provide decentralized treatment and processing technologies for other countries like Norway, mainly because the products Norwegian people need are more specific to Norwegian purposes and regulations.

DeSah works a lot with Oland systems (which is a cost-efficient sustainable way to extract ammonium from wastewater) in which a Rotating Biological Contactor (RBC) is implemented. An expert (anonymous) claims that these systems are hardly usable on large scales (DeSah claims otherwise). For larger scale projects, it is expected that actors that are currently delivering treatment and processing technologies for the conventional system will take over. Firms like Convert, PAQUES and Biothane develop systems needed for this specific fermentation step (UASB or Upflow Anaerobic Sludge Blanket). However, they are not interested in building these systems on a small scale. Interviewee 4 (consultant) expect these companies to be interested in Strandeiland due to the large scale.

Thermal energy recovery (sub-TIS thermal energy) works with a heat exchanger, which is a very simple technique according to interviewee 2 (an employee at a governmental organization). He explains that heat exchangers have been used for perhaps a century and a half. In the DESAR concept, the technique will be used a bit differently than before, because the heat will be recovered from relatively low temperatures. This heat exchange technology is still developing rapidly (they become more efficiently). The entrepreneurial activity for this technology is saturated. Waterboards (in collaboration with actors like DeSah) are able to provide these thermal energy recovery systems.

6.1.2 Knowledge development (F2)

All activity of 'learning by searching' and 'learning by doing' that lead to the development of knowledge relevant for the innovation system, is understood as knowledge development. Evaluation of the function knowledge development is based on assessment of publications related to the sub-TISs and on qualitative data received from experts.

For the vacuum sub-TIS, 9% of the total publications comes from Dutch institutions from which the first author was part of (*Table 6.1*). The Netherlands is the third most cited country worldwide behind the USA and Switzerland (*Appendix B-2*). Most knowledge about vacuum technologies in the Netherlands is generated by Wageningen University (39%, see *Table 6.2*). The publication analysis showed that Zeeman (Dutch professor) was involved in most (5,3% of 208) publications worldwide, indicating that Zeeman played an important role for the development of the vacuum sub-TIS (*Appendix B-2*). Todt, working at Jets-Biocompact was involved in 2,4% of all 208 publications, indicating that Jets-Biocompact (vacuum toilet/system company) is active in the R&D of vacuum toilets and systems. The overall annual scientific growth rate of publications related to the vacuum sub-TIS is about 15%, meaning that the worldwide publication output in this sub-TIS grows with 15% per year on average (*Appendix B-2*).

Table 6.1 Main information vacuum sub-TIS publication analysis (publication of institutions from which the first author was part of).

Main information	
Total publications world wide	208
Total Dutch publications	18
Ratio Dutch publications compared to total publications	9%

Table 6.2. Ratio of Dutch affiliations involved in publications in vacuum sub-TIS.

Source	Ratio of Dutch affiliations involved in publications (in %)
Wageningen university	39%
Wetsus, Centre for Sustainable Water Technology	19%
TU Delft	8%
LeAF	8%
KWR Watercycle research institute	6%
ATTERO B.V.	3%
DeSah B.V.	3%
Municipality Breda	3%
IsLe Utilities B.V.	3%
GMB	3%
Paques B.V.	3%
NIOO-KNAW (Netherlands institute for ecology)	3%

The Netherlands scores relatively poor on knowledge development in the wastewater treatment sub-TIS when compared to the other sub-TISs. For the wastewater treatment sub-TIS, only 1% of the total publications comes from Dutch institutions from which the first author was part of (*Table 6.3*). Most knowledge in the Netherlands is generated by Wageningen University (18%, see *Table 6.4*). The overall annual scientific growth rate of publications related to the vacuum sub-TIS is about 10%, meaning that the worldwide publication output in this sub-TIS grows with 10% per year on average (*Appendix B-3*).

Table 6.3. Main information water treatment sub-TIS publication analysis (publication of institutions from which the first author was part of).

Main information	
Total publications world wide	761
Total Dutch publications	7
Ratio Dutch publications compared to total publications	1%

Table 6.4. Ratio of Dutch affiliations involved in publications in wastewater treatment sub-TIS.

Source	Ratio of Dutch affiliations involved in publications (in %)
Wageningen university	17%
TU Delft	8%
Leiden university	8%
Royal HaskoningDHV	8%
Waternet	8%
GMB BioEnergie B.V.	8%
ENVAQUA B.V.	8%
Royal Institute for Sea Research (NIOZ)	8%
LeAF	8%
Wetsus, Centre for Sustainable Water Technology	8%
KWR Watersycle research institute	8%

For the thermal energy sub-TIS, 5% of the total publications comes from Dutch institutions from which the first author was part of (*Table 6.1*). Most knowledge in the Netherlands is generated by TU Delft (46%, see *Table 6.5*). TU Delft is the fourth most relevant affiliation worldwide, based on publications of (both first and co-) authors that are part of this specific affiliation. The Netherlands is the third most cited country worldwide behind the USA and China (*Appendix B-4*). The overall annual scientific growth rate of publications related to the vacuum sub-TIS is about 16%, meaning that the worldwide publication output in this sub-TIS grows with 16% per year on average (*Appendix B-4*).

Table 6.5 Main information thermal energy sub-TIS publication analysis (publication of institutions from which the first author was part of).

Main information	
Total publications world wide	609
Total Dutch publications	31
Ratio Dutch publications compared to total publications	5%

Table 6.6 Ratio of Dutch affiliations involved in publications in thermal energy sub-TIS.

Source	Ratio of Dutch affiliations involved in publications (in %)
TU Delft	46%
Utrecht university	11%
KWR Watersycle research institute	9%
Waternet	7%
Wageningen university	7%
Nijhuis Water Technology B.V.	3%
Wetsus, Centre for Sustainable Water Technology	3%
Waterboard of Rijnland	1%
Techno Invent B.V.	1%
MARAS B.V. - Material recycling and sustainability	1%
Water Authority Brabantse Delta	1%
Stichting E.V.A. Lanxmeer	1%
HVC	1%
MWH Global	1%
GMB BioEnergie B.V.	1%

Experts (all 16) explain that the experimental atmosphere (positive attitude towards doing pilots) in the Netherlands is beneficial for the knowledge development for all three sub-TISs. This is important because the development of DESAR technologies are also highly dependent on formal and informal institutions (according to interviewee 1 and 12). How these institutions are embedded and how they possibly conflict with the development of DESAR technologies cannot exclusively be learned from doing research and from laboratorial experiments alone.
Interviewee 12 (researcher at knowledge institute) also explains a downside of the way knowledge is currently being developed in the Netherlands. Knowledge development is currently too much focused on individual technologies, institutions and knowledge areas within the DESAR concept instead of a focus on the DESAR system as a whole concept (all three sub-TISs together).

Knowledge development in the Netherlands is generated by three main sources: research institutes, universities and technology producing firms. There are at least three major research institutes doing research on the DESAR topic in the Netherlands: AMS institute (doing living labs), STOWA and Wetsus. Together, they are involved in knowledge development in the DESAR technology field. Zeeman (among others) started in 2000 with research on DESAR technologies. She inspired other professors and universities to do research on DESAR technologies and is seen as an important pusher of DESAR technologies (according to interviewee 5, 7, 14, and confirmed by the publication analysis). TU Delft mainly explored thermal energy recovery and water treatment technologies (according to interviewee 2, an employee at a governmental organization and confirmed by the publication analysis). Wageningen University mainly explored source separation technologies (according to vacuum toilets/systems) and to a less extent water treatment technologies (according to interviewee 4, 7, 11, 14 and confirmed by the publication analysis). Finally, firms such as DeSah and Jets-Biocompact have their own R&D departments that create knowledge regarding DESAR technologies. The Netherlands scores relatively poor on knowledge development in the wastewater treatment sub-TIS when compared to the other sub-TISs. The quantitative bibliometrics only gives an overview of the relative importance of Dutch research in the sub-TISs, but not on a DESAR level in general, compared to other TISs in the water sector

6.1.3 Knowledge diffusion (F3)

All activity regarding the exchange of knowledge among actors that is relevant for the innovation system, is understood as knowledge development. Evaluation of the function knowledge diffusion is mainly based qualitative data received from experts and strengthened by a collaboration network analysis. It should be noticed that a collaboration network only gives insights in knowledge diffusion in terms of collaboration between affiliations as derived from scientific publications and less about knowledge diffusion in the application field of DESAR technologies (for example manufacturers, installers and institutes in the public domain).

Some experts feel like actors involved in the Dutch pilots are reinventing the wheel again and again, because knowledge diffusion is not going smoothly. Even within the same city, this knowledge diffusion could be better. Interviewee 12 (researcher at knowledge institute) explained that certain issues at Strandeiland occurred while implementing DESAR technologies, which could have been prevented if past experiences from other pilots had been shared more sufficiently and if lessons had been learned. He added on this: "*the municipality is actually not very well organized to do something with the existing knowledge"*. Experts suggest that there is a role for consultancy firms to facilitate these aspects better in future projects.

Both the waterboards and DeSah are involved in knowledge diffusion in all three sub-TISs. Waterboards work closely with knowledge institutes and universities. The waterboards and the regional water authorities have knowledge exchange groups in which (tacit) knowledge is diffused as much as possible. DeSah also plays a role in sharing (tacit) knowledge within the Netherlands and also internationally as they are involved in almost all pilots.

Actors within the sub-TIS of thermal energy are connected with a coalition of partners (called NAT, see *Paragraph 5.1.11*) working or specialized in thermal the thermal energy technology field (surface water, wastewater and drinking water). The purpose of this network is to bring actors together so that knowledge related to thermal energy technologies can be shared and partnerships can be made. This is a valuable network in the thermal energy sub-TIS used for knowledge diffusion (according to interviewee 2, an employee at a governmental organization).

One expert (interviewee 15, an employee at a supplier of vacuum toilets/systems technologies) explained that different technologies and approaches are needed depending on both cultures and climate issues. Technologies are more adopted and optimized to local conditions. He argues that that the exchange of knowledge from a scientific perspective is *"quite okay today"*, since scientific publications are worldwide available and there are conferences all around the world. Knowledge exchange is, according to this expert, more needed on a legal level. Knowledge diffusion between countries that are closely related in terms of regulations or locations (for example similar regions in Netherlands) can be very valuable. He adds: *"Especially on a governmental level… …Municipalities in the Netherlands, like Amsterdam, are quite progressive. It would be good if they have some kind of exchange with some conservative Norwegian municipalities. Just to show that it is actually possible and beneficial to use a decentralized approach"*. It would be better to diffuse knowledge mainly within Europe because the conditions are quite different in various continents. All the cultures are different and therefore the composition of the black water varies quite strongly (according to interviewee 15).

The significancy of the results of the assessment of publications via Bibliometric and Scopus are limited. The collaboration network analysis will therefore only be used to give insight on how the networks of the sub-TISs can schematically be visualized. For the vacuum sub-TIS, it can be noticed that Wageningen university is positioned in the center of the Dutch network (*Figure 6.1*). For the wastewater treatment sub-TIS, it can be noticed that the Dutch network consists of smaller networks that are not connected (*Figure 6.2*). This can be a result of the relatively low number of Dutch publications in this sub-TIS. For the thermal energy sub-TIS, it can be noticed that TU Delft is positioned in the center of the (largest) Dutch network (*Figure 6.3*). These insights again indicate the prominent role of Wageningen university and TU Delft.

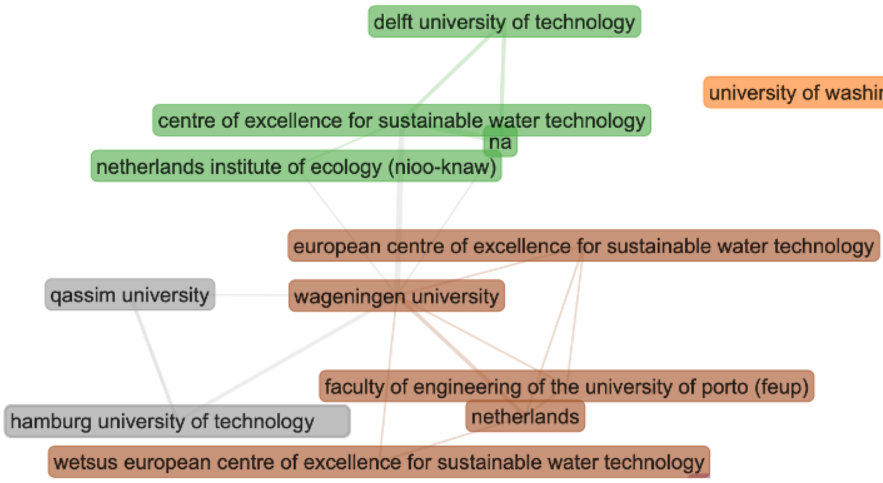


Figure 6.1 Affiliation network vacuum sub-TIS.

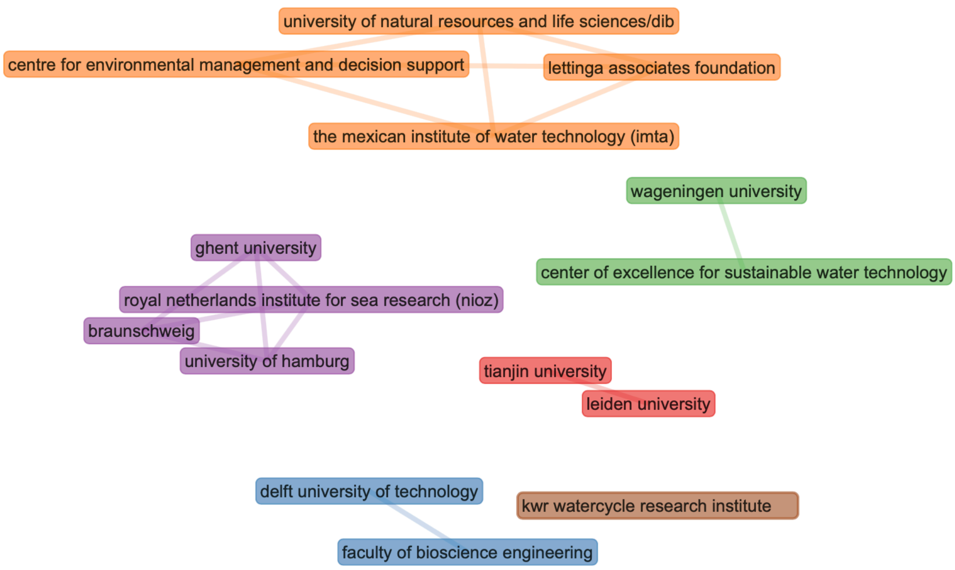


Figure 6.2 Affiliation network wastewater treatment sub-TIS.

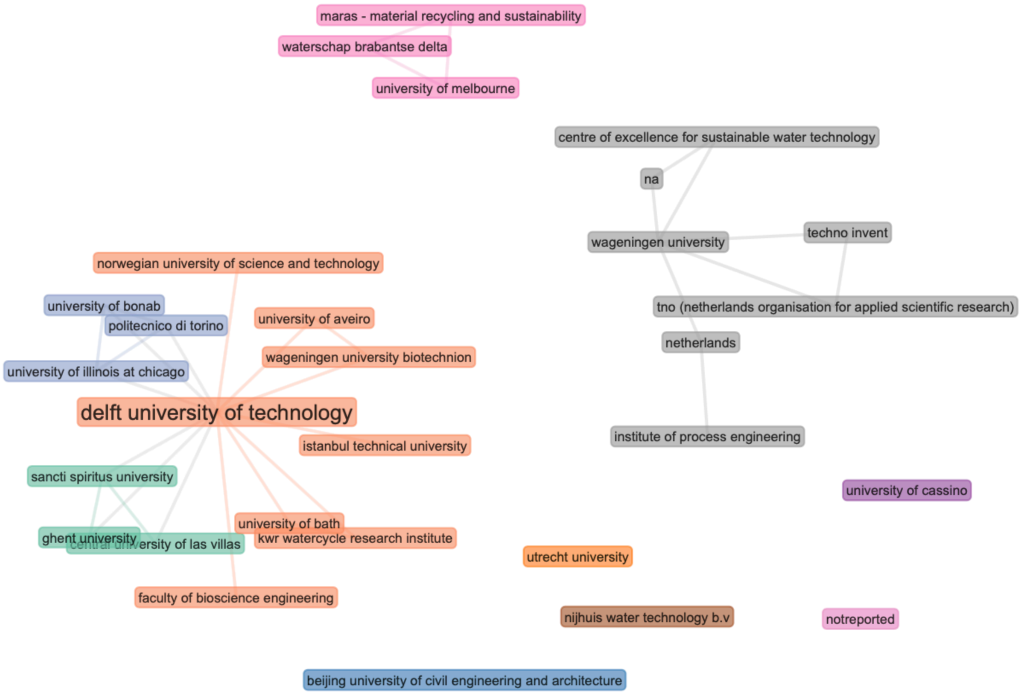


Figure 6.3 Affiliation network of thermal energy sub-TIS.

6.1.4 Guidance of the search (F4)

All activity within the innovation system that can influence the visibility and clarity of specific needs and expectations among technology users, is understood as guidance of the search. The Dutch government aims to have an economy that is completely circular by 2050. In order to reach this, resources need to be (as much as possible) reused, meaning that the resource cycles need to close. An intermediate goal has been set in 2030 in which 50% less resources of primary raw materials should be used (minerals, fossils and metals) (Rijksoverheid, 2016). Nonrenewable recourses need to be replaced for renewable resources. The closed resource cycles should also lead to a security of supply of scarce raw materials. DESAR technologies potentially fit in well with the goals of the government. Resources like phosphate, cellulose and bioplastics can be reused as alternative resources for new and existing products. Experts are familiar with the goals of the government. For example, interviewee 5 (an employee at a supplier of decentralized treatment technologies) noted: *"We try to close the loops of the energy of the water and the nutrients. So, we make a circular approach, more sustainable treatment. And we try to do it in a decentralized level, which is more effective"*. However, the government does not provide guidance on how this circular economy should be reached. Interviewee 1 (consultant) argued that the government should provide tools for a transition. The government is explained to be conservative in their guidance. He adds: "*We do not know exactly how we should reach the end goal… …It would be nice if we receive some indications that says: decentralized sanitation is the way to go".*

Although the experimental atmosphere in the Netherlands might be beneficial for the knowledge development of DESAR technologies in the Netherlands (*Paragraph 6.1.2*), experts also mention a few downsides about the way pilots in the Netherlands are set up. Interviewee 1 (consultant) argued that the rules round the experiments are so tight that the space for experimenting is limited. Actors that are experimenting in the Netherlands (for example by doing pilots) have to meet all kinds of norms, resulting in careful behavior that does not always lead to the visibility and clarity of specific needs and expectations.

There are some formal institutions that are contradictory with the government's intended goals. The law for reclaiming and reusing resources from wastewater is considered to be contradictory to what the government wants to achieve (as explained in *Paragraph 5.2.1*). The government guides towards a circular economy by closing resource cycles. However, the law simply does not allow this at the moment.

6.1.5 Market formation (F5)

All activity that drives the formation of DESAR technologies, is understood as market formation. Experts explain that markets for DESAR sub-TISs have higher potential in new housing estates, simply because it is harder to implement DESAR technologies in houses that are already connected to the conventional sewer system. Interviewee 11 (researcher at knowledge institute) explained: *"Actually, our conventional sewer system is an important limiting factor, because this conventional sewer system has been placed for 100 years, and we cannot dig it up and start over. That is a bottleneck for the application of DESAR technologies. Because renovations should both be taking place inside the houses and outside the houses. And that is not synchronous either".* This non-synchronous state of affairs is a reason for experts to believe that a hybrid system will likely exist in the future. Interviewee 5 (an employee at a supplier of decentralized treatment technologies) elaborates on this by explaining that DESAR technologies cannot be seen as a solution for everything. The choice for implementing DESAR technologies depends on local characteristics and problems. For the market formation, this means that the DESAR technologies will be mainly applied in new housing estates (at least on the short term). In 2019, 74.000 new homes were built (CBS, 2019). This is a rough indication of a potential yearly market that is interesting for DESAR technologies.

Experts explain DESAR as one concept with different technological parts that can be applied depending on what is needed in a specific situation. Experts make an interesting statement on how DESAR should look like in the future. By combining the three sub-TISs, business cases become more attractive. Interviewee 2 (an employee at a governmental organization) explained: *"Our research on elements of DESAR really shows how useful they potentially could be; however, they are more costly than traditional sanitation. It is more expensive until you add the element of thermal energy recovery from wastewater. From that point on you have a value stream that is able to change the business case of DESAR to a profitable one".* The bridge between DESAR and the energy sector has high potential, especially because houses need to get off the gas grid. This shows the lucrative potential of generated energy from biogas and thermally recovered energy. Right now, the waterboards are doing feasibility studies with local energy cooperatives, which have 70.000 members in the Netherlands (484 cooperatives). Waterboards suggest to implement the thermal energy recovery themselves or to create a monopolistic private-public organization that operates within the sector. Project developers however, prefer to leave thermal energy to the market. In September 2020, the municipal council of Amsterdam will decide whether or not to include a municipal heat company. The way the thermal energy sub-TIS market will form depend on this decision. Interviewee 2 explained that if the municipal council decide to not include a municipal heat company, the utility for energy companies will take over, which subsequently "*will slow down the process a lot"*.

There are over 10 pilots in the Netherlands that make use of DESAR technologies, which are listed in *Table 4.2*. These experiments are considered to be beneficial for the market formation. Interviewee 14 (researcher at knowledge institute) expects that it is only a matter of time before market niches will develop in these pilots. According to this expert, the markets will develop as a consequence.

Experts see DeSah as the only company in the market that is able to provide decentralized water treatment technologies on small scales, indicating that DeSah is currently an important player for the development of DESAR technologies (wastewater treatment sub-TISs) in the Netherlands, but also internationally.

6.1.6 Mobilization of resources (F6)

All activity concerned with input of resources (financial, physical and human capital) within the innovation system, is understood as mobilization of resources. The experts explain that financial capital is a critical resource. Interviewee 5 (an employee at a supplier of decentralized treatment technologies) added on this by explaining that the breaking point to start making profit is when the DESAR technologies are connected to around 2000 and 3000 people. This calculation takes into the account the building costs, operating costs, and deprecation costs of the equipment. However, it does not take into account the environmental benefits, the social benefits or any income you can gain from selling biogas, fertilizers or reclaimed water. Because of this threshold of 2000-3000 people, large investment costs are required. Experts explain two main mechanisms to gain funding for pilots, the first one being subsidy. Experts acknowledge that there was a form of European subsidy available a few years back for pilots working with DESAR technologies. However, this subsidy was only available for pilots in the region of Amsterdam (Waternet had access to these subsidies) and there is no more money left. STOWA also played a big role at the start of new sanitation in the Netherlands by (among other things) subsidizing the first DESAR projects in the Netherlands (for example Sneek1, Sneek2 Noorderhoek and Wageningen). In addition, subsidies are available for thermal energy recovered from surface water. However, there are no subsidies available for thermal energy recovery from wastewater and it is not yet clear whether this will be included in the (near) future (thermal energy sub-TIS). The second mechanism is the equalization fund. In most municipalities (for example in Amsterdam) there is an intern fund called the equalization fund. This fund cannot be seen as subsidy, since it has been earned by the municipality itself. It can be seen as some kind of saving account (according to interviewee 6, an employee at a governmental organization). Experts agree that more subsidy is required. Interviewee 5 (an employee at a supplier of decentralized treatment technologies) explained: "*More money needs to be invested in order to get this system functioning. So, we need more subsidy from the government"*.

Another critical resource is human capital. Experts expect that human capital becomes limited if DESAR technologies scale up in the future. Interviewee 2 (an employee at a governmental organization) adds: *"If you want to scale up, then you need to grow a lot more. The way I see it is that there should start a whole new sector that takes up new sanitation".* DeSah plays an important role in training employees so they can do the operation and maintenance of water treatment technologies. They call themselves a system integrator and technology governor in which they come up with ideas, design and built them. For larger pilots like Buiksloterham, they train employees of Waternet (the local waterboard) so they can do the purification themselves. From this point on, the product has been sold and belongs to Waternet. However, there are some places where DeSah also does some maintenance and operation (for example in Sneek1).

6.1.7 Creation of legitimacy (F7)

The seventh and last function will include all activity that helps to create legitimacy for DESAR technologies and all activity aimed at counteracting resistance from the incumbent regime. The government does not provide guidance on how a circular economy should be reached. According to experts, the success and failure of DESAR depends on the perseverance of a group of pioneers. Typical pioneers according to the experts are STOWA, professors like Zeeman and a group of people within waterboards. Another factor that has been beneficial for making DESAR technologies more legitimate, is the progressive and sustainable ambition of the Dutch society (according to interviewee 8, an employee at a governmental organization). Experts also suggested that even if there are additional costs involved, that this should not be a reason to back off from DESAR technologies. Interviewee 9 (researcher at knowledge institute) explained this: *"Because we also have to consider externalities. Costs that the environment and society have to pay that are not included in the price that people pay for conventional solutions. But of course, you have to make it acceptable. You should communicate really well if costs are higher than when using the conventional system*". According to experts (interviewee 2 and 14), people are getting more confident with DESAR technologies. However, you still meet a lot of skepticisms. Interview 3, 5, 7, 10, 11, 13, 14, 15 and 16 all confirm that skepticisms have made arguments in the past about the bad smell and the noise of vacuum toilets (vacuum sub-TIS). Interviewee 7 (an employee at a governmental organization) explained: *"It is like a mission; change is always hard for people"*. Project developers and housing corporations are repeatedly mentioned as to be conservative towards DESAR technologies. Interviewee 11 (researcher at knowledge institute) explained that municipalities and the waterboards are gradually willing to change. However, project developers and housing corporations are really a constraining factor. Investment costs that are becoming too high, and project managers and housing corporations are therefore not hungry to change their portfolio towards DESAR technology-oriented solutions (*Paragraph 6.1.1*).

The pilots lead to knowledge development, technological improvement, but also acceptability, legitimacy and reliability. Interviewee 5 (an employee at a supplier of decentralized treatment technologies) explained: *"Every case is a good example for future clients… …Smaller pilots are ok, but when you tell them about a huge pilot in Amsterdam (Strandeiland), they immediately say: O, I know Amsterdam. I think it is really good for marketing"*. Interviewee 1 (consultant) adds on this by explaining that the pilots will help for acceptance in society: *"When will DESAR become acceptable? When you talk about a transition, what groups in society will accept DESAR, when is it an interesting alternative?... … Is this acceptable or will it be seen as nuisance? And if it is seen as nuisance, are we going to remove it? We need to experiment with these dilemmas. We do not have a definitive plan; however, we should flesh out that plan".*

Also, for reasons of legitimacy and support, it is preferred to have more actors that can provide decentralized wastewater treatment technologies (wastewater treatment sub-TIS). DeSah is the only available supplier for small scale decentralized water treatment technologies. Interviewee 15 (an employee at a supplier of vacuum toilets/systems technologies) explained that this is sometimes difficult when it comes to public projects, in which it is a requirement that you have at least three or four bids. If you have only one actor that is able to provide these technologies, you cannot run such a process. In addition, it would be better to have more actors that provide these decentralized water treatment technologies when you want to compete with the conventional sanitation system: "*DeSah is not powerful, but then you are actually competing with conventional solutions. And then this conventional lobby will claim; ok, there is only one kind of actor in this market. You are kind of locked to only one company"*.

Another expert (interviewee 5, an employee at a supplier of decentralized treatment technologies) mentions differences between the Netherlands and Germany: *"You (*Dutch people*) made a lot of innovations very fast. For example, this decentralized sanitation systems, it started more or less from Germany and the Netherlands around the same time. But in Germany, they seemed a bit afraid, from going to the lab into real life. They take very slow steps. So, they don't apply their innovations very fast. In the Netherlands, I don't know exactly the reason, but they applied it really fast"*. This might be an indication that legitimacy in the Netherlands is relatively 'good' compared to Germany (all sub-TISs).

6.2 Evaluating the DESAR sub-TISs

Based on the analysis of the structure of the DESAR innovation system (*Chapter 5*) and its dynamics (*Paragraph 6.1*), the functional patterns of the three sub-TISs could be identified. The relative 'goodness' and 'badness' (functionality) can subsequently be determined.

Experts were asked to describe the development of DESAR technologies in the Netherlands. They explained that the system development of all sub-TISs are in a formative phase and are reaching a growth phase soon. Interviewee 14 (researcher at knowledge institute) noted: *"It seems like we are reaching a growth phase… …I have the impression that more and more of these projects are being set up by institutions themselves. If you were to make it an S-curve, it would indeed seem that the curve is now starting to rise a bit".* A typical sign of a growth phase is that technology diffuses through bridging markets and eventually reaches the mass market (*Chapter 2.2* and *Table 2.3*). Two examples are given: Firstly, energy can be recovered from thermal energy (thermal energy sub-TIS) and the production of biogas (wastewater treatment sub-TIS). This bridge between DESAR technologies and the energy sector has high potential. Interviewee 2 (an employee at a governmental organization) explained that several feasibility studies together with municipalities or local energy cooperatives are conducted in which options are explored to get off the gas grid and all these initiatives can go hand in hand with the concept of DESAR. Secondly, the sludge produced in a decentralized wastewater treatment plants (wastewater treatment sub-TIS) can in theory be used as fertilizer in the agriculture. This is not possible now, due to legislation limits. The upscaling of DESAR technologies in the Netherlands and markets indicates that they most possibly will be bridged in the near future.

Policymakers and entrepreneurs should strive for a System Building Motor or a Market motor to emerge. Motors typically arise during the development of TISs as a transformation of less powerful motors. A Motor that is able to transform to a System Building Motor (which in turn is able to transform to a Market Motor), is the Entrepreneurial Motor (typical a Motor that emerges in a formative phase). An entrepreneurial Motor is dominated by entrepreneurial activity (F1), but also by knowledge development (F2), knowledge diffusion (F3), guidance of the search (F4) and resource mobilization (F6).

The next step is to evaluate each sub-TIS and identify functions that are critical for the sub-TISs to develop more. *Table 6.7* gives an overview of inducement and blocking mechanisms that can be assigned to all three sub-TISs.

Table 6.7 Overview of inducement and blocking mechanisms that can be assigned to all three sub-TISs.

Function	Inducement mechanisms	Blocking mechanisms
F1. Entrepreneurial activity	- Large number of pilots in the Netherlands in which entrepreneurial activity can take place; - Waterboards are willing to diversify their portfolio towards more DESAR technology related solutions; - Users create opportunities that encourage entrepreneurial activity to happen.	- Municipalities have the power to regulate entrepreneurial activity.
F2. Knowledge development	- The positive experimental atmosphere in the Netherlands is beneficial for the knowledge development.	- Knowledge development is too much focused on individual parts of the DESAR concept instead of a focus on the DESAR system as one concept.
F3. Knowledge diffusion	- Tauw, Waternet and DeSah are able to share valuable tacit knowledge between pilots.	- Knowledge diffusion between pilots is limited according to experts; - Knowledge diffusion between countries is mainly valuable on a legal level. High variety of sanitation usage and culture exists between continents and therefore different solutions are needed.
F4. Guidance of the search	- The government defined a clear end goal in 2050 with an intermediary goal in 2030.	- There is no guidance on how to reach this end goal. Actors want more clarity and support; - Rules around doing pilots in the Netherlands are too tight which causes boring experiments; - Current institutions are contradictory with the government's guidance. Resource cycles cannot close because the law does not allow it for wastewater streams.
F5. Market formation	- Market formation has high potential in new housing estates; - The positive experimental atmosphere in the Netherlands is beneficial for the market formation.	- Market formation lacks potential for existing/old households.
F6. Mobilization of resources	- DESAR technologies have lucrative potential after the threshold of 2000-3000 people has been reached;	- Pilots are often on a small scale and are therefore more costly than conventional solutions; - More financial capital is required; - Human capital is expected to become limited when DESAR technologies scale up.
F7. Creation of legitimacy	- There are pioneers in the Netherlands that create legitimacy for DESAR technologies; - Pilots are beneficial for the creation of legitimacy of DESAR technologies. Strandeiland is considered to be an important pilot for creating legitimacy, due to its size and localization; - legitimacy in the Netherlands is relatively 'good' compared to Germany.	

6.2.1 Evaluation of the Vacuum sub-TIS

Although the entrepreneurial activity is sufficient (F1) when it comes to suppliers of vacuum toilets/systems, some existing actors need to adjust towards DESAR technology solutions (housing corporations and project developers). Therefore, this function is considered to be average compared to the other sub-TISs. The vacuum sub-TIS is considered to have sufficient activity related to knowledge development (F2). Knowledge diffusion is not sufficient (F3), since actors are reinventing the wheel when it comes to vacuum toilets and systems in different pilots. The market formation (F5) activity is considered to be average (relatively to other sub-TISs. Although there is a potential market available, it is hard to implement DESAR technologies in houses that are already connected to the conventional sewer system. There are not enough resources mobilized like human capital and financial resources (F6) to support the development of the vacuum sub-TIS. This can partly be explained because of the lack of guidance (F4) on how to reach the end goal in 2050, taking into account the contradiction of some institutions that are in conflict with the government's intentions. It becomes more legitimate to use vacuum toilets/systems (F7), however, there are still a lot of skepticisms arguing that vacuum toilets/systems make too much noise and smell too much.

In order for an entrepreneurial Motor in the vacuum sub-TIS to develop, the following functions can be improved: knowledge diffusion (F3), guidance of the search (F4) and resource mobilization (F6). Inducement and blocking mechanisms specific to the vacuum sub-TIS can be found in *Table 6.8*. The evaluation of the vacuum sub-TIS compared to the other sub-TISs can be found in Table *6.11*.

Table 6.8 Inducement and blocking mechanisms specific to vacuum sub-TIS.

Function	Inducement mechanisms	Blocking mechanisms
F1. Entrepreneurial activity	- Vacuum toilets/systems market is sufficient (vacuum sub-TIS);	- Housing corporations and project developers (vacuum and wastewater treatment sub-TIS) have a hard time in diversifying their portfolio (mainly because of policy that regulates fixed rental prices).
F2. Knowledge development	- Knowledge development of vacuum sub-TIS is sufficient; - Dutch researcher (Zeeman) involved in 5,3 vacuum sub-TIS related publications world-wide; - Wageningen University dominant in knowledge development.	
F7. Creation of legitimacy		- Skepticisms argue that vacuum toilets/systems make too much noise and smell too much (vacuum sub-TIS); - Project developers are repeatedly mentioned as to be conservative towards DESAR technologies.

6.2.2 Evaluation of the wastewater treatment sub-TIS.

Entrepreneurial activity (F1) is considered to be insufficient because there is only one relevant actor present that is able to deliver decentralized water treatment technologies on a small scale. Furthermore, the Netherlands has a poor knowledge development (F2) in the wastewater treatment sub-TIS when compared to the other sub-TISs. The wastewater treatment sub-TIS is considered to be sufficient when it comes to market formation (F5) since DeSah is currently a key player on the market and other actors that provide these technologies on a larger scale are expected to join the market in the future. On the up side, knowledge about wastewater treatment technologies can be diffused easily (F3) because DeSah is involved in all pilots. DeSah is also important for mobilization of (human) resources (F6), since they train employees of the waterboards. Finally, there is a lack of guidance (F4) on how to reach the end goal in 2050 (taking into account the contradiction of some institutions that are in conflict with the government's intentions).

In order for an entrepreneurial Motor in the wastewater treatment sub-TIS to develop, the following functions can be improved: entrepreneurial activity (F1), knowledge development (F2) and guidance of the search (F4). Inducement and blocking mechanisms specific to the wastewater treatment sub-TIS can be found in *Table 6.9*. The evaluation of the vacuum sub-TIS compared to the other sub-TISs can be found in Table *6.11*.

Table 6.9 Inducement and blocking mechanisms specific to wastewater treatment sub-TIS.

Function	Inducement mechanisms	Blocking mechanisms
F1. Entrepreneurial activity	- Incumbent suppliers for wastewater treatment technologies are expected to take over on larger scale projects.	- There is only one real supplier (DeSah) for decentralized water treatment technologies for blackwater and greywater; - Housing corporations and project developers (vacuum and wastewater treatment sub-TIS) have a hard time in diversifying their portfolio (mainly because of policy that regulates fixed rental prices).
F2. Knowledge development		- Knowledge development of wastewater treatment sub-TIS is insufficient compared to other sub-TISs.
F3. Knowledge diffusion	- Tauw, Waternet and DeSah are able to share valuable tacit knowledge between pilots.	
F5. Market formation	- DeSah has positioned themselves as a key player for the development of DESAR technologies in the Netherlands, but also internationally.	
F6. Mobilization of resources	- DeSah is able to train employees so they can do maintenance and operation of machines.	
F7. Creation of legitimacy		- There is only one supplier for small scale decentralized water treatment technologies (wastewater treatment sub-TIS). More are preferred to create support and legitimacy.

6.2.3 Evaluation of the thermal energy sub-TIS.

The thermal energy sub-TIS is considered to have sufficient entrepreneurial activity (F1) since the heat exchangers are well established in the market. Also, the knowledge development (F2) and diffusion (F3) are considered to be sufficiently fulfilled. A lack of guidance (F4) exist on how to reach the end goal in 2050, taking into account the contradiction of some institutions that are in conflict with the government's intentions. Furthermore, there are not enough resources mobilized (F6) (like human capital and financial capital) to support the development of the thermal energy sub-TIS. It has yet to be decided whether or not municipal heat companies are going to be included, leading to uncertainty in the formation of market(s) (F5). However, the experts emphasize on the lucrative potential of thermal energy recovery in future markets. Therefore, the market formation function is considered to be sufficient.

In order for an entrepreneurial Motor in the wastewater treatment sub-TIS to develop, the following functions can be improved: guidance of the search (F4) and resource mobilization (F6). Inducement and blocking mechanisms specific to the thermal energy sub-TIS can be found in *Table 6.10*. The evaluation of the vacuum sub-TIS compared to the other sub-TISs can be found in Table *6.11*.

Table 6.10 Inducement and blocking mechanisms specific to thermal energy sub-TIS.

Function	Inducement mechanisms	Blocking mechanisms
F1. Entrepreneurial activity	- Heat exchangers (needed for thermal energy recovery) market is sufficient (thermal energy sub-TIS).	
F2. Knowledge development	- Knowledge development of thermal energy sub-TIS is sufficient.	
F3. Knowledge diffusion	- NAT is a valuable network for knowledge diffusion in the thermal energy sub-TIS.	
F5. Market formation	- Experts emphasize on the lucrative potential of thermal energy recovery. The combination of sub-TISs creates an attractive business case.	- It has yet to be decided whether or not municipal heat companies are going to be included (thermal energy sub-TIS). If they don't do that, then the utility or energy companies will take over, which subsequently will slow down the development of DESAR.

Based on the evaluations of the three sub-TISs, a relative comparison has been made (*Table 6.11)*. Guidance of the search (F4) is evaluated as insufficient for all sub-TISs. The vacuum sub-TIS is evaluated as the worst performing sub-TIS, while the thermal energy sub-TIS is performing the best.

Table 6.11 Evaluation of the three sub-TISs (relatively). 1 = poor, 2 = average, 3 = sufficient.

Function	Vacuum sub-TIS	Wastewater sub-TIS	Thermal energy sub-TIS
F1. Entrepreneurial activity	2	1	3
F2. Knowledge development	3	1	3
F3. Knowledge diffusion	1	3	3
F4. Guidance of the search	1	1	1
F5. Market formation	2	3	3
F6. Mobilization of resources	1	2	1
F7. Creation of legitimacy	1	2	2
Total score	11	13	16

6.2.4 System failures

Weaknesses in a system may lead to system failure, meaning that a system fails to develop or does so in a stunted fashion. Policy should therefore be aimed at fixing system failures related to Entrepreneurial activity (F1), knowledge development (F2), knowledge diffusion (F3), guidance of the search (F4) and resource mobilization (F6) in all three sub-TISs. Based on the functional pattern, the blocking mechanisms and the Motors of innovation, three types of system failures can be identified. The entrepreneurial Motor can more easily develop in all three sub-TISs if these system failures are being fixed.

Capability failures

Firstly, there is a lack of companies that provide small scale wastewater treatment technologies. Secondly, there is a lack of willingness of existing actors (housing corporations and project developers) to diversify their portfolio. Thirdly, there is a lack of (sufficient) actors that diffuse knowledge among pilots. Thirdly and finally, there is a lack of human capital available. The sub-TISs need more human capital in order to grow.

Network failures

Firstly, there is a poor interaction between actors of different pilots in which experiences are shared. Secondly, there is a poor interaction between government and the rest of the actors on how to reach the end goal in 2050. Thirdly and finally, there is a poor interaction between public-private companies.

Institutional failures:

Firstly, there is a lack of guidance in the form of policies. Current policies are contradictory with the government's guidance. Resource cycles cannot close because the law does not allow it. Secondly, there is a lack of knowledge development in the wastewater treatment sub-TIS. Thirdly, there is a lack of subsidy. Fourthly, there is a lack of experimenting space in pilots that is needed for learning purposes. Currently, the rules are too tight.

7. DESAR technologies in a sustainability transition

The MLP framework can in addition be used to get a better understanding of the broader transition process.

7.1 Stabilizing factors

Incumbent regimes (urban water management regime and the housing/building regime) are stabilized by existing sociotechnical configurations.

The urban water management regime is stabilized by three main factors. Firstly, the law does not allow resource cycles to close (strict regulations that prohibit the reuse of resources from wastewater). This makes it hard for novel innovations to create an advantage over the urban water management regime. Secondly, the incumbent technologies are embedded in the society. People are used to technologies like a gravity sewer (and toilet). Behavior needs to change when people are going to use a vacuum toilet/system. A third stabilization factor is the taboo on human urine and feces for usage in agriculture. People do not like the idea that human feces will be used to grow food.

The housing/building regime is stabilized by three main factors. The housing/building regime is stabilized for the most part by regulations. Firstly, policy is in place that causes rental prices to be fixed. This creates stabilization for the incumbent housing/building regime because investments of novel technologies cannot be passed to the users in the form of a higher rental price. Secondly, there are strict rules about design standards (national building regulation), which are specifically designed for the incumbent technology. An example is the obligation for municipalities to connect every household to the central sewer system.

7.2 Destabilizing factors

According to the experts, pilots play an important role for the development of DESAR technologies for various reasons. All pilots create knowledge development, technological improvement, acceptance and legitimacy. Stability in the existing socio-technical system makes it hard for novel technologies to become part of the regime. By executing pilots, actors are able to work around some existing policies that normally hamper the development of DESAR technologies. Municipalities are not obligated to connect households in pilots to a central sewer, housing corporations and project developers are able to work around the design standards (national building regulation) and there are financial resources available in the form of equalization funds and to a smaller extent by subsidies. Experts explained scarcity of (clean) water, sustainable energy and other resources (like phosphate, cellulose and bioplastics) to be main landscape factors that put pressure on the incumbent regimes (urban water management regime and building/housing regime). Incumbent technologies and regimes are not able to close resource cycles and cause too much wastage of (clean) water. Scarcity can be allocated to both climate change and a changing composition of the population. A second landscape factor is the limited capacity of incumbent technologies. The population keeps growing to a certain point in which the current infrastructure needs to be expanded or changed by alternative solutions.

Geels (2002) explained that elements at the regime level are stable because they are linked together. These elements and linkages are subsequently the result of activities of social groups which (re)produce them. When the linkages in the configuration loosen up, novel innovations might escape the niche-level and might be able take over the incumbent regime in the form of fitting and conforming, and/or stretching and transforming (Smith & Raven, 2012). The interviews gave insight in the interplay of stabilizing mechanisms at the regime level and pressures that destabilize the regime from the landscape level in combination with emerging innovations at the niche level. Reconfigurations occur when developments at multiple levels link up and reinforce each other. Municipalities, waterboards, housing corporations and project developers are active at the regime level. When looking at Buiksloterham and Strandeiland, we see that housing corporations and project developers behave in a conservative way and are not willing to change (keep reproducing existing elements and linkages). In contrast, waterboards are considered to be a pusher of DESAR technologies. Waterboards are collaborating with DeSah (water treatment technology supplier), knowledge institutes and consultancies. Waternet (local waterboard Amsterdam) have their own department working with thermal energy recovery technologies (which collaborates with local energy cooperatives and actors within NAT). Municipalities are being pushed by the waterboards to work with DESAR technologies, in turn the municipalities collaborate with vacuum systems/toilet suppliers, housing corporations and project developers. The waterboards are therefore important actors that are able to link up the niche level with the regime level.

8. Conclusions

The central aim of this study is to identify the conditions for DESAR technologies to contribute to a sustainability transition in the urban water management sector in the Netherlands. There is a lack of information on how these DESAR technologies are developing and how they potentially could be used for a transition of parts of the current wastewater infrastructure. We adapted a systemic perspective that provides an encompassing approach (TIS) to analyze the core structures and processes that are necessary for developing a certain technology. The MLP framework has in addition been used to get a better understanding of the broader transition process. Pilots in the Netherlands represent space for experimenting were the alignment of technical and social elements can be tried out and tested (leading to niche dynamics) and also space were actors can establish new capabilities, build up new networks and find out the suitability of institutions. Because of their size and visibility (in terms of media attention) in the Netherlands, we assumed that the pilots Buiksloterham and Strandeiland were important contexts for TIS(s) to develop. Therefore, we used these two pilots as main input for our data collection.

In order to identify the conditions for DESAR technologies to contribute to a sustainability transition in the urban water management sector in the Netherlands, the following research question has been composed: *"What barriers and drivers can be identified in the DESAR innovation system in the Netherlands and how may these technologies contribute to a sustainability transition in the Dutch urban water management sector?".* In this study, a qualitative research method was used in which sixteen experts (suppliers, municipalities, waterboards, professors, consultants, housing corporations, project developers etc.) in the field have been interviewed. Because of the heterogeneity in terms of structural components within the DESAR technology field, but keeping in mind the technology continuum, three different sub-TISs have been identified. The first sub-TIS contains vacuum toilets/systems technology (vacuum sub-TIS). The second sub-TIS contains treatment technology of both greywater and blackwater and the recovery of resources (wastewater treatment sub-TIS). The third sub-TIS contains technology of thermal energy recovery from wastewater (thermal energy sub-TIS).

Based on the evaluations of the three sub-TISs, a relative comparison has been made. The analysis demonstrated that *Guidance of the search* (F4) is evaluated as insufficient for all sub-TISs. The vacuum sub-TIS is evaluated as the worst performing sub-TIS, while the thermal energy sub-TIS is performing the best.

The most important barriers hampering the development of the DESAR sub-TISs have been identified. Firstly, the government does not provide guidance on how a circular economy should be reached and how resource cycles should be closed (all three sub-TISs). This lack of guidance is strengthened by the fact that current institutions are perpendicular on what the government wants to achieve. Resource cycles cannot close because the law does not allow it for wastewater streams (strict regulations that prohibit the reuse of resources from wastewater). Secondly, there is of lack of suppliers the market that is able to deliver decentralized treatment technologies (wastewater treatment sub-TIS). Municipalities work with tenders, in which it is not preferred to have only one supplier. Also, for reasons of legitimacy and support, it is preferred to have more actors that can provide decentralized wastewater treatment technologies. Thirdly, housing corporations and project developers behave in a conservative way and are not willing to change (vacuum sub-TIS and thermal energy sub-TIS). Existing policy aims at fixed rental prices, which means that higher investment costs cannot be calculated to the consumer. Housing corporations and project developers are now hampering the development of DESAR technologies by lobbying against it. Fourthly, although pilots are considered to be good for the development of DESAR technologies, there are still some drawbacks that have been identified in all three sub-TISs. It has been calculated that DESAR technologies can be lucrative at a scale around 2000-3000 people. Pilots on a smaller scale are therefore not lucrative. Not only are pilots costly, the rules round the experiments are so tight that the space for experimenting is limited. Actors that are experimenting in the Netherlands have to meet all kinds of norms, resulting in careful behavior that does not always lead to the visibility and clarity of specific needs and expectations. In addition, the municipalities are seen as the clients for most pilots, which give them the power to decide what technologies are used and which actors will be included. This gives them the power to allow entrepreneurial activity to happen or not. Fifthly, there are some knowledge development and diffusion barriers that have been identified in all three sub-TISs. Knowledge development in the wastewater treatment sub-TIS is insufficient and knowledge development in general is too much focused on individual DESAR parts instead of the whole DESAR concept. It is therefore difficult to apply created knowledge at the system level of DESAR. Knowledge diffusion between pilots is also limited. Experts mention that actors in different pilots are reinventing the wheel repeatedly because experiences are not shared sufficiently. Sixthly, there is a lack of financial resources and human capital in all three sub-TISs. Seventhly and finally, it has yet to be decided whether or not municipal heat companies are going to be included (thermal energy sub-TIS). If not, then the utility of energy companies will take over, which subsequently will slow down the development of DESAR technologies.

The most important drivers that contribute to the development of the DESAR sub-TISs have been identified. Firstly, there is a clear end goal which is formulated by the government (circular economy in 2050). Although the guidance towards this goal is considered to be insufficient, DESAR technologies potentially fit in well with the goals of the government, which is therefore seen as a driver for development of DESAR technologies. Secondly, there is sufficient entrepreneurial activity in vacuum toilets/systems (vacuum sub-TIS) and heat exchangers (thermal energy sub-TIS). It is even expected that large scale suppliers for water treatment technologies might have interest in joining as a supplier for decentralized water treatment technologies (wastewater treatment sub-TIS). Thirdly, there is a positive atmosphere in the Netherlands in terms of doing pilots. There are over 10 pilots that are experimenting with DESAR technologies. According to the experts, the pilots play an important role for the development of DESAR technologies for creating knowledge, technological improvement, acceptance and legitimacy. Fourthly and finally, DESAR technologies have a lucrative potential. Experts explain DESAR as one concept with different technological parts that can be applied depending on what is needed in a specific situation. By combining the three sub-TISs, business cases become more attractive. The bridge between DESAR and the energy sector has high potential, especially because houses need to get off the gas grid. This shows the lucrative potential of energy recovery (also biogas production) that might be very attractive for the market.

DESAR technologies have the potential to contribute to a sustainability transition in the Dutch urban water management sector. Niche dynamics within the sub-TISs of DESAR technologies are expected to become part of the incumbent urban water management (fit and conform niche empowerment). Experts believe that a hybrid system (both centralized and decentralized sanitation) will likely exist in the future, meaning that the DESAR technologies will be mainly applied in new housing estates. There is no need to fundamentally restructure the regime in order for the niche dynamics within the sub-TISs to flourish. Reconfigurations occur when developments at multiple levels link up and reinforce each other. Waterboards can play an important role in this because they are able to link up the niche level with the regime level. The housing/building sector provides a boundary condition that can support or hamper developments of DESAR technologies further. DESAR technologies are not expected to lead to a transition in the housing/building sector.

DESAR technologies are not able (yet) to become part of the incumbent regime. The results showed that all three sub-TISs are experiencing some barriers that hamper their development. These barriers subsequently led to three sorts of system failures (capability, network and institutional failures). By fixing the system failures, the DESAR technologies have more change of becoming part of the urban water management regime.

This study has demonstrated that combining TIS and MLP provides complementary results. In addition, this study showed that pilots can have a positive influence on the reconfiguration process in which developments at multiple levels link up and reinforce each other. In spite of this, it is believed that not all context structures that interact with the DESAR sub-TISs have been identified in this study. More research will be needed to enhance a combined framework.

9. Discussion

The pilots have been used to identify conditions for DESAR technologies to contribute to a sustainability transition in the urban water management sector. The outcomes of this study can help to make prospects about the transition in the Dutch urban water management sector. The results showed that all three sub-TISs are experiencing some barriers that hamper their development, subsequently leading to three types of system failures. By fixing the system failures with fitting policy, the DESAR technologies have more change of becoming part of the urban water management regime.

9.1 Policy advice

DESAR technologies are not able (yet) to become part of the incumbent regime(s). The results showed that all three sub-TISs are experiencing some barriers that hamper their development. These barriers subsequently lead to three sorts of system failures (capability, network and institutional failures). Niches that are in a way compatible with the regime or have potential to have an advantage over regimes may be more successful than others (Markard & Truffer, 2008). By fixing the system failures, the DESAR technologies have more change of becoming part or support the incumbent regimes. Based on the functional pattern, the inducement and blocking mechanisms, and the Motors of innovation, three types of system failures were identified (capability, network and institutional failures). Policy advice is aimed at fixing these system failures.

For capability failures, this would mean that policy can be aimed at stimulating and organizing participation of actors. Firstly, more companies are preferred that are able to provide decentralized wastewater treatment technologies (now it is only DeSaH). It is expected that actors that currently delivering treatment and processing technologies for the conventional system will take over. Firms like Convert, PAQUES and Biothane develop systems needed for this specific fermentation step (UASB or Upflow Anaerobic Sludge Blanket) and are (in theory) able to join this market. However, they are not interested in building these systems on a small scale. Subsidy can help to attract these larger companies for the wastewater treatment sub-TIS. Secondly, policy that causes rental house prices to be fixed can be adjusted (for example by not fixing rental prices for houses that include DESAR technologies or by including subsidies) so that housing corporations and project developers are more willing to diversify their portfolio towards DESAR technologies.

For network failures, this would mean that policy can be aimed at stimulating the occurrence of interactions. Weak ties are preferred to be strengthened. Firstly, the interaction between pilots can be improved. The government can encourage actors to share experiences with each other in multiple ways, for example by obligating municipalities and waterboards to share their experiences, assign the task of sharing experiences to consultancy firms like Tauw. Secondly, the interaction between public and private organizations can be improved. Contracts between public and private companies are ideally constructed in a way so that uncertainties are reduced as much as possible.

For institutional failures, this would mean that the policy can provide guidance on how a circular economy should be reached and how resource cycles should be closed (for example with subsidies for the usage of technologies that are preferred by the government). In turn, existing policy can be adjusted so that resource cycles can more easily be closed (for example by allowing fertilizers to be reused in the agricultural sector). The results suggest that some of the strict rules stated in the national building regulation (for example the obligation to connect to a central sewer) and rules that make it impossible to reuse or reclaim resources can ideally be changed. Results also showed that knowledge development in the wastewater treatment sub-TIS is insufficient. The government could stimulate such research with subsidizing related affiliations in this field. Furthermore, the government might want to make a decision rather soon on how thermal energy recovery is going to be governed (via a municipal heat company or via the market) as the current situation brings uncertainty. Finally, experts emphasize on the importance of Strandeiland, mainly due to its scale. It is still unclear whether or not vacuum toilets will be included in the pilot and subsequently who is responsible for the quality and functionality (Alliantie or Jets). It would be beneficial for the development of DESAR technologies if vacuum toilets will be applied at Strandeiland.

9.2 Research limitations

This study includes several limitations. Firstly, the TIS framework does not give much explicit attention to the dynamics of surrounding contexts, like parallel development and competition of several technologies. In this study, we tried to take into account coupled dynamics between TISs and various contextual structures. The MLP framework helped to get a better understanding of the socio-technical transition. External links were mapped to get a better idea of influences that have impact on the development of DESAR technologies but not affected by internal TIS processes. Interactions between horizontal sub-TISs were analyzed by looking at mutual structural components (structural couplings). However, the analyzed structural coupling in this study were limited to the three sub-TISs alone. Bergek et al. (2015) described three different types of structural couplings, in which surrounding and related TISs was only one of them. Not all context structures that interact with the DESAR sub-TISs are expected to be studied, which might have influence on the validity of the conclusions.

Secondly, the broader (global) context of the system is not explained in great detail. Conceptualizing an innovation system without a geographical boundary is considered to be a distinctive feature of the TIS concept (Binz et al., 2014). By taking a technology as a starting point, the TIS cuts across spatial boundaries. However, studies like this one delineate ex ante on the basis of a national boundary (the Netherlands). The broader (global) context of the system is not explained as something more than a conceptualization of a global technological opportunity set to which actors have access in an arbitrary manner (we did find some evidence about the international networks via an assessment of publications related to the sub-TISs). The study cannot be used for (statistical) generalization purposes on cases of DESAR technologies in other countries. Experts suggested that conditions are quite different in various continents. All the cultures are different (and with that levels of legitimacy) and also the composition of the black water varies quite strongly. The results of this study cannot be used for (statistical) generalization purposes on cases of DESAR technologies in other countries. However, the results can be used for conceptual generalization, since this is not bounded to a geographical boundary.

Thirdly, two pilots were used as a main input for data collection during this study (Buiksloterham and Strandeiland) because they were considered to be the most salient pilots in the Netherlands. Although they indeed seem to be important in the Netherlands, it is unknown if they were fully able to give insight in the development of DESAR technologies. In order to avoid being caught in a closed circle of actors, experts that were involved in other pilots were also interviewed to avoid capture. However, the study is still (mostly) focused on the region of Amsterdam, which might not be representative for the whole Dutch DESAR development.

Fourthly, DESAR technologies were explained by experts as a technology continuum that should rather be seen as one concept instead of a set of different technologies. However, heterogeneity was found in the structural components of these different technologies. The separation of the whole DESAR concept into various sub-TISs might be reason for a debate.

Fifthly, this study is based on qualitative data from interviews. This can be seen as a limitation as this data provided by the interviewees is not significantly demonstrated.

9.3 Theoretical implications

A combined TIS and MLP framework was used to get a better understanding of the relationship between technological development and sectorial change. There has been little overlap in the use of the TIS and MLP frameworks in the literature, although they are based on common theoretical roots and show promising complementarities. According to Markard & Truffer (2008), further analysis was needed in order to explore the benefits and difficulties of such an integrated framework. It is necessary to do empirical test cases (like this study) to demonstrate the actual usefulness of an integrated framework. A combined approach will be beneficial if it meets some (or all) of the identified shortcomings of the individual frameworks (Markard & Truffer, 2008).

Firstly, there should be more focus on micro-level innovation processes at the level of organizations. The pilots in the Netherlands represent space for experimenting were the alignment of technical and social elements can be tried out and tested (leading to niche dynamics) and also space were actors can establish new capabilities, build up new networks and find out the suitability of institutions. The pilots can be seen as micro-level innovation processes, which we studied at the level of organizations.

Secondly, the mutual interdependencies between actors and institutions should be kept in mind. This means that the roles and strategies different actors play in innovation processes and the interaction of actors and institutions should be analyzed, giving insight in how resources are distributed among actors and how this contributes to the development of networks and the potential of actors to innovate. The TIS framework provided analytical power with its elaborated framework with structural components and the functional analyses, which are well complementary and able to explain these interdependencies between actors and institutions (Markard & Truffer, 2008).

Thirdly, consistent performance comparisons need to be developed in order to recommend how to support the development of a particular innovation (not only by looking at the diffusion of the innovation). According to Markard & Truffer (2008), there is no optimal structure to assure a well performing system. A system can perform better or worse compared to another. The key to this performance comparison is their assessment in terms of functions. We tried asses the performance of the sub-TISs by taking into account the maturity of the systems (phase of development), via an assessment of publications and relative differences in performance between sub-TISs.

Fourthly, the review of the environment is less systematic. The system perspective falls short in explaining technological transitions. The system perspective only partly takes aspects into account outside the system's environment. For example, external institutions that hinder the innovation process are just treated as blocking mechanisms, while they may be the result of strategic actions of incumbent actors. Furthermore, novel technologies in competing innovation systems might affect the focal TIS. Interactions between horizontal sub-TISs were analyzed by looking at mutual structural components (structural couplings) and some external factors have been identified (landscape factors and forces closer to the TIS). Novel technologies or products that emerge in competing or complementary innovation systems and thus affect the innovation were neglected for the most part. For example, a possible complementary technology that have been mentioned by an expert (interviewee 2, an employee at a governmental organization) is the cold-heat pump, that can be used side to side with the thermal energy extraction technology. It is expected that not all context structures that interact with the DESAR sub-TISs are studied, as is explained in the research limitations paragraph.

It can be concluded that at least three of the shortcomings have been met, meaning that that a combined framework in this case was beneficial (Markard & Truffer, 2008). In addition, the role of pilots in a transition process has become clearer (more specifically, the role that pilots play in internal to the MLP framework). According to the experts, pilots play an important role in the development of technologies for various reasons. All pilots create knowledge development, technological improvement, acceptance and legitimacy. Stability in the existing socio-technical system makes it hard for novel technologies to become part of the regime. By doing pilots, actors are able to work around some existing policies that normally hamper the development of DESAR technologies. This study confirmed the findings of earlier works (for example: Sengers et al., 2019) that pilots can have a positive influence on the reconfiguration process in which developments at multiple levels link up and reinforce each other.

A first suggestion for further research is to more systematically study the broader context of the system in more detail. What happens outside and across the system boundary of DESAR technologies has been worked out in a less systematical way. The validity of the conclusions will improve if the surroundings (context structures that interact with the DESAR sub-TISs) are studied in more detail.

A second suggestion for further research is to connect the results of this study to other studies that cross Dutch boundaries. The technology development of DESAR is an example of a spatially sticky GIS configuration (third quadrant) (Binz & Truffer, 2017), in which technological innovation depends heavily on subsystems and structural couplings in territorially delimited contexts. Markets in such a configuration show strong geographical variation in terms of specialized needs, regulations and levels of legitimacy. It might be interesting to connect the outcomes of this study to the ones of other studies with a similar set-up in order to find out more about the TIS(s) on an international or even a global level.

References

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions*, *16*, 51–64. https://doi.org/10.1016/j.eist.2015.07.003

Bergek, A., & Jacobsson, S. (2003). The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries. In *Change, Transformation and Development*. https://doi.org/10.1007/978-3-7908-2720-0_12

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Binz, C., & Truffer, B. (2017). Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, *46*(7), 1284–1298. https://doi.org/10.1016/j.respol.2017.05.012

Binz, C., Truffer, B., & Coenen, L. (2014). Why space matters in technological innovation systems - Mapping global knowledge dynamics of membrane bioreactor technology. *Research Policy*, *43*(1), 138–155. https://doi.org/10.1016/j.respol.2013.07.002

Bryman, A. (2016). Social Research Methods - Alan Bryman - Oxford University Press. In *Oxford University Press*.

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of Evolutionary Economics*. https://doi.org/10.1007/BF01224915

CBS. (2019). *Bijna 66 duizend nieuwbouwwoningen in 2018*. https://www.cbs.nl/nl-nl/nieuws/2019/04/bijna-66-duizend-nieuwbouwwoningen-in-2018

Edquist, C. (2009). Systems of Innovation: Perspectives and Challenges. In *The Oxford Handbook of Innovation*. https://doi.org/10.1093/oxfordhb/9780199286805.003.0007

Edquist, C., & Johnson, B. (1997). Institutions and organizations in systems of innovation. In *Systems of innovation: Technologies, institutions and organizations*. https://doi.org/10.1016/S0024-6301(98)90244-8

Frederiksberg, D. K., & Kastelle, T. (2009). The evolution of innovation systems. *Druid*, *May 2014*.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*. https://doi.org/10.1016/S0048-7333(02)00062-8

Hegger, D., Vliet, B. J. M. Van, & Spaargaren, G. (2008). *Decentralized Sanitation and Reuse in Dutch Society : Social Opportunities and Dries Hegger , Bas Van Vliet , Gert Spaargaren Decentralized Sanitation and Reuse in Dutch Society : Social Opportunities and Risks Final report for the EET-DESAR project*. *January 2014*.

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

Hoogma, R., Kemp, R., Schot, J., & Truffer, B. (2002). Experimenting for sustainable transport: The approach of strategic niche management. In *Experimenting for Sustainable Transport: The Approach of Strategic Niche Management*. https://doi.org/10.4324/9780203994061

Howells, J. (1996). Tacit knowledge, innovation and technology transfer. *Technology Analysis and Strategic Management*. https://doi.org/10.1080/09537329608524237
Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: The evolution of technological systems in renewable energy technology. *Industrial and Corporate Change*. https://doi.org/10.1093/icc/dth032
Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis and Strategic Management*. https://doi.org/10.1080/09537329808524310
Konrad, K., Truffer, B., & Voß, J. P. (2006). Multi-regime dynamics in the analysis of sectoral transformation potentials: evidence from German utility sectors. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2007.08.014
Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B., & Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. *Science*, *352*(6288), 928–933. https://doi.org/10.1126/science.aad8641
Lens, P., Zeeman, G., & Lettinga, G. (2001). Decentralised Sanitation and Reuse: Concepts, Systems and Implementation. *Water Intelligence Online*. https://doi.org/10.2166/9781780402949
Leung, L. (2015). Validity, reliability, and generalizability in qualitative research. *Journal of Family Medicine and Primary Care*. https://doi.org/10.4103/2249-4863.161306
Lundvall, B. (1992). National systems of innovation. In *London, Pinter*.
Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013
Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*. https://doi.org/10.1016/j.respol.2008.01.004
Mels, A. (LeAF). (2005). *Afvalwaterketen ontketend*. 4–35. http://stedelijkwaterbeheer.stowa.nl/Upload/publicaties2/mID_4924_cID_3914_93616776_rapport 2005 12.pdf
Moron, A., Schaart, N., Verheijen, E., Wets, M., Kokhuis, K., & Stam, S. (2018). *Thematische studie Nieuwe Sanitatie* (Issue november).
Nelson, R. R., & Rosenberg, N. (1993). Technical Innovation and National Systems. In *National Innovation Systems: a comparative analysis*. https://doi.org/10.1016/0048-7333(96)00880-3
Nelson, R. R., & Winter, S. G. (1982). An Evolutionary Theory of Economic Change. *Harvard University Press, Cambridge*. https://doi.org/10.2307/2232409
North, D. C. (1994). Economic performance through time. *American Economic Review*. https://doi.org/10.2307/2118057
OECD. (2014). Water Governance in the Netherlands. In *OECD Studies on Water*. https://doi.org/10.1787/9789264102637-en
Raven, R. (2007). Co-evolution of waste and electricity regimes: Multi-regime dynamics in the Netherlands (1969-2003). *Energy Policy*. https://doi.org/10.1016/j.enpol.2006.07.005
Rijksoverheid. (2016). Nederland circulair in 2050. *Het Ministerie van Infrastructuur En Milieu En Het Ministerie van Economische Zaken, Mede Namens Het Ministerie van Buitenlandse Zaken En Het Ministerie van Binnenlandse Zaken En Koninkrijksrelaties.*
Rip, A., & Kemp, R. (1998). Technological change. *Human Choice and Climate Change*. https://doi.org/10.1007/BF02887432

Rosenberg, N. (1971). The economics of Technological Change. *Harmondsworth: Penguin*.
Rosenberg, N. (1972). Factors affecting the diffusion of technology. *Explorations in Economic History*. https://doi.org/10.1016/0014-4983(72)90001-0
Rotmans, J., Kemp, R., & Van Asselt, M. (2001). More evolution than revolution: Transition management in public policy. In *Foresight*. https://doi.org/10.1108/14636680110803003
Sabatier, P. A. (1988). An advocacy coalition framework of policy change and the role of policy-oriented learning therein. *Policy Sciences*. https://doi.org/10.1007/BF00136406
Scott, W. R. (1995). Institutions and Organizations: Foundations for Organizational Science. In *Legal Theory*. https://doi.org/10.1017/S1352325200000288
Scott, W. R. (2008). Institutions and organizations: Ideas and interests. In *Institutions and Organizations: Ideas and Interests*.
Sengers, F., Wieczorek, A. J., & Raven, R. (2019). Experimenting for sustainability transitions: A systematic literature review. In *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2016.08.031
Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*. https://doi.org/10.1016/j.respol.2011.12.012
Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy*. https://doi.org/10.1016/j.respol.2005.07.005
Suurs, R. A. A. (2009). Motors of sustainable innovation: Towards a theory on the dynamics of technological innovation systems (PhD thesis). In *Innovation Study Group, Utrecht University, Utrecht*.
Van De Ven, H. (1993). The development of an infrastructure for entrepreneurship. *Journal of Business Venturing*. https://doi.org/10.1016/0883-9026(93)90028-4
Van Der Roest, H. F., Van Bentem, A. G. N., & Lawrence, D. P. (2002). MBR-technology in municipal wastewater treatment: Challenging the traditional treatment technologies. *Water Science and Technology*, *46*(4–5), 273–280. https://doi.org/10.2166/wst.2002.0604
Verbong, G., & Geels, F. (2007). The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004). *Energy Policy*. https://doi.org/10.1016/j.enpol.2006.02.010
Wieczorek, A. J. (2014). *Towards sustainable innovation : analysing and dealing with systemic problems in innovation systems. april 1972*. https://dspace.library.uu.nl/handle/1874/301675
Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and Public Policy*, *39*(1), 74–87. https://doi.org/10.1093/scipol/scr008

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Appendix

Appendix A – Diagnostic questions for semi structured interview

Thank you for your willingness to participate. I am currently writing my Master Thesis for my study Innovation Science in Utrecht in which I want to study decentralized sanitation and reuse technologies, or DESAR technologies for short. More specifically, I want to identify barriers and drivers that induce or hamper the development of DESAR technologies and I would like to find out how these DESAR technologies may contribute to a sustainability transition in the Dutch urban water management sector.

I have talked to many experts, but not one that was related to a vacuum sewer company. Your perspective on this subject will likely help me finding out how DESAR technologies are developing and what barriers and inducement exist. I would like to send you a copy after completion.

The interview will be structured into three blocks. Firstly, I would like to know more about the development of DESAR technologies in the Netherlands. Secondly, I would like to discuss the roles of experiments like Buiksloterham for these developments. Thirdly and finally, I would like to discuss the prospects are of urban water management and the role of DESAR technologies in the future.

Are you OK if I record the interview for transcribing purposes?

1. **How far are DESAR technologies developed in the Netherlands and how important are they for the Dutch urban water management?**

Can you tell me what you see as the most important developments in the DESAR field and what their longer-term market potential looks like?

- *What are the most important technologies and systems?*
- *Do you think that the DESAR field is rather homogenous, i.e. developments and strategies in the different technologies supporting each other? Or do you also see competition?*
- *What are the most important networks?*
- *Who are the most important actors?*
- *What are the most important institutions?*

→ *follow up question could be: Do we see very different sub-streams in it?*

How relevant is the DESAR topic for the Dutch urban water management?

How would you describe the progress of the transition towards DESAR technologies in the Netherlands?

- *Is there any controversy within this ecosystem?*
- *Are there any sort of barriers, for example in terms of regulations, norms, expectations of end users, that are very important to consider?*
- *What are typical inducements in that help DESAR technologies to develop?*

2. **What is the role of the two experiments Buiksloterham and Strandeiland in the larger development?**

Are the experiments Buiksloterham and Strandeiland considered to be key activities needed for the development of DESAR technologies in the Netherlands?

Are there any other important relevant activities in the form of networks, experiments or some other form of grassroots and what are they?

What are the most promising/interesting innovations that are developed in these experiments in your view?

What is the actual contribution of the experiments for system maturation?
- *What do the experiments enable for Dutch Urban water management?*
- *What resources do they provide?*
- *Is this important for system integration?*
- *What roles do they play for bringing actors together or getting public attention?*

Are the technological components or systems used in the experiments Buiksloterham and Strandeiland related to the same kind of people and institutions or would you say that they are part of different eco systems?

Who is pushing the experiments forward?
Who is providing resources?
Was it difficult to set the experiments up?

When will the experiments be a success? In other words, what would be considered the ideal outcome of the experiments?

3. **What is the contribution of DESAR technologies to future urban water management?**

Are DESAR technologies considered to be important for sustainability?

What will be the key developments along the way?

In what time periods would you expect major developments to happen?

I do not have any questions left at this point. I sincerely want to thank you for your time. Is there anything that you would like to share, but did not come up in the interview?

Can you provide me with some names that I should interview next?

TRANSLATION TO DUTCH

Bedankt voor het willen meewerken aan dit interview. Momenteel ben ik bezig met mijn Master Thesis voor mijn studie innovatiewetenschappen in Utrecht, waarin ik decentralized sanitation and reuse technologies, DESAR-technologieën in het kort, aan het onderzoeken ben (of nieuwe sanisatie). Meer specifiek: ik wil graag factoren identificeren die de ontwikkeling van DESAR technologien ten goede komen of juist afremmen. Daarnaast wil ik graag onderzoeken hoe DESAR-technologieën zouden kunnen bijdragen aan een duurzame transitie in de Nederlandse stedelijke watersector.

Ik heb in mijn thesis tot nu toe veel gehad aan Decentralized sanitation and reuse in Dutch society. Daarnaast tipte Grietje Zeeman mij om met jou een gesprek te hebben. Jouw perspectief is voor mij heel relevant om uit te vinden hoe DESAR-technologieën zich aan het ontwikkelen zijn en wat voor factoren hieraan bijdragen of juist tegenwerken. Ik zou u vervolgens graag op de hoogte willen houden van mijn studie en de uitkomst daarvan in de nabije toekomst.

Het interview is opgedeeld in drie blokken. Allereerst zou ik graag meer willen weten over de ontwikkeling van DESAR-technologieën in Nederland. Ten tweede zou ik graag met u de rollen van experimenten (zoals Buiksloterham en Strandeiland) willen bespreken en hoe deze experimenten bijdragen aan de ontwikkeling van deze technologieën. Als laatste zou ik graag met u willen bespreken wat de vooruitzichten/toekomstperspectieven zijn van deze DESAR-technologieën op de Nederlandse stedelijke watersector.

Zou u het ok vinden als ik het interview opneem zodat ik het later nog terug kan luisteren en kan transcriberen?

1. **Hoe zijn DESAR-technologieën op dit moment ontwikkeld in Nederland en hoe belangrijk worden zij geacht voor de Nederlandse stedelijke watersector?**

Wat ziet u als de belangrijkste ontwikkelingen in het DESAR-veld, en wat voor lange termijn potenties ziet u hiervoor in de markt?

- *Wat zijn de belangrijkste technologieën en systemen?*
- *Zou u zeggen dat het DESAR-veld homogeen is met betrekking tot ontwikkelingen, strategieën en verschillende technologieën? Of ziet u hier veel competitie in?*
- *Wat zijn de belangrijkste netwerken?*
- *Wat zijn de belangrijkste belanghebbenden of actors?*
- *Wat zijn de belangrijkste instituties?*

→ *Zien we verschillende stromen binnen het DESAR-veld?*

Hoe relevant is het topic van DESAR voor de Nederlandse stedelijke watersector?

Hoe zou u de voortgang van de transitie naar DESDAR-technologieën in Nederland beschrijven?

- *Is er controversie binnen het ecosysteem?*
- *Zijn er belemmeringen in de vorm van bijvoorbeeld regelgeving, normen, verwachtingen, en zijn deze belemmeringen belangrijk om in acht te nemen?*

- *Wat zijn typische factoren die DESAR-technologieën helpen om te ontwikkelen?*

2. **Wat is de rol van de experimenten Buiksloterham en Strandeiland voor de totale ontwikkeling van DESAR-technologieën?**

Worden de experimenten Buiksloterham en Strandeiland gezien als de belangrijkste activiteiten die nodig zijn voor de ontwikkeling van DESAR-technologieën?

Zijn er nog andere belangrijke relevante activiteiten in de vorm van netwerken en experimenten en wat zijn deze?

Wat zijn interessante innovaties die worden ontwikkeld in de experimenten naar uw mening?

Wat is de daadwerkelijke contributie van de experimenten voor de ontwikkeling/rijping van een ecosysteem?
- *Wat stellen de experimenten in staat voor Nederlandse stedelijke watermanagement?*
- *Wat voor middelen voorzien/verschaffen de experimenten?*
- *Is de contributie die de experimenten hebben belangrijk voor de integratie van deze technologieën in Nederland?*
- *Wat voor rol spelen de experimenten in het samenbrengen van belangrijke actoren en voor het verkrijgen van publieke aandacht?*

Zou u zeggen dat de technologische componenten die gebruikt worden in de experimenten Buiksloterham en Strandeiland in verband staan met dezelfde actoren en instituties, of zou u stellen dat ze onderdeel zijn van verschillende eco-systemen?
- *Wie is voornamelijk verantwoordelijk voor het pushen van de experimenten naar mogelijk succes?*
- *Wie zorgt er voor de belangrijke benodigde middelen?*

Was het lastig om de experimenten op te zetten? Wat was er lastig?

Wanneer zouden de experimenten tot een succes bestempeld worden? Wat is de ideale uitkomst?

3. **Wat is de contributie van DESAR-technologieën voor toekomstig stedelijke watermanagement?**

Worden DESAR-technologieën beschouwd als belangrijke duurzaamheid oplossingen?

Wat verwacht u dat belangrijke ontwikkelingen zullen zijn in de toekomst?

Wanneer verwacht u dat belangrijke ontwikkelingen plaats zullen vinden?

Ik heb verder geen vragen meer op dit moment. Ik wil u ontzettend bedanken voor uw tijd. Is er nog iets wat u kwijt zou willen en wat ik niet gevraagd heb in het interview? Heeft u wellicht nog contacten voor mij waarvan u zegt dat ze interessant zouden kunnen zijn voor mijn onderzoek?

Appendix B – Knowledge development Scopus database analyses

Appendix B-1. Search strings used in Scopus per sub-TIS.

Vacuum sub-TIS – 208 results
(TITLE-ABS-KEY(("Vacuum toilet*" OR "source separation") AND ("wastewater" OR "graywater" OR "greywater" OR "blackwater"))) AND PUBYEAR > 1999 AND PUBYEAR < 2021 AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (DOCTYPE,"ar"))

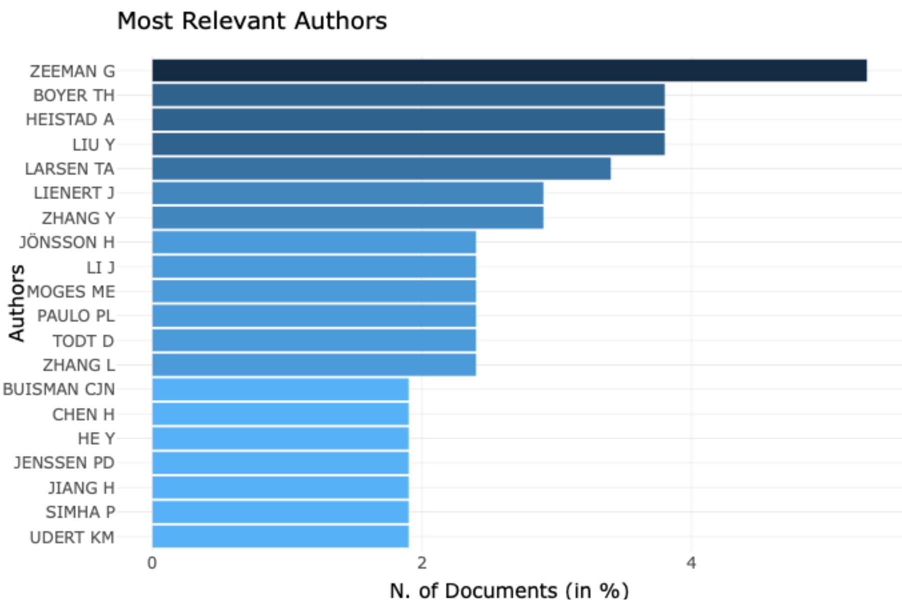
Wastewater treatment sub-TIS – 761 results
(TITLE-ABS-KEY (("Fecal sludge management" OR "FSM" OR "composting") AND ("wastewater" OR "graywater" OR "greywater" OR "blackwater") AND ("treatment" OR "decentralized"))) AND PUBYEAR > 1999 AND PUBYEAR < 2021 AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (DOCTYPE,"ar"))

Thermal energy recovery sub-TIS – 609 results
(TITLE-ABS-KEY (("thermal energy" OR "Heat") AND ("Wastewater" OR "black water" OR "greywater" OR "graywater") AND ("recover*") AND NOT ("geothermal" OR "oil"))) AND PUBYEAR > 1999 AND PUBYEAR < 2021 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar"))

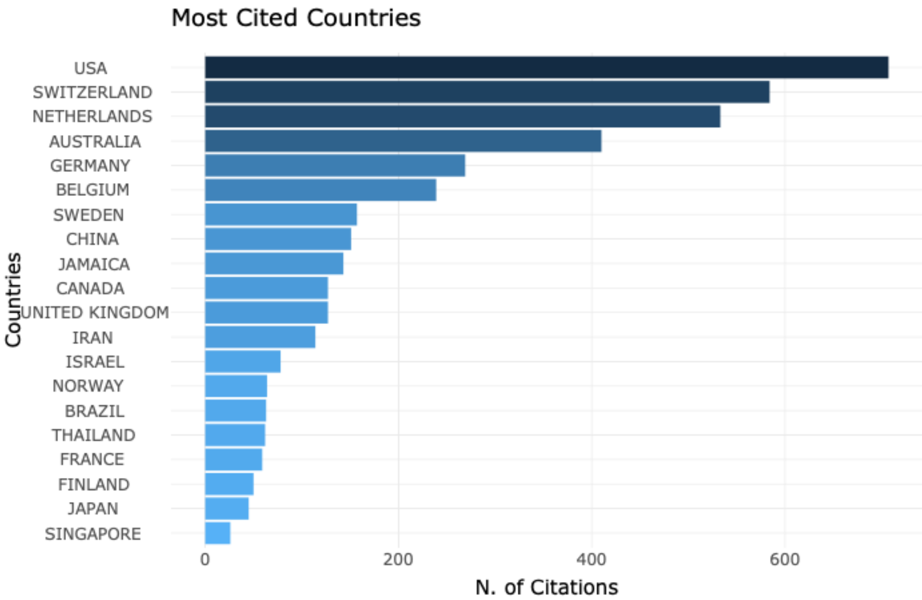
For the thermal energy recovery TIS the bibliometric search has been narrowed by excluding “geothermal energy” to focus on thermal energy recovery from domestic water streams only.

Appendix B-2. Findings in vacuum sub-TIS.

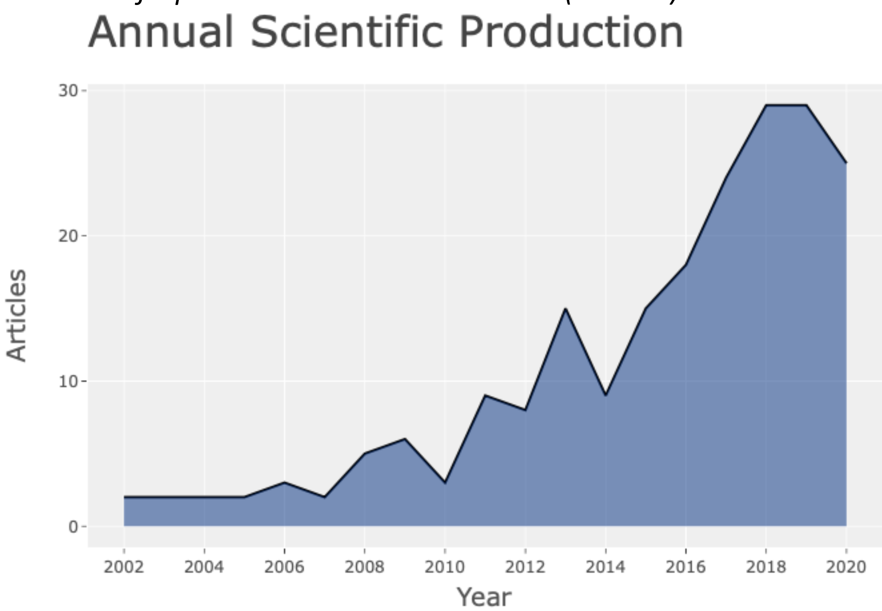
Most relevant authors in vacuum sub-TIS:



Netherlands is the third most cited country in vacuum sub-TIS:

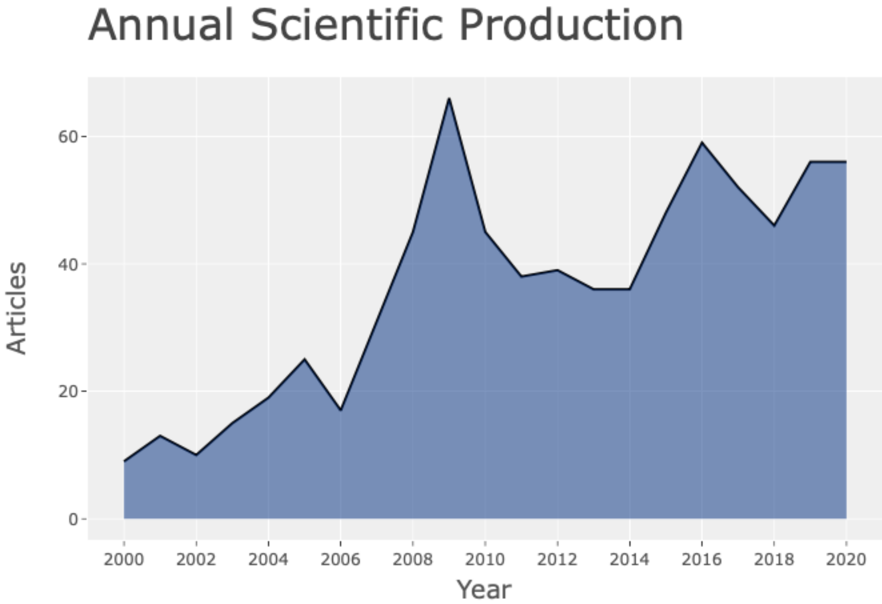


Annual scientific production in vacuum sub-TIS (15.06%):



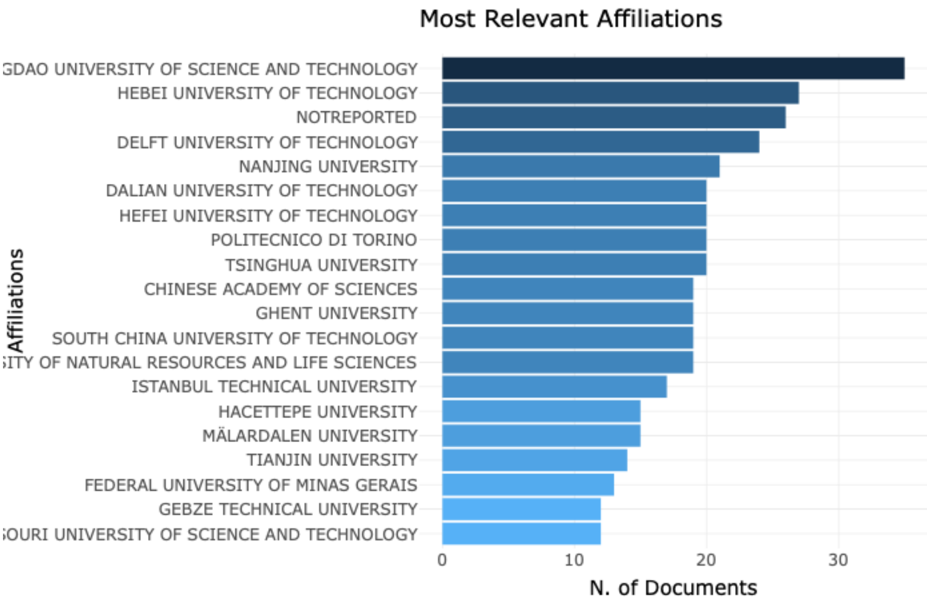
Appendix B-3. Findings in the wastewater treatment sub-TIS.

Annual scientific production in wastewater treatment sub-TIS (9,57%):

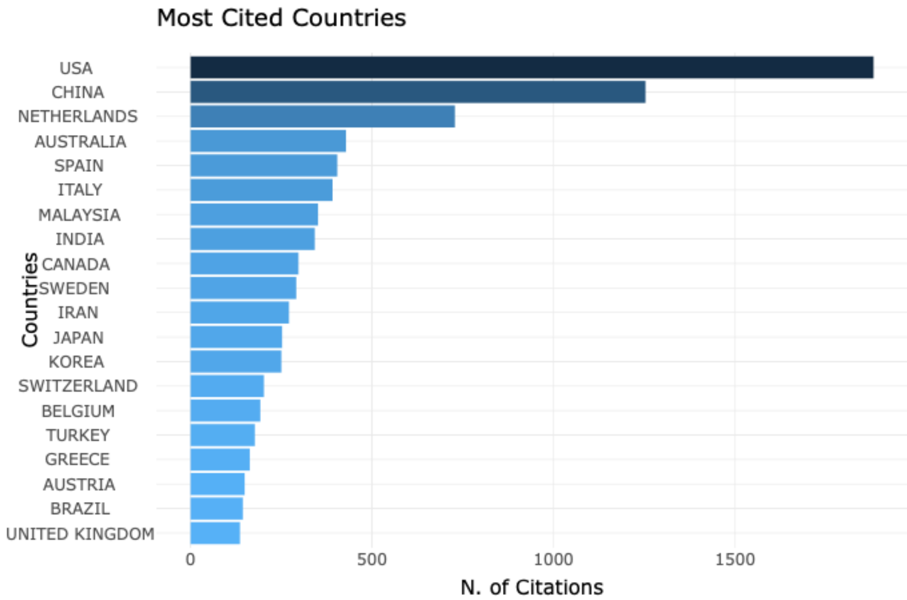


Appendix B-4. Findings in the thermal energy sub-TIS.

Most relevant Affiliations in the thermal energy sub-TIS (TU Delft on place 4):



The Netherland is the third most cited country in the world when it comes to thermal energy sub-TIS:



Annual scientific production of thermal energy sub-TIS (16,37%):