# Towards sustainable wastewater management:

## *Assessing future prospects and upscaling potential of the Resource Recovery Sanitation niche in Germany and The Netherlands*

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*Joint International Master in Sustainable Development*

September 2015

A Master's Thesis of the Faculty of Geosciences for obtaining the degree of Master of Science in Sustainable Development (Environmental Sciences)

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# Preface

> *"Dai diamanti non nasce niente*
> *dal letame nascono i fiori"**
>
> Fabrizio De Andrè, 1967

In the past two years I have imagined myself writing a master thesis on many sustainability issues, sanitation definitely not being one of them. But somehow after coming across the topic in early September 2014, I felt I could not let it go. Certainly I am fascinated by the challenge of introducing sustainable technologies and practices within sanitation, a truly wicked problem that is too often neglected. However, there is something else that convinced me – it catches peoples' attention and it usually ends up with laughing (if you manage to surpass the first awkward moments). In fact, I am smiling even now – thinking about a distinguished respondent telling me, after one hour of relatively formal interview that "in the end, you know, we are talking about shit!". That is the thing with the sanitation topic, you always end up having fun.

During the past months I have had the opportunity to discuss my research with visionary and inspiring people – those who with their ideas and daily work have succeeded in setting in motion the slow mechanism of societal change. Changing wastewater paradigm is as compelling as it is complicated; sanitation is the system that we more give for granted, the one that is more than all hidden into our society's behavioural norms. I was lucky enough to approach sustainable sanitation from two of the countries where this concept has been originally developed, and to study wastewater management systems that are increasing our odds of beating the worldwide sanitation challenge. These facts stimulated my already high curiosity for the topic, which seems offering huge opportunities for rethinking in more respectful and balanced terms the ways we interact with each other and with the natural environment.

I would like to sincerely thank all the people that have made this research so interesting. In particular my supervisor Peter Driessen for his precious guidelines, advice and debates that taught me how to adopt a critical approach. I would also like to express my gratitude to all the people that have engaged with me in fruitful interviews in Germany and in The Netherlands and to the inspiring team from Metabolic. Finally, I am very thankful to my family and Ben for their untiring support and for being a source of continuous intellectual stimulation.

* *"Nothing grows from diamonds*
*from manure flowers bloom"*

# Abstract

Conventional wastewater systems are extremely resource-intensive and interfere with nutrient cycles causing damages to aquatic environments. Moreover they are struggling to cope with demographic changes, increasing water demands and energy prices as well as challenges posed by climate change such as modifications in rainfall patterns. The economic impacts of wastewater systems are also a major concern: national expenses for infrastructure maintenance, expansion and operations are in the order of *billion* euros per year. As the resilience of current wastewater systems is at risk, they may not be able to secure high quality service provision in the long term.

Growing awareness on the challenges that wastewater systems are confronted with has stimulated the development of Resource Recovery Sanitation (RRS), a sustainable approach to sanitation geared towards the recovery and reuse of the different *waste*water components – i.e. water, energy and nutrients flows. Resource Recovery Sanitation is two-faceted; by upgrading and reusing wastewater flows on the one hand it reduces the need for external inputs in sanitation and other sectors, on the other it minimizes the amount of pollutants leaking into the environment. This circular approach to wastewater management has found application in a growing number of small-scale pilot projects, whose future pathways are still uncertain.

Employing the Multi-level Perspective on socio-technical transitions and Strategic Niche Management as main analytical tools, this research explores future prospects of two of these pilot projects – De Ceuvel in The Netherlands and DEUS 21 in Germany. It sheds light on the mechanisms driving transition processes in the field of wastewater management to understand the scope for the current sanitation paradigm to move towards a more sustainable state, and the role of the RRS niche in contributing to it. The analysis follows a three-tiered approach. First it investigates what are the main factors and processes influencing the success of the two case studies, and then it explores constraining and stimulating factors influencing their upscaling pathways that derive from the predominant sanitation system and the institutional, political and economic background they are inserted in.

The research indicates that albeit promising, the process of upscaling the RRS niche is currently in a very early stage, with resource recovery pilot projects still representing a small fraction of wastewater management solutions. The network of people interested and involved in RRS is expanding across different segments of society, which is an important step for encouraging their higher institutionalisation and wider implementation. These pilots are playing an important role in the optimization of technical and social aspects of sustainable sanitation systems. Nevertheless, a complete transition of conventional sanitation is not expected to take place in countries like The Netherlands and Germany. Here a compelling need for changing our wastewater system is not (yet) perceived since the drivers that would stimulate a more pervasive transformation – water and nutrient scarcity – are not there. Yet, RRS systems offer alternatives to one of the most pressing shortcomings of the conventional approach to wastewater management: *inflexibility*. Moreover, there are already contexts in which RRS systems represent an economically competitive alternative (e.g. new estate developments where wastewater

infrastructure is not yet present; places where ageing infrastructure requires high investment costs to be kept in operation). In fact, it appears that future wastewater systems in Germany and The Netherlands (and countries with similar wastewater models) will integrate conventional infrastructure and elements of or clusters of (semi-) decentralized RRS systems. However, despite growing interest in sustainable wastewater management systems, reuse aspects are lagging behind.

**Key concepts:**

Sustainable wastewater management
Resource recovery sanitation systems (RRSS)
Sustainable socio-technical transitions
Multi-level Perspective (MLP)
Strategic niche management (SNM)
Up-scaling niche experiments

# Chapter 1: Introduction

## 1.1 The limitations of conventional wastewater systems

The construction of extensive water-based sanitation systems in European and North American cities throughout the late 19th and 20th centuries has been driven by the assumption of wastewater being only suitable for disposal, and the shared perception of water being an abundant resource (Bell, 2015; Berndtsson and Hyvonen, 2002). Since then, the western approach to wastewater management has been based on the linear flows of water and nutrients – the so-called "flush-and-discharge" model (Esrey et al., 2001; Haq and Cambridge, 2012) – and centralized structures (Meinzinger et al., 2010). This model has then been exported wherever societies could bear its costs. While originally intended as a solution to mounting health concerns due to urban population growth and resulting increased risks of disease spreading, these sanitary systems seem inadequate to meet the environmental, social and economic challenges of present times (Werner et al., 2010).

### *Water, energy and climate change*

Conventional wastewater systems are extremely resource-intensive in that they require great amounts of (drinking) water to collect and transport excreta to centralized treatment plants and energy to ensure removal of contaminants to prevent pollution of receiving waters. Estimates highlight that they employ roughly 15,000 l of water per person per year (Quitzau, 2007) to dispose of only 500 l of urine and 50 l of faeces (yearly production per person) (Esrey, 2001). This quantity does not account for water losses, which may reach up to 80% for certain systems (KFW, 2014). The wasteful use of large quantities of high quality water is no longer justified: European countries have witnessed growing water stress in terms of quantity and quality in the last decades (Bixio et al., 2006) and 1.2 billion people worldwide face severe water scarcity. The per capita availability of drinking water resources has substantially decreased over the last century, with water use growing at more than twice the rate of population increase (UNDP, 2006). Conventional wastewater systems may in the future not being able to cope with increasing water demands.

The heavy reliance on water of sanitation systems renders them vulnerable to changes in rainfall patterns caused by climate change (Caffoor, 2008); wastewater infrastructure is not designed to cope with sudden droughts as well as violent floods, which are increasingly causing severe malfunctioning of the network (e.g. sewer overflows) (Fraunhofer ISI, 2012). Moreover, the practice of diluting human excreta in the sewage system also results in higher energy consumption during transportation and treatment phases, given that larger volumes of wastewater need to be processed. In fact, conventional wastewater systems are voracious energy consumers and Greenhouse gas (GHG) emitters[1] (Daw et al., 2012). European wastewater treatment plants (WWTPs) alone consume a total of 15,021 GWh/year (EU, 2015), and these

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[1] German data report a yearly emission of 2.2 million tons of CO2 from their 10,000 WWTPs (ATT et al., 205).

figures do not include energy consumption of wastewater collection. Wastewater electricity use accounts for 30-35% of municipalities' energy bill (EPA, 2013; Fraunhofer ISI, 2012). In a context of rising energy costs – from an average of 0.0756 E/kWh in 2005 to 0.110 E/kWh in 2011 within the EU-27 (Bodik & Kubaska, 2013 – the costs associated with high energy consumption levels are a major concern for the future of wastewater management; and large inefficient wastewater infrastructures are not equipped to cope with such challenge. Energy consumption is also positively correlated with water scarcity since water has to be transported longer (requiring more conveyance energy) to reach water-short regions (Singh et al., 2012).

### Environmental impacts

Municipal WWTPs are important point sources of nutrient pollution (WRI, 2014). Despite intensive treatment, the effective removal of pollutants and nutrients is often unsatisfactory and effluents discharged into surface and groundwater result in environmental damage to aquatic systems (*Ibidem*). The phenomenon caused by nutrient enrichment is called eutrophication defined by Ferreira et al. (2011: 121) as:

> *A process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services.*

There are several sources of nutrient enrichment (e.g. agricultural runoff) and it is difficult to calculate precisely the share caused by wastewater. The World Resources Institute (2014) estimated that sewage contributes to 12% of riverine nitrogen input in the United States, 25% in Western Europe and 33% in China. In fact, estimates report that roughly 40% of the Nitrogen (N) that arrives at a conventional industrialized wastewater treatment plant flows out with the effluent water (Jonsson et al., 1998) and 25% of the Phosphorus (P) mined globally since 1950 has been leached into waterways or stored in landfills (Cordell et al., 2009). The Fraunhofer ISI Institute (2012) reports that in Germany 16,400 tonnes/year of P are released from urban wastewater treatment plants to surface water bodies. The unidirectional approach of conventional sanitation deeply interferes with the nutrient cycle causing the loss of valuable resources (either released as effluents or landfilled as solids in sludge) that, being essential components of our food system, need to be replaced by artificial fertilizers. The system is not only inefficient but also highly dependent, in particular concerning P, on the availability of a finite resource that is expected to be exhausted[2] within 100 years (Cordell et al., 2011).

There are other environmental impacts deriving from the discharge of micropollutants (MPs) – inorganic and organic trace chemicals present at concentrations from µg/L to pg/L (Clouzot et al., 2013) including pharmaceuticals and hormones. With population aging, the consume of such substances is increasing (ATT et al., 2015) and there is raising concern on their potentially harmful ecological impacts (a.o. De Graaff et al., 2011). Conventional WWTP technologies are not efficient in removing them, since they were designed for eliminating organic matter and

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[2] Conventional and easily exctractable sources.

nutrients (Clouzot et al., 2013; Joss et al., 2008; Schwarzenbach et al., 2006). In fact, the high dilution of wastewater decreases their concentrations and affects the efficiency of treatment.

## *Socio-economic impacts*

The financial sustainability of extensive waterborne sanitation systems is questionable as well: The cost structure of conventional wastewater systems is composed of high fixed costs (Hollaender, 2014) because they rely on extensive sewage infrastructure. Investments and maintenance costs account for 50-75% of water service providers and are financed by the public (Langergraber and Muellegger, 2005; Marlow et al., 2013). Aging infrastructure demands continuous investments being sewage systems in despair already 60 years after construction (Hegger et al., 2007). National expenses in sewerage management (network maintenance, expansion and WWTPs operation) are in the order of *billion* euros – 2 billion euros for the Netherlands (Van Riel et al., 2015) and 4.4 billion euros for Germany (ATT et al., 2015). The two countries' budget per km of sewers amounts on average to 8,000 euros/year and 15,000 euros/year for German and Dutch cities respectively (*Ibidem*). Demographic changes and challenges posed by climate change – water scarcity, increasing energy prices, and extreme meteorological events – may translate in future increase of operation and maintenance costs and eventually of wastewater fees (Fraunhofer ISI, 2012). The opportunity cost of investing large amounts of public resources into vulnerable wastewater systems might become very high in the future.

- **15,000 l water/p/year** to dispose of 500 l of urine and 50 l of faeces
- Up to **80% water losses** in the network
- **Large energy consumption and GHG emissions**: 15,021 GWh/year for EU WWTPs
- **Water pollution** (eutrophication): 40% of N and >20% of P still in effluents
- Inefficiency in removing **micropollutants**

- **$75 billion/year** investment costs globally by 2025
- Sewerage management costs (maintenance, expansion, operation):
  - **2 billion €/year** (Netherlands)
  - **4.8 billion €/year** (Germany)
- Average capital expenditures per km of sewers
  - **8,000 €/year/km** (Germany)
  - **15,000 €/year** (Netherlands)
- **Increasing energy costs** in EU: from 0.0756 €/kWh in 2005 to 0.11 €/kWh in 2011
- Wastewater electricity accounting for **30-35% of municipalities energy bill**

- Inflexibility unable to cope with **demographic changes and climate change** effects on rainfall patterns
  - possible fee increase
  - service disruptions
- **High opportunity cost** of public investments
- **Geopolitical tensions** deriving from decreasing conventional and easily exctractable P reserves

*Figure 1.1 Impacts and future challenges of conventional wastewater systems (ATT et al., 2015; Bodik & Kubaska, 2013; Clouzot et al., 2013; De Graaff et al., 2011; Esrey, 2001; Fraunhofer ISI, 2012; EPA, 2013; EU 2015; Jonsson et al., 1998; KFW, 2014; Quitzau, 2007)*

## Towards new wastewater management paradigms

Given that 2.5 billion people worldwide still lack access to improved sanitation facilities (WHO/UNICEF, 2014) and that 90% of wastewater is not adequately treated before discharge (Werner et al., 2009), it seems that unidirectional water-based systems do not represent the most sustainable solution to provide adequate sanitation in the future for urban as well as remote areas in both developed and developing countries. As Cao (2011:44) puts it:

> *One cubic metre of domestic wastewater contains enough water for 5-10 persons per day [...] and about 2 kWh-equivalent of energy, and sufficient nutrients for at least one square meter of agricultural production area per year.*

It is therefore a key priority for societies to develop an alternative wastewater management paradigm that is able to derive benefits from wastewater. One that is based on circular energy, water and material (i.e. nutrients) flows, affordable and non-resource intensive technologies and which values wastewater as a resource allowing for its reuse. This transformation requires a conceptual shift – from "wastewater" systems to resource recovery systems (RRS) (Guest et al., 2009). If wastewater management is driven by recovery and reuse principles instead of removal and disposal ones, our society can move towards restorative sanitation systems that have positive economic, social and environmental impacts (Howe & Mitchell, 2012).

Growing awareness on the fundamental limitations of unidirectional sanitation has stimulated the quest for alternative systems and a wide variety of actors – including research centres, NGOs, private and public utility companies – have engaged in this challenge and developed the most diverse technologies and business models to implement sustainable sanitation systems. These systems have been implemented as pilot projects, giving rise to a Resource Recovery Sanitation (RRS) niche. Germany, The Netherlands and Sweden are frontrunners in the development of the RRS niche, with a considerable number of implemented pilot projects (*Ibid*.). These projects, however, are struggling to achieve diffuse implementation, despite their technological feasibility (Guest et al., 2009).

## 1.2 Alternative approaches to wastewater management

The term "wastewater" refers to domestic, industrial and agricultural effluents flowing through a sanitation system (or directly discharged in absence of it) (Corcoran, 2010). It consists of a combination of different material flows, so-called products (Table 1.1). Products are organic and inorganic materials that are generated by humans (e.g. urine), during technological processing (e.g. flush water) or storage (e.g. faecal sludge) (Tilley et al., 2010; 2014). Each product has different characteristics in terms of density, nutrient concentration, pathogen content etc. Nevertheless, from the point of view of conventional sanitation, they all fall into the category of wastewater (Soller et al., 2003). Indeed, conventional wastewater systems combine different products and process them simultaneously, such as in the case of urine, faeces and greywater that are all collected and transported in the same pipes and then treated at the same central location. This practice gives rise to flowstreams (see Appendix 7.1) that are large in volume, extremely diverse in composition and pathogen/pollutant content, and very diluted. The high degree of combination of flowstreams reduces the possibility of products' reuse and forces their joint treatment and disposal. Therefore, breaking down the term *wastewater* into different components is crucial for determining the appropriate set of technologies to handle them in the most beneficial way for its users and the environment.

*Table 1.1 – List of products flowing through a sanitation system (Source: Tilley et al., 2010)*

| Product | Description |
|---|---|
| **Urine** | Liquid waste excreted by the body. |
| **Faeces** | (Semi-) solid wastes excreted by the body. |
| **Excreta** | Combination of urine and faeces. |
| **Black water** | Mixture of excreta and flushing water, along with anal cleansing water or dry cleansing material (depending on what is practiced). |
| **Faecal Sludge** | General term for the undigested or partially digested slurry or solid that results from the storage or treatment of blackwater or excreta. |
| **Beige water** | Water that is used for anal cleansing after defecation. |
| **Greywater** | Water that has been used for bathing, hand-washing, cooking, clothes-washing or other types of cleaning. |
| **Stormwater** | General term for the rainfall that runs off from roofs, roads and other surfaces before flowing towards low-lying land. It is the portion of rainfall that does not infiltrate into the soil. |

Conventional planning approaches to sanitation too often focus on single technological/ infrastructural aspects– toilets, sewage network and treatment systems (Van Vliet et al., 2010). Recent approaches, instead, conceptualize sanitation as management systems that process different material flowstreams from the point of generation to the point of (re-use or) ultimate disposal (Tilley et al., 2014), capturing the sanitation chain as a whole (Van Vliet et al., 2010).

*Figure 1.2 The process steps constituting the whole sanitation chain (Adapted from Tilley et al., 2010)*

### 1.2.1 Basic principles of Resource Recovery Sanitation (RRS)

Resource Recovery Sanitation (RSS) is a new approach to wastewater management based on the creation of circular sanitation chains. In this perspective sanitation systems are a connected network of elements interacting with water, energy and nutrient cycles and surrounded by social relationships between its users, providers and end-users of its outputs.

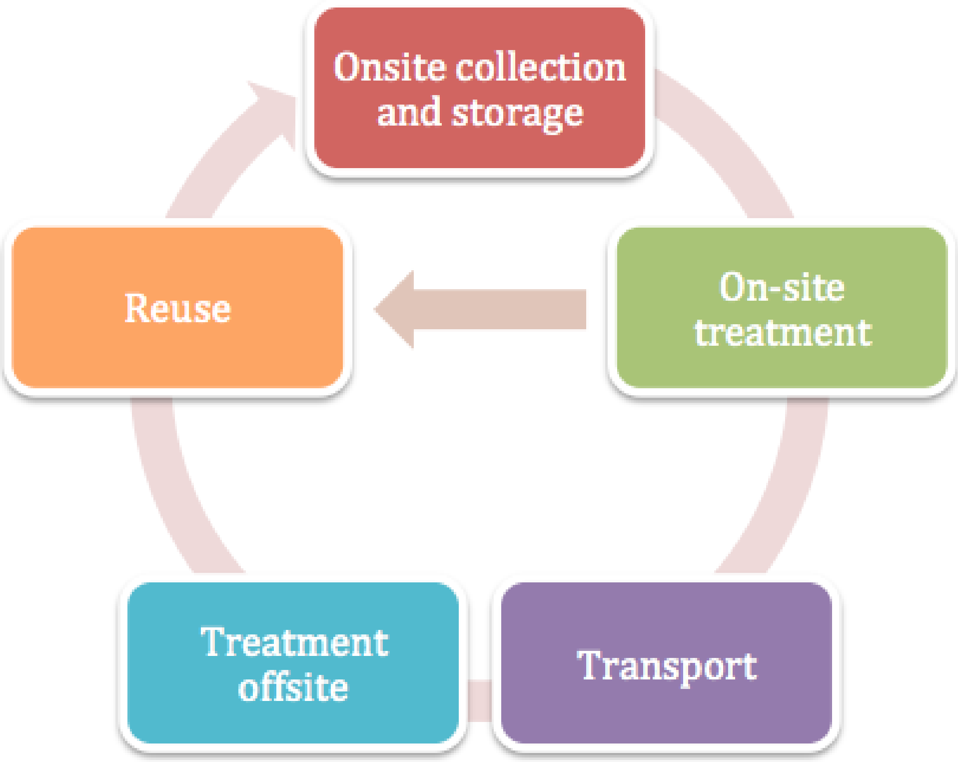

*Figure 1.3 The circular sanitation chain (adapted from Tilley et al., 2010)*

Resource recovery sanitation does not refer to a specific technology; this concept has been often identified with the term *ecological sanitation* or *Ecosan* (Esrey, 2000; Werner et al., 2009), from which this research borrows several conceptual elements. However, we have chosen a different terminology that is based on Tilley and colleagues' (2010; 2014) framework because with this research we want to create awareness on the potential that the various products composing wastewater have as *resources*. Moving away from conventional wastewater management paradigms is not a purely *ecological* matter: linear sanitation chains waste precious resources with long-term negative economic, social and environmental consequences.

As shown in figure 1.4, the wastewater cycle is currently characterized by large output flows from urban centres. These are responsible for creating imbalances in water and nutrient cycles – they put pressure on limited water resources causing additional water stress and severe nutrient enrichments in water bodies, affecting aquatic ecosystems (Matuska et al., 2010). Sewage treatment, when performed, is energy intensive because wastewater flows are combined[3] and heavily diluted. Resource recovery sanitation (RRS) is an alternative to the traditional substance elimination approach (Wang et al., 2015) that aims at enabling synergies between sanitation, agricultural and energy systems by upgrading and reusing material flows, thus minimizing both wasteful outputs and external inputs (Fig. 1.2). In fact, it is possible to recover precious resources from the sanitation flowstreams – what we now simply call *wastewater* - including water, energy and nutrients. With RRS there is no silver bullet fitting each situation – each system has to be designed specifically to meet local needs and resource constraints. Resource

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[3] See p.12 for impacts of combining different wastewater streams.

recovery can be performed at centralized as well as (semi-) decentralized level. The former is an end-of-pipe solution that implies the upgrade of existing WWTPs with recovery technologies, while the latter refers to ex-novo systems introducing alternative socio-technical elements throughout the sanitation chain[4].

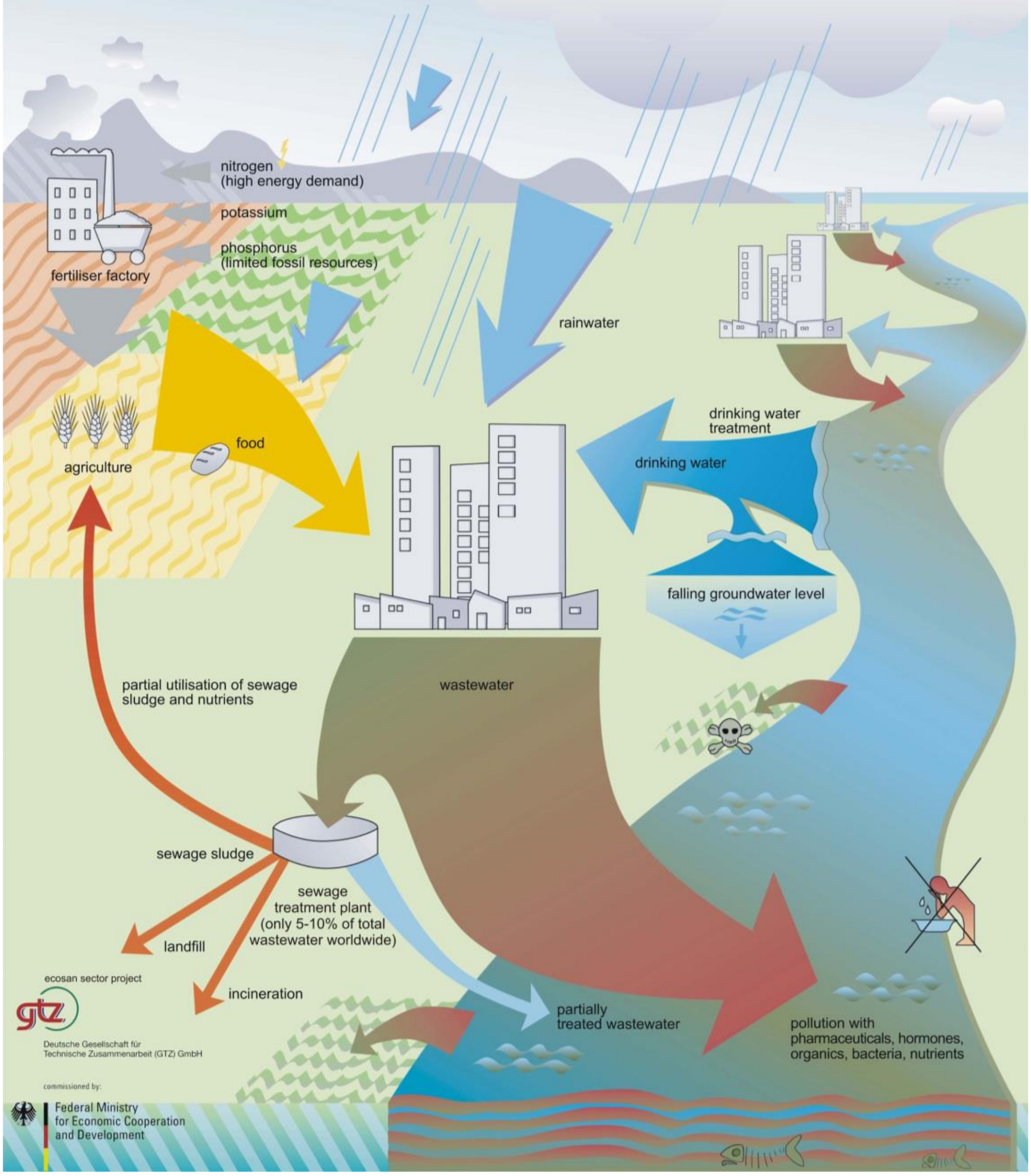

*Figure 1.4 The conventional wastewater cycle (GIZ, 2005)*

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[4] For example, they introduce source separation of streams at household level according to degree and type of pollution and re-use potential, and the subsequent specific treatment of each stream (Rajagopal et al., 2013).

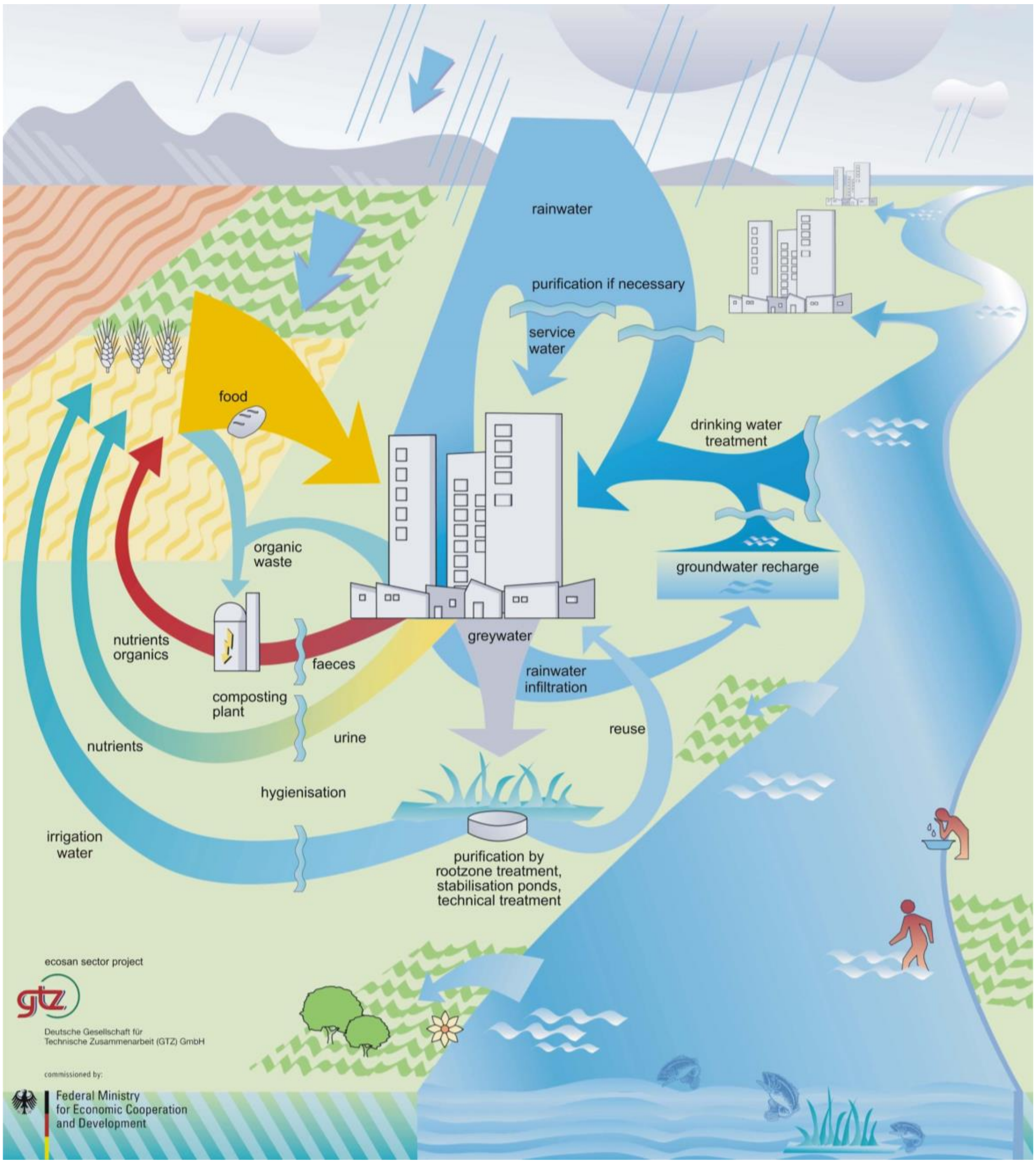

*Figure 1.5 The sustainable wastewater cycle (GIZ, 2005)*

### Recovery and Reuse of water

The reuse of wastewater as alternative water source is the least innovative aspect of RRS, since it is already practiced in many countries to meet the demand for non-potable water. Estimates claim that 20 million hectares in the world are irrigated by raw, treated, and/or partially diluted wastewater  (Papa et al., 2015). The use of reclaimed water from sanitation systems reduces the pressure on ground- and surface water, thus tackling water scarcity and contributing to the maintenance of environmental flows. Direct reuse in agriculture of raw wastewater as it happens in e.g. Thailand and Vietnam and which is mainly driven by cost considerations – in this way farmers have access to free water – should however not be encouraged due to safety concerns (E. Tilley, personal communication, 2015). If treated, instead, wastewater may supply water for landscape irrigation, industrial applications, surface water replenishment, groundwater recharge, and where legally allowed, agriculture (Bakopoulou et al., 2011; Dogan et al., 2015; Marlow et al., 2013). Moreover, studies have shown a yield increase of crops irrigated with treated wastewater due to its higher nutrient content and lower salinity compared to freshwater (Elmeddahi et al., 2015). While experts are progressively recognizing treated wastewater reuse as a strategic option for contexts affected by water shortages, there are legal, economic and social challenges still hampering its full reuse (*Ibidem*; Papa et al., 2015). This trend holds true in particular for Western countries, where reuse quality standards are becoming more stringent[5] and in some cases (e.g. The Netherlands) they inhibit agricultural reuse practices.

Appropriately processed wastewater could also supply potable water, although this possibility requires even more thorough quality assessments compared to non-potable reuse systems due to the greater risks to human health it poses. Recent studies have concentrate on the greywater fraction of wastewater, which accounts for 60-80% of household wastewater (Eriksson et al., 2002; Hérnandez Leal, 2010) as potential source of drinking water due to its lower content of pathogens and organic matter (Etchepare, Van der Hoek, 2015). Although more research is needed to explore its safety, potable reuse of greywater could lead to beneficial outcomes for safe drinking water provision worldwide (*Ibidem*). Recovery of water from sanitation systems can also be performed through rainwater and stormwater harvesting, even though their reuse in industrialized countries is still highly debated, as we will discuss in chapter 4.

### Recovery and reuse of energy

Another valuable product that can be recovered from RRSS based on source-separation approaches is biogas as energy source, produced through the anaerobic digestion of faecal matter (Katukiza et al., 2012). Additionally, kitchen waste may be processed together with faeces and increase the biogas yield up to 50% (Fraunhofer IGB, 2013). The energy output can be used to cover the electricity needs of the WWTP itself or to provide household heating (Aoki et al., 2006), while the solid matter left following the treatment process can be used to increase organic matter in soil thus improving its ability to withhold water and maximize fertilizer utility (ADBA, 2013; Richert et al., 2010). Anaerobic wastewater treatment is less energy intensive compared to conventional sludge digestion since it does not require aeration neither heating. In fact, the microorganisms responsible for decomposing the organic matter thrive in environmental temperatures of 16-18 C°, which is not difficult to obtain simply with a good insulation also in cold climates (T. Eschenbacher, personal communication, May 22, 2015). The Fraunhofer IGB estimated the total yearly biogas production per capita to be 230-330kWh with an input of 36.5m$^3$ and 30-55 kg of wastewater and kitchen waste respectively per capita per year (Schliessmann, 2013).

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[5] In terms of chemicals and microbial contaminants.

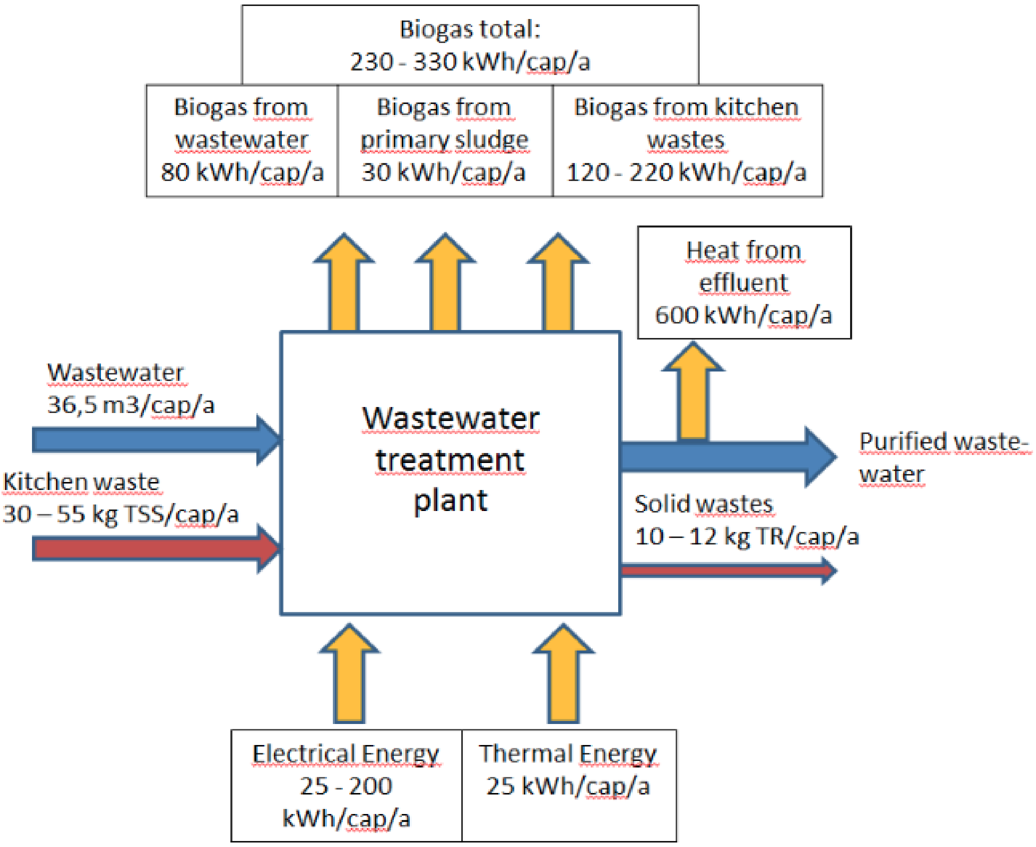

*Figure 1.6 Energy and mass balance per capita per year of an anaerobic wastewater treatment module (Schliessmann, 2013)*

### Recovery and reuse of nutrients

The potential value of human excreta in terms of nutrients is well known within the scientific community and historically farmers have used it as agricultural asset[6] (Haq and Cambridge, 2012; Spångberg et al., 2014). Indeed, urine and faeces can provide significant quantities of the main macro nutrients required by plants (i.e. N, P, K) (Richert et al., 2010:1). The Stockholm Environment Institute (SEI) estimated that adults produce 550l of urine per year, which contains 4000g of N and 365g of P, and 51kg of faeces containing 550g of N and 183g of P (*Ibidem*). Researchers have pointed out that the amount of N, P and Potassium (K) excreted per person yearly can theoretically cover an individual's wheat and maize requirement for one year (Esrey, 1999) and that urine, which is essentially sterile and contains 80% of the excreted N and 50% of the excreted P (Kuntke et al., 2012; Mihelcic et al., 2011), could provide half of the P necessary to grow cereal crops (WHO, 2006). Nutrients can be recovered in many different forms through processes requiring a varying degree of technological knowledge. Simple applications include the direct use of biosolids (e.g. sludge) or storage-sterilized, source-separated urine as fertilizers, while more sophisticated treatment techniques allow for the harvesting of struvite (Guest et al., 2009). Struvite ($MgNH_4PO_4 \cdot 6H_2O$) is a slow-release fertilizer containing substantial amount of P and considerable quantities of N and Magnesium (Mg) (Rahman et al., 2014). Being struvite a product recovered in one of the case studies of this research, we will discuss its characteristics in chapter 5.

The use of sludge as nutrients supplier in agriculture has a long tradition, and in European countries it is tightly regulated. The maximum concentration values for heavy metals and pathogens are established at European level (Directive 86/2788/EEC) and Member States (MS) are allowed to set higher standards. Strict legislative guidelines render impossible the direct application of sludge that has to be previously treated. While this approach is consistent with human health protection, excessively strict limits have progressively discouraged the reuse of sludge in agriculture in favour of other applications such as for construction works. It has to be noted that this practice, despite ensuring reuse, does not allow for closure of nutrient cycles and is therefore not advisable from a RRS point of view. Alternatively, in centralized sanitation systems, the sludge produced at WWTPs can be incinerated and landfilled. These practices displace nutrients that could be instead reused on agricultural fields that will in turn require external inputs in the form of fertilizers.

Resource recovery from sanitation is two-faceted; on the one side it enables resource reuse and thus decreases needs from external inputs in the form of water, energy and nutrients in other sectors, on the other it reduces the amount of pollutants leaking into the environment. Discharging cleaner effluents is an important benefit of RRSS, which can contribute significantly to tackle surface and ground water deterioration. In particular it prevents nutrient enrichment of waters with N and P compounds, which is responsible for the occurrence of eutrophication phenomena (Molinos-Senante et al, 2013). Vast zones are being impacted by eutrophication and other hazardous ecological effects of current sewage handling practices,

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[6] Barles (2007) reports that not so long ago, in 1913, 40% of the N flowing into Paris was recycled as agricultural input.

with damaging effects on fluvial and marine environments such as decreased biological diversity and fish mortality.

The removal of hazardous substances from wastewater is a crucial process for the protection of human and environmental health. However, the current practices for performing such task are associated with high environmental costs in terms of energy consumption, solid waste production and greenhouse gas (GHG) emissions (Wang et al., 2015). Furthermore, they are capital intensive and require large-scale engineering works. Resource Recovery Sanitation is an innovative approach that can improve the sustainability of current wastewater cycles contributing to food security, alleviating environmental and economic pressures resulting from conventional, unidirectional sanitation systems.

## 1.3 Research objectives and Research questions

### 1.3.1 Knowledge gap and Research objectives

Sustainable sanitation has received increasing attention in the last decade and a growing number of pilot projects geared towards resource recovery and reuse are being implemented throughout the world. However, despite the benefits that RRSS could generate, their implementation in areas currently served by centralized waterborne sewage infrastructure poses several challenges. While technical knowledge is advancing and has proven its efficiency (Guest et al., 2009) and the potential value of recovered wastewater products is being positively assessed (Winker et al., 2009), there is a need for exploring the complex of social, institutional and economic factors that are stimulating or preventing the breakthrough of innovative sanitation systems and constraining the desirable transformation towards sustainable sanitation (aGuest et al., 2009; Katukiza et al., 2012; Maass et al., 2014). Indeed, the systematic analysis of governance factors acting as drivers and barriers is lagging behind, thus hampering the design of effective strategies to foster the transformation of the wastewater sector. This research addresses this knowledge gap by studying the key variables influencing the potential of RRSS pilot projects to achieve wider implementation in order to gain understanding into their interplay and provide recommendations on how to overcome challenges and enable opportunities.

This research is practice-oriented (Verschuren & Doorewaard, 2010) since it is concerned with solving the policy problem of achieving more sustainable wastewater management practices; the theoretical relevance of the research project (*Ibidem*) lies in its contribution to the development of theoretical knowledge on the governance of sustainable socio-technical transformation processes within societies (Elzen et al., 2004; Farla et al., 2012; Kemp & Loorbach, 2006; Kemp et al., 2005; Loorbach, 2007 & 2010; Markard et al., 2012; Smith et al., 2005; Smith & Stirling, 2008; Tukker et al., 2008). This research's object is the RRS niche, for which two pilot projects (i.e. case studies) in Germany and The Netherlands that represent small-scale experiments with alternative wastewater management are studied. The novelty of the research lies in (1) the study of change processes within a domain (i.e. sanitation) that has so far received less attention from the scientific community vis-à-vis the energy, transport and agricultural sectors (Hegger et al., 2007; Van Vliet et al., 2010); and (2) the focus on exploring ex-ante *future* pathways of small-scale experiments. In fact, the majority of empirical studies analysing change processes in societal systems following the introduction of (sustainable) innovation are *ex-post* analyses (e.g. Geels, 2002; Geels, 2006; Raven et al., 2011). The present research explores future prospects of experiments that have not (yet) been incorporated into mainstream applications.

The objective of this research project is to contributing to foster the adoption of sustainable socio-technical innovations in the field of wastewater management by making an analysis of the constraining and stimulating factors that two RRSS pilot projects are facing in their implementation and deriving policy recommendations on how to overcome barriers and enhance their opportunities to reach wider application.

### 1.3.2 Introduction to the theoretical framework

This section provides a short overview of the theoretical framework underpinning the research. The theories will be further discussed in chapters 2 and 5.

This research approaches the challenges of sustainable development in terms of *transitions* to more sustainable production and consumption patterns (Smith et al., 2010; Weber & Hemmelskamp, 2005). The term *transition* is thoroughly defined in chapter 2; for now it can be understood as major changes in the current configuration of social, cultural, institutional and technological elements and processes of societal systems such as sanitation[7] (Vezzoli et al., 2008). Given that changes within the sanitation domain are multifaceted – as they require complimentary adjustments in institutions, mentalities, worldviews and technologies – there is a need of adopting a theoretical perspective that considers technological change in a wider, societal context (Geels, 2005). These theoretical lenses are offered by the research field of (environmental) system innovation, which studies change processes of socio-technical systems and their evolution pathways towards sustainability (Tukker et al., 2008).

Drawing upon system innovation theories, the recently developed Multi-level Perspective (MLP) on socio-technical transitions (Geels, 2002; Rip & Kemp, 1998) is an interesting perspective for this research project because it is an analytical tool that links the development of innovation within niches with large-scale structural transformations in society (Smith et al., 2010); thus, it simplifies the analysis of complex societal change dynamics that are required to achieve sustainable development goals (*Ibidem*). Such analytical framework is used in this research as a tool for understanding what are the mechanisms behind the unfolding of (potential) transitions in the sanitation sector. The MLP posits that changes in socio-technical systems take place through the interplay of dynamics at multiple levels (Geels 2005:368):

- Niches (micro level): small-scale experiments with (radical) socio-technical innovations;

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[7] Other examples are energy and food systems.

- Regimes (meso level): entities realising societal functions in a stable and dominant way (Smith et al., 2010). These consist of three dimensions – (1) the network of actors and social groups, (2) the complex of formal and informal rules that regulate the actors' activities and (3) the set of material and technical elements (Geels & Schot, 2007). The three dimensions exert stabilising pressures that render regimes fundamentally resistant to change, thus hampering transitions of socio-technical systems;
- Landscapes (macro level): contextual elements of the broad environment containing niches and regimes that challenge the prevailing socio-technical regime and open up opportunities for niches breakthrough (Genus and Coles, 2008). Examples of such factors are environmental and demographic change, political, economic and cultural developments.

The structure provided by the MLP forms the fundamental analytical structure of the research, which develops along micro, meso and macro levels of analysis. However, since the high level of abstraction of the MLP poses several challenges to its application to empirical research (i.e. the analysis of specific pilot projects) (Genus & Cole, 2008; Smith et al., 2010), it is here integrated with Strategic Niche Management (SNM) (Kemp, 1994; Schot et al., 1994; Kemp et al., 1998; Rip & Kemp, 1998; Smith, 2003; Weber, 2003). The theory has been developed in the early 1990s driven by the realization that many sustainable technologies were failing to reach mainstream applications (Coenen et al., 2010). SNM shares the multi-level approach of the MLP, focusing on the micro level for which it proposes a series of criteria that, according to the authors, enhance their potential for triggering changes at the meso-level and thus fostering systems' transitions (Hoogma et al., 2002; Raven, 2005; Schot & Geels, 2008).

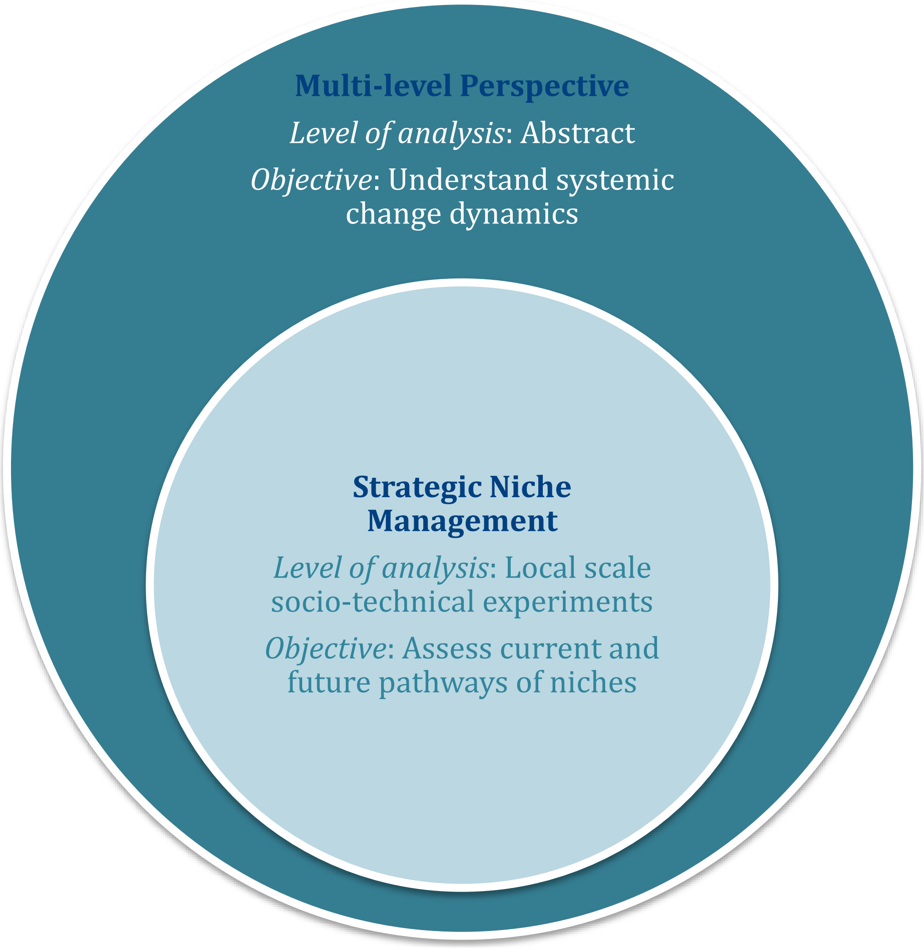

*Figure 1.7 Schematic representation of the integration between MLP and SNM forming the theoretical approach of the research.*

### 1.3.3 Research questions

In order to achieve the stated objectives and translate this analysis into a structured research design, a set of questions have been developed that will be answered through a combination of theoretical and empirical research. The main underlying research question is formulated as follows:

*What are the main factors influencing the success of two leading niche experiments in resource recovery sanitation systems (RRSS) in Germany and the Netherlands, what are promising pathways for further up-scaling of these niche experiments, and to what extent do these experiments have the potential to contribute to the sustainable transition of the current sanitation system?*

Prior to introducing the sub-questions, the notion of upscaling has to be defined. This is derived by the theories underpinning the analytical framework of the research. Upscaling refers to the process that socio-technical innovations undergo when shifting from prototypical state to viable market niche (Caniels & Romijn, 2008) – with the consequence of progressively reaching broader and more widespread application in society (Coenen, 2010:2) and achieving higher institutional embeddedness. This process encompasses scale, scope and intensity of niche experiments (Kemp et al., 1998), at the end of which sustainable practices that are initially deviant or unusual, become [...] mainstream in terms of thinking (culture), doing (practices) and organizing (structure) (Coenen, 2010:4).

In order to acquire the knowledge necessary to answer the research question, three sub-questions have been developed. The combined answers to the sub-questions will provide the information that is needed to answer the main research question (Verschuren & Doornewaard, 2010).

1. How can we assess the success of RRSS niche experiments and their up-scaling potential?
2. What are the constraining and stimulating factors influencing up-scaling of RRSS niche experiments?
3. What are the prospects for a sustainable transition of the current sanitation system to unfold? And what is the role of RRSS pilot projects in contributing to such developments?

The research employs the embedded case study method (Verschuren & Doorewaard, 2010) with the larger unit being the Resource Recovery Sanitation (RRS) niche and the sub-units two local-scale demonstration projects. After preliminary assessing a number of pilot projects in the field of RRS, two of them have been chosen in Germany (DEUS 21) and The Netherlands (De Ceuvel). The rationale behind case selection – whose strategy is thoroughly described in Chapter 3 – is to compare projects that show different socio-technical configurations (e.g. technical and management scale, involvement of end-users) and verify to what extent the observed niche, regime and landscape factors (independent variables) determine their future pathways (dependent variable) and to draw conclusions on the upscaling prospects of the RRS niche – i.e. the larger unit. Data collection methods employed are desk research, 19 semi-structured interviews and site visits. The analysis of the mostly qualitative information gathered followed an iterative process; interviews were transcribed colour-coded (Creswell, 2007).

## 1.4 Outline of the thesis

The theoretical part of the thesis is presented in Chapters 2 and 3. In particular, Chapter 2 discusses the three-tiered analytical framework of this thesis. The chapter explains the different steps of the research framework, their theoretical underpinning and their connection to the research questions. This chapter lays the foundations for the empirical section in that it highlights the factors influencing the development of niche experiments at the theoretical level, which are then investigated empirically. Chapter 3 describes the methodology for the empirical research, explaining the sampling strategy and the data collection methods (i.e. semi-structured interviews and desk research). This research employs the case study method for which two pilot projects in Germany and The Netherlands have been selected.

Chapters 4 and 5 form the empirical part of the thesis and integrate the findings of the theoretical chapters with the empirical research. An in depth analysis of the case studies is presented in Chapter 4, which contains the findings of the niche, regime and landscape factors influencing their future pathway. Chapter 5 discusses the theoretical and empirical findings and provides the answer to the central research question as well as policy recommendations based on the results of the research. Furthermore, a reflection on the theoretical framework is presented.

In conclusion, following the list of references, an appendix contains the questionnaire used during the semi-structured interviews, a review of sustainable sanitation technologies and technical information sheets concerning the case studies.

# Chapter 2: Theoretical background and research framework

This research explores the scope for a transition of conventional wastewater management towards sustainability and the prospects of RRS pilot projects to contribute fostering it. The research framework consists of four main analytical steps, designed to answer the central research question. Each step yields elements that, combined with the previous one, provide the answer to each of the sub-questions. First, the mechanism of change within socio-technical systems is studied, to shed light on the complex dynamics influencing the introduction and upscale of RRSS. This step provides the fundamental analytical structure of the research, which follows a three-tiered approach from the case study level up to the broader socio-political context in which pilot projects are inserted. The theoretical underpinning of this part is the Multi-level Perspective (MLP), a framework developed from System Innovation literature that also encompasses elements from Transition studies (Elzen et al., 2004; Geels et al., 2004; Tukker et al., 2008).

The second part of the research framework focuses on the smallest level of analysis; by applying Strategic Niche Management (SNM) theory (Kemp, 1994; Schot et al., 1994; Kemp et al., 1998; Rip & Kemp, 1998; Smith, 2003; Weber, 2003) it assesses the factors determining the quality of the German and Dutch selected pilot projects, uncovering the main internal factors and processes influencing their success. The systematic analysis of factors for each project is based on the criteria developed within SNM, which, according to the proponents of the theory, are crucial elements defining the future pathways of such experiences.

The last part of the research framework explores the interactions of the selected pilot projects with the broader environment they are inserted in. Here, constraining and stimulating factors influencing upscaling from the projects that derive from the predominant sanitation system and the institutional, political and economic background are studied. Since the MLP and SNM do not provide a clear and well-defined list of factors for this level of analysis, we have extrapolated a working set of factors from previous empirical studies employing such theoretical perspective (e.g. Van Eijk & Romijn, 2008; Loorbach, 2007. Full list provided in Appendix 7.2) and integrated it with interviews findings and documents analysis. As a result, the set of factors identified in the research for this level of analysis is of an explorative and hypothetical nature.

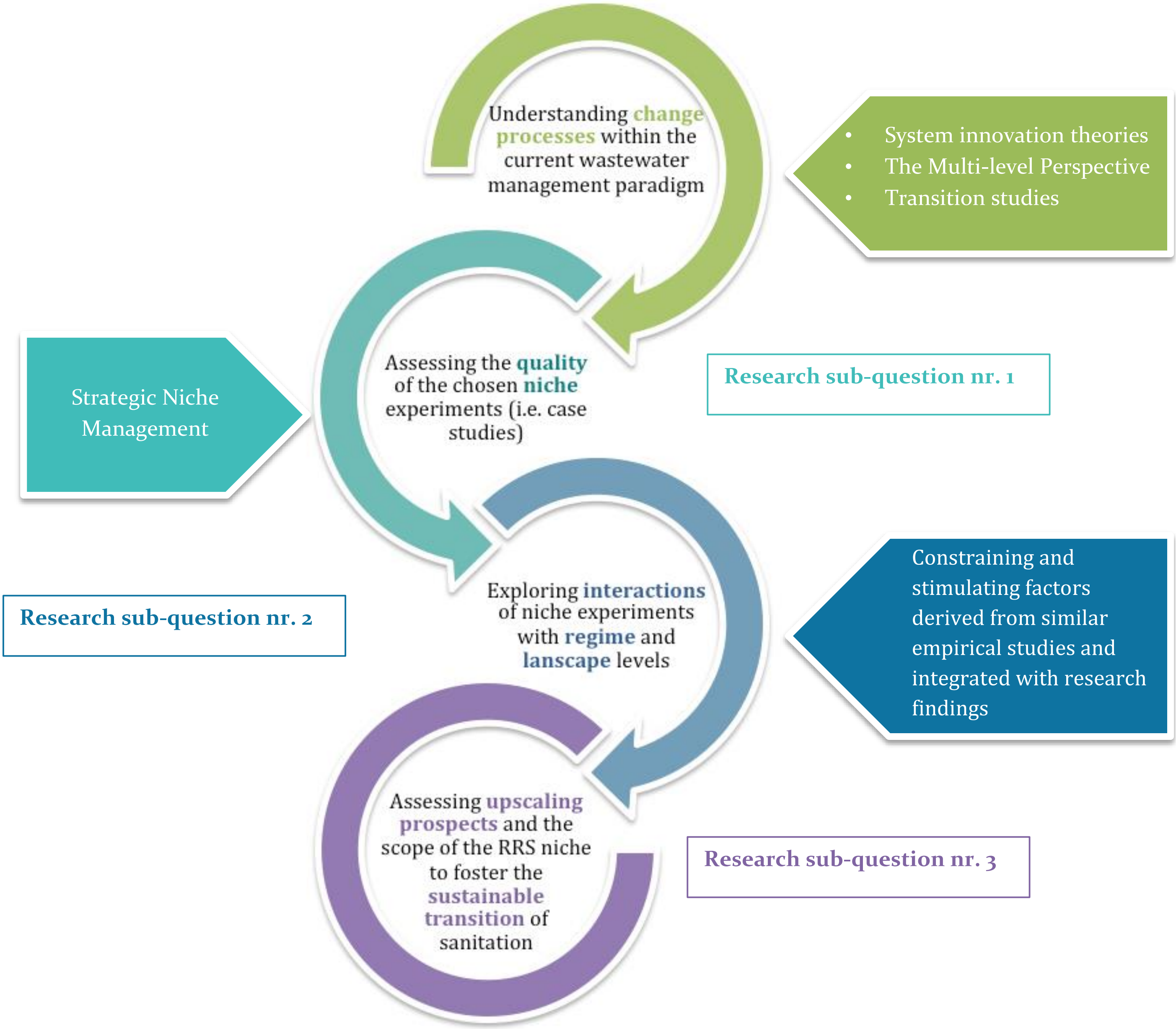

*Figure 2.1 Overview of the research framework*

## 2.1 Understanding change processes within the current wastewater management paradigm

Safarzynska et al., (2012) have defined the mechanism of diversity generation (i.e. change) as *innovation*, which may be an outcome of incremental improvements in an existing design (or practice) or of the introduction of a radically new solution (*Ibidem*). RRS is a new approach to wastewater management that is conflicting with the dominant paradigm of "treat and dispose"; its introduction disrupts consolidated technological, institutional, and social elements. Hence, RRSS can be regarded as an innovation process within the current sanitation system (Berkhout et al., 2009).

Although the study of innovation processes per se falls outside the scope of this thesis, it is useful to discuss the key elements of this field of research to grasp the meaning of system changes in more general terms. Schumpeter has developed a fundamental definition of innovation as the process concerning the *setting up of a new production function* encompassing *the case of a new commodity as well as those of a new form of organisation* and combining *factors in a new way* (Galanakis, 2006). The author intends production in an economic sense as the combination of productive services; this aspect is also highlighted in later definitions, considering innovation as *a new way of doing things* […] *that is commercialised* (Porter, 1990: 780) or as a process *accomplished only with the first commercial transaction involving the new product, process system or device* (Freeman & Soete, 1990: 6). According to Schumpeter, the term innovation comprises new technological as well as organisational arrangements; innovation processes unfold when existing factors – technologies or knowledge – are combined in a new way.

While early contributions to innovation theories focused on the technological dimension (i.e. promotion of cleaner technologies and end-of-pipe solutions), the interest has progressively shifted to broader changes in production and consumption patterns (Berkhout et al., 2009; Smith et al., 2010)[8]. Innovation scholars have adopted a systemic perspective, giving rise to a strand of literature known as *systems innovation* (Bell, 2007; Nelson, 2008; Von Tunzelmann et al., 2008). As a result other non-technological aspects – such as institutional, cultural and geographical contexts (Smith et al., 2010.) – have been incorporated as important factors shaping innovation and systems change trajectories (Gallouj & Savona, 2009). The incorporation of socio-economic features as vital parts of innovation processes is a fundamental step in the elaboration of the *socio-technical systems* concept, which applied to the sanitation sector, allows us to shed light on change mechanisms and unravel their dynamics. A socio-technical system is a combination of technical artefacts, regulations, user practices and cultural meanings, markets, maintenance and supply networks (Elzen et al., 2004), and system innovations are large-scale transformations which unfold in response to changes in the configuration of those heterogeneous elements (Smith et al., 2010).

### *Sanitation as a socio-technical system*

Sanitary infrastructures, like other large-scale infrastructural systems such as energy supply and transportation, have reached a high level of technological standardization and socio-institutional embeddedness (in terms of user practices, rules and regulations, physical assets etc.). They are also characterized by huge sunk infrastructural costs and a long lifespan (60-100 years). Decision-making processes in urban (waste)water management are dominated by a restricted and homogeneous network of technical experts whose decisions are primarily based on economic rationalism (efficiency agendas) (Farrelly & Brown, 2011; Fischer, 1990; Ingram & Schneider, 1998). The resulting predominant governance paradigm is a combined top-down and market-based one, with reforms being mainly carried out in regulatory, structural and efficiency aspects (Elzen & Wieczorek, 2005; Farrelly & Brown, 2011).

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[8] For a thorough overview of the evolution of innovation literature see Smith et al. (2010).

These aspects substantially complicate the introduction of (radical) innovations (Hegger, 2007; Mitchell et al., 2012), which will meet strong socio-cultural and institutional barriers, beside technological ones. Existing systems of this kind are more prone to stability and tend to evolve along predefined trajectories (Hughes, 1987) that are strengthened by actors' vested interests. Moreover, infrastructural planning and resource management in urban centres have traditionally being executed in a segmented way, failing to acknowledge and enable synergies between different sectors. Conventional wastewater management is a sad example of such compartmental thinking, with potentially beneficial material flows for the energy and agricultural sectors being dumped in front of an ever-increasing quantity of inputs being demanded to keep the systems running. This mismatch is typical in the case of Phosphorus: for the wastewater sector P is perceived as pollutant whereas for the agricultural sector it is a precious fertilizing asset (Cordell et al., 2009). The fragmented approach is deeply rooted in Western societies' mentality and further hampers the development of alternative sanitation systems, which are, by definition, of an integrated nature. Breaking the path-dependence of wastewater management is a long-term and challenging task; moving away from the existing trajectory based on expansion of waterborne sewage infrastructure and incremental improvements in efficiency relies on the ability to unlock the potential for new designs, operation and management configurations to be progressively implemented in more and diverse contexts.

### *Defining changes within socio-technical systems: contributes from Sustainability Transitions Theories*

Changes within socio-technical systems have been called "transitions", due to their long-term and multilevel character, involving social, economic, technical, institutional and cultural domains (Geels, 2011; Rotmans et al., 2001). The systematic analysis of transitions in socio-technical regimes has given rise to a broad and diverse literature strand – transition theories – whose roots are to be found in system innovation, science and technology studies (Hegger, 2007) and evolutionary innovation theory (van Eijk and Romijn, 2008). Within this field, particular attention in the past 10-15 years has been given to *sustainability* transitions, in response to the need of profoundly re-thinking modes of consumption and production incorporating environmental, social and economic concerns (van den Bergh et al., 2011; Farla et al., 2012, Markard et al., 2012).

In general terms, transitions are understood as gradually unfolding processes of structural transformation and reconfiguration of interdependent components encompassing different societal levels (Berkhout et al., 2009; Coenen et al. 2010; Kern & Smith, 2008). The concept of transitions has been defined in broad terms, comprising radical shifts in the socio-technical regime as well as system renewal resulting from constant incremental innovation (i.e. reconfiguration) (Geels and Schot, 2007; Genus and Cole, 2008; Lachman, 2013). This broad conceptualization of transitions allows us to employ sustainable transitions theories in the context of this research, where we do not envisage a universal change of the current sanitation system with complete technological substitution (transition) but rather the emergence of a gradual diversification in which RRSS play a more relevant role (transformation, incorporation).

Transitions are a multi-phase phenomenon that follows an S-curve describing an ideal pattern – 1) predevelopment, 2) take-off, 3) acceleration (or breakthrough), and 4) stabilization (Rotmans et al., 2001; Safarzynska, 2012). In reality, however, change processes do not take place in such a linear and progressive way, and potentially successful socio-technical innovations often fail to ever reach the take-off phase. Sustainability transitions theory is a niche-based approach (Markard et al. 2012) in that it considers niche-based experiments as crucial elements for initiating change processes within socio-technical systems. Beside niches, there are other elements influencing transition pathways that operate at higher societal levels (Smith & Raven, 2012). These are thoroughly described by the Multi-level Perspective.

### *The Multi-level Perspective on socio-technical transitions*

The MLP draws upon system innovation theories aiming at analysing and explaining change processes (i.e. transitions) of entire systems of production and consumption (Geels, 2004; Kern & Smith, 2008; Smith et al., 2010) by capturing the variety of socio-technical elements operating at different societal levels that influence transformative innovations in socio-technical systems (Weber & Hemmelskamp, 2005). The MLP's strength lies in the systemic approach it adopts to grasp the mechanisms driving structural transformations of socio-technical systems, yet its breadth also leads to the framework's main drawback: over simplistic abstraction of reality (Sayer, 1992). Such implication affects the explanatory power of the MLP when analysing real-world systemic changes since these deviate from the framework's theoretical construction.

The MLP posits that that changes in socio-technical systems take place through the interplay of dynamics at multiple levels (Geels 2005:368) – landscape pressures (macro level) and niches developments (micro level) that challenge the prevailing socio-technical regime (meso level) (Genus and Coles, 2008). Although the literature does not provide a unique and commonly accepted definition of the three levels and the boundaries between them are subject to uncertainty and overlaps when applied to empirical cases, we can explain them as follows:

The concept of socio-technical regime originally derives from Nelson and Winter's (1982) and constitutes the meso level of the MLP. Regimes are dominant socio-technical configurations fulfilling a specific societal function (Berkhout et al., 2009; Geels, 2004; Kern & Smith, 2008); they encompass three dimensions – (1) the network of actors and social groups, (2) the complex of formal and informal rules that regulate the actors' activities and (3) the set of material and technical elements (Rip & Kemp, 1998). Considering the sanitation regime, examples of relevant actors and social groups are (waste)water utility companies, households, municipalities and other governmental bodies in charge of either providing or regulating wastewater services, and sanitary engineering firms. The second dimension is defined in broad terms and includes regulations, laws and standards as well as cognitive rules such as belief systems and expectations, behavioural norms, routines and practices, and cultural preferences (Geels, 2002 and 2004). The sum of material artefacts that compose wastewater infrastructure systems such as sewage networks, treatment plants, toilets etc., form the last dimension of the sanitation socio-technical regime. According to the MLP, changes in established socio-technical regimes arise with difficulty due to stabilising mechanisms occurring in the three dimensions (Verbong & Geels, 2007). In fact, actors tend to reproduce the activities connected to a specific socio-technical configuration; user practices are regulated by norms which determine acceptable behavioural patterns and shape technological trajectories that are thus directed towards incremental improvements of existing systems, rather than innovation. Furthermore, group of actors progressively accumulate power and develop vested interest in the preservation of the status quo. The existing infrastructure is another element resistant to change given the sunk investments required to build it, its limited flexibility and long lifespan – characteristics that form what the literature has called “hardness” of artefacts and material networks. These features also apply to wastewater infrastructure; if we think that the construction of piped networks and treatment plants rely on public funds and are conceived as to stay in use for at least 60 years, the resulting technological designs tend to be highly static and their immobility is further reinforced by their embeddedness in daily social practices.

These stabilising dynamics within particular socio-technical regimes, as the Western sanitation system, result in path dependence and lock-in situations that hinder evolutions deviating from predefined technological trajectories (i.e. systems’ inertia) (Geels, 2004; Phillimore, 2001; Rip & Kemp, 1998; Schot et al., 1994). According to the MLP, development of innovations that can challenge the stability of existing socio-technical regimes takes place in protective spaces at the micro level, the so-called niches (a.o. Elzen et al., 2004; Geels, 2002; Kemp et al., 1998; Schot et al., 1994; Smith & Raven, 2012). Niches offer protection to innovations from market selection pressures operating within incumbent socio-technical regimes, giving opportunities for adjustments and performance improvements, which enhance their competitiveness in light of a future breakthrough. Protective space typically refers to public research programmes and supporting policies that are aimed at shielding and nurturing innovations in their early stages, and which progressively open the way to market-niches once the innovations have reached further maturity. Support thus comes from network of actors investing in alternative systems with initial high price/low performance characteristics. The literature has identified three internal processes that determine the potential for future success of a niche on the market – 1) the articulation of expectations and visions, 2) the building of social networks, and 3) Learning processes at multiple dimensions (Schot & Geels, 2008). These aspects form the basis of the analysis conducted in the second part of the research, where elements and processes within the chosen case studies are assessed against the theoretical hypotheses (see p. 37).

Niches and regimes are nested into broader socio-technical landscapes, which form the macro level. According to the MLP, landscape developments, such as macro-economic, political and demographic trends, are exogenous factors that exert influence on niches and socio-technical regimes (*Ibidem*; Van Bee et al., 2010). These factors are mostly slow changing, however in some circumstances changes can occur very quickly, in the form of shocks (e.g. wars). The punctual definition of which elements are part of this level, however, is quite evasive. The literature analysis we have conducted suggests that landscapes are niche and regime backgrounds composed of contextual elements including macro-economic patterns, demographic changes, broad political developments, socio-cultural attitudes and other “frame” elements that exert influence on regimes and create window of opportunities for niches (Berkhout et al., 2009; Geels, 2011; Rip & Kemp, 1998; Smith et al., 2005). However, each author stresses different elements. In fact the theory has been criticized for considering the landscape level a residual category including all sorts of contextual influences (Geels, 2011). The lack of consistency in the definition of landscape elements has had major implications for this research. In fact it signified conducting an explorative empirical analysis of the exogenous factors influencing the upscale of RRS pilots, with the consequence of producing a set of hypothetical elements whose theoretical justification is only partial.

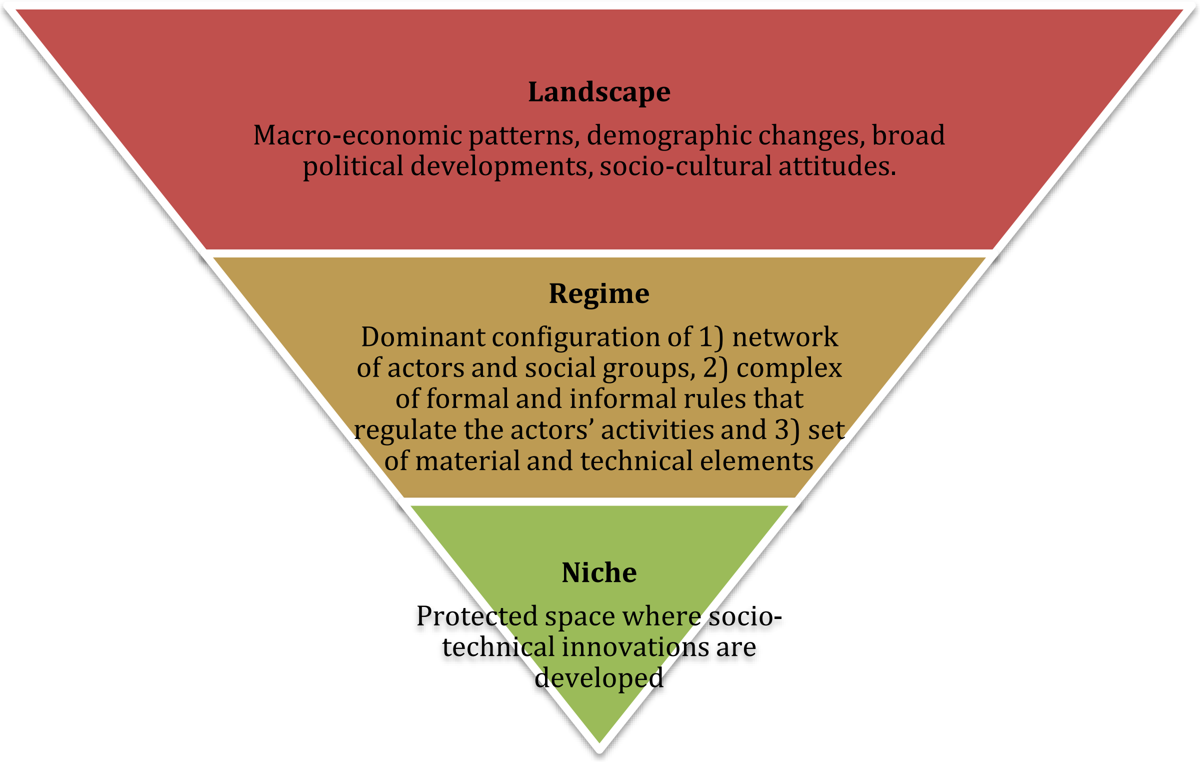

*Figure 2.2 The three conceptual levels of the MLP*

The continuous interaction of the three levels gives the MLP a dynamic character, and when developments at the different levels link up they start reinforcing each other and result in socio-technical system changes (Geels 2005 and 2011; Van Driel and Schot, 2005). Changes unfold following a generic pattern that starts with innovations gaining momentum within the niche, then follows the creation of window of opportunities at the landscape level that puts pressure on the regime which eventually destabilises and thus facilitates the introduction of innovation (Geels, 2011).

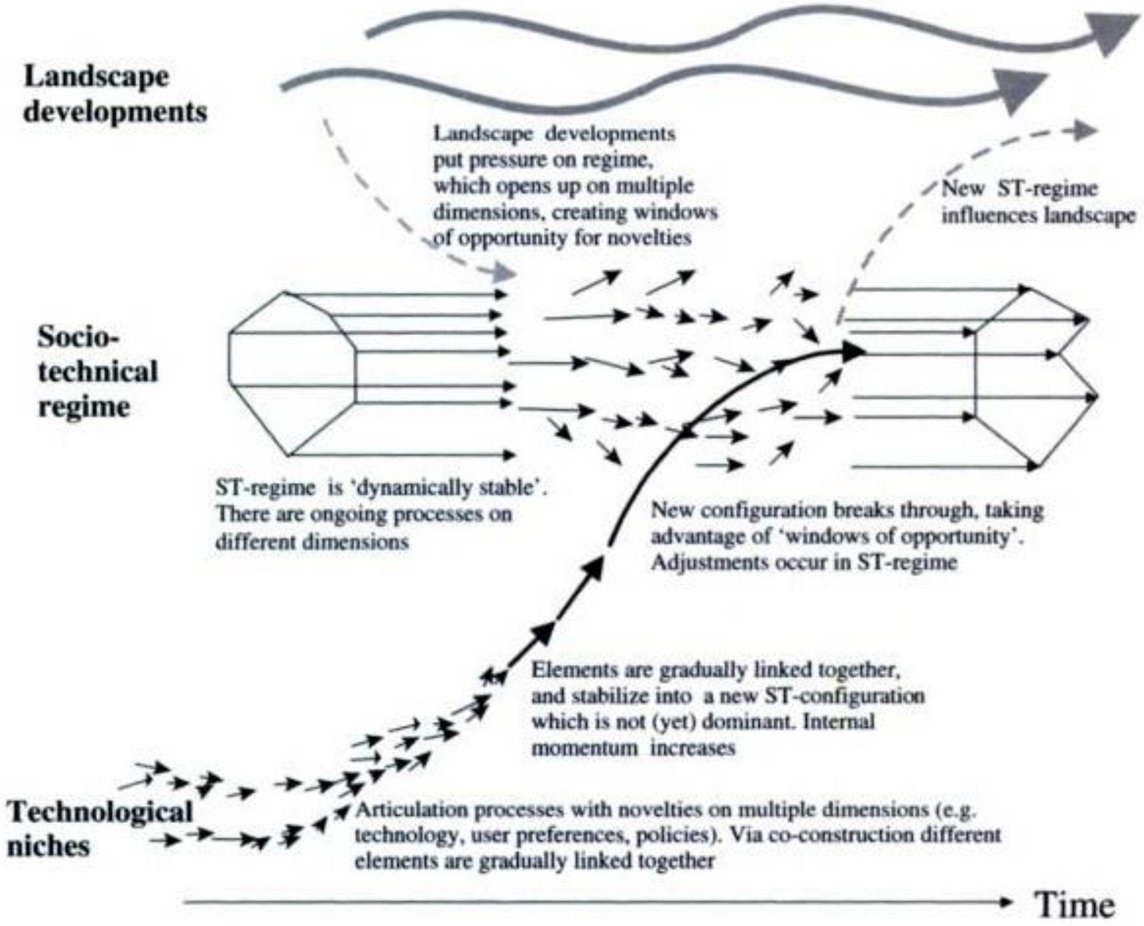

*Figure 2.3 – Conceptualization of change processes in the MLP (Source: Geels, 2000).*

As Smith et al. (2010) point out, this explanation of change processes tends to oversimplify the interactions between the different levels occurring in real-world socio-technical systems. The different conceptual levels do not have clear-cut boundaries – as the MLP seems instead suggesting – and it may be possible for *some* niche elements to be incorporated into regimes without window of opportunities to have opened at landscape level (*Ibidem*). Proponents of the MLP fail to explain how changes at landscape levels occur; in Van Bree et al. (2010) words: [landscape] *developments are outside the sphere of influence of regime actors and can put pressure on the current configuration of the regime* (p.531) (on the point see also Berkhout et al., 2004; Geels, 2011). Such a highly theoretical understanding of transition processes impairs the ability of the MLP to fully understand the complexity of the mechanisms actually occurring. This simplification reduces the accuracy of research projects aiming at assessing the status of on-going changes and deriving policy recommendations for fostering them in the future.

## 2.2 Assessing the quality of the niche experiments chosen as case studies

As discussed above, the development of innovations – such as RRSS – is hampered by the stability of socio-technical regimes – such as the current sanitation system – which results in the system's inertia. According to transitions theory and the MLP, niches play a pivotal role in socio-technical regime changes, being conceptualised as the seeds of change (Hegger, 2007). Indeed, if niche innovations gain momentum, they can compete with established regimes (Geels and Raven, 2006). The second part of the research framework zooms in the micro level, to investigate what are the constraining and stimulating factors that the chosen niche experiments are facing. The theoretical foundation of this research step lies in Strategic Niche Management (SNM) theory (Kemp, 1994; Schot et al., 1994; Kemp et al., 1998; Rip & Kemp, 1998; Smith, 2003; Weber, 2003). Applied to the context of this research, SNM contributes identifying key factors and mechanisms explaining success and failure of RRSS pilots. Based on that, lessons can be learnt on how to conceive RRSS projects as to enhance their future diffusion pathways. The method of analysis that SNM employs is based on the study of real-world demonstration projects to explore potential alignments of the innovation and existing socio-technical systems. RRSS are the type of innovation that SNM looks at because they are socially desirable, serve long-term goals such as sustainability and face a mismatch with regard to the current wastewater regime in terms of technological design as well as socio and institutional configuration (e.g. regulations or consumer practices) (Schot & Geels, 2008).

*Niches* are spaces in which experiments with (radical) innovations are carried out. During this process, other mechanisms take place that are not strictly related to technological aspects, including articulation of actors' expectations, optimization of social configurations surrounding the innovation and the emergence of a user demand. According to SNM proponents, endogenous niche formation processes are key in determining their success, and appropriately constructed niches could act as building blocks for broader societal changes towards sustainable development (Schot and Geels, 2008: 537). The literature suggests that there are three internal processes upon which the quality of niche formation depends (a.o. Elzen et al., 1996; Kemp et al., 1998; Schot and Geels 2008). These refer to 1) the articulation of expectations and visions to steer activities in a shared direction, attract external attention and provide legitimacy to funding programs; 2) the building of social networks to enlarge support for the innovation and expand its resource base; and 3) the occurrence of learning processes to develop deeper and broader knowledge across multiple dimensions interacting with the niche-innovation (e.g. technical aspects, market preferences, policy measures, cultural and symbolic meanings) (*Ibidem*). These endogenous steering processes have been assessed during the empirical analysis (see *Operationalization of concepts, p.37,)*.

*Strategic management* refers to the process of supporting – i.e. inducing or accelerating (Kemp et al., 1998) – the development of innovations within niches by protecting them from mainstream selection[9] (Caniels & Romijn, 2006). Niche protection has been defined as the three-tiered process of shielding, nurturing and empowerment of niches (Smith & Raven, 2012). In particular they have to be shielded from selection pressures exerted by (Kemp et al., 1998):

- Existing industry structures such as resource allocation procedures, decision-making processes, network relations, and user-producer interaction mechanisms.

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[9] The definition proposed by Kemp et al. (1998: 186) and based on Schot et al. (1994) is: strategic niche management is the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology.

- Infrastructural arrangements and standards that specifically fit with and have been developed for incumbent technologies.
- Market factors (e.g. demand/supply and price generation mechanisms) and consolidated user preferences.
- Out-dated public policies and resisting political power with vested interest in maintaining incumbent regimes.
- Cultural meanings and psychological factors connected with established regimes and sceptical towards changes.

Niche protection also entails active actions aimed at supporting their development, i.e. nurturing mechanisms. These range between strategic demand and supply interventions in the form of regulations, tariffs etc. as well as information campaigns aimed at enhancing the competitiveness of niche innovations against incumbents and stimulate further adoption. Moreover, nurturing may also come in the form of support to the development of the three key internal mechanisms. Nurturing mechanisms are crucial to stimulate innovation's performance improvements that increase its possibility of success beyond the niche. The last dimension of niche protection is empowerment, which can follow two different strategies. *Fit and conform* empowerment is a process aimed at aligning niche-innovations to the existing socio-technical regime and make them competitive within unchanged incumbent environments. This strategy evidently results in a reduction of the innovative power in name of an increase in compatibility with existing systems. Alternatively, the literature suggests the *stretch and transform* empowerment – the process of reforming socio-technical regimes as to accommodate niche innovations. This type of empowerment refers, for instance, to the institutionalisation of niche practices in order to achieve quicker and smoother the phasing out of activities and routines connected to incumbent regimes (*Ibidem*). The creation and management of niches is not only conceptualized in a top-down way (e.g. imposed by governments)[10]. Niche managers encompass a wide variety of actors including social entrepreneurs, NGOs, policy-makers, private companies, citizen groups and so forth (Kemp et al., 1998).

In short, the measures proposed by SNM to facilitate the future course of sustainable socio-technical innovations developed within protective spaces (i.e. niches) are (1) institutional reforms to destabilize incumbent regimes; (2) the promotion of niche activities; and (3) the facilitation of processes for translating ideas and practices from niches into mainstream settings (Nill & Kemp, 2009; Smith et al., 2010:445). The operationalization of SNM poses however relevant challenges (Caniels & Romijn, 2006). In fact, the management activities proposed by SNM appear to be broad guidelines rather than punctual prescriptions supported by methodological coherence and practical studies – an intuition that has been confirmed by the empirical analysis conducted in the framework of this research. Within SNM, the space dedicated to the discussion of processes fostering niche breakthrough is rather limited vis-à-vis the assessment of endogenous steering processes. As pointed out by Caniels & Romijn (2006), SNM is useful for *ex-post* analysis of success and failure factors in the introduction of specific radical innovations (p.2) but provides few guidelines on how to effectively steer towards the

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[10] In fact, SNM has been criticized for a bias towards bottom-up change models (Berkhout et al., 2004; Geels, 2011:32).

incorporation of niche innovations towards more mainstream applications. This affects the appropriateness of the theory in suggesting activities enhancing upscaling of niche experiments and unlocking socio-technical transition pathways – i.e. its use as ex-ante policy tool (Coenen et al, 2010).

The main focus of SNM on niche creation processes implies for this research – studying an *already* existing niche – that the theory has proven useful for assessing ex-post its internal success (failure) factors (second part of the research framework) while it has yielded few insights on promising upscaling pathways (third part of the research framework).

### Operationalization of niche success

As discussed, SNM identifies three endogenous processes for which specific hypotheses have been developed as desired characteristics leading to successful niche formation. During the empirical research, we have tested such hypotheses to assess whether and to what extent these mechanisms are occurring, and if they are responsible for positive project developments.

*Table 2.1 – Internal niche processes and hypotheses for successful niche building and development (Source: adapted from Schot & Geels, 2008)*

| Internal processes | Hypotheses – factors leading to successful niche building and development |
|---|---|
| **The articulation of expectations and visions** | Expectations and visions have to be:<br>a) Robust and shared by many actors<br>b) Specific in order provide sufficient guidance<br>c) Based on and validated by on-going project experiences. |
| **The building of social networks** | Social networks have to be:<br>a) Broad and inclusive of diverse stakeholders as to facilitate the articulation of multiple views and voices and attract the participation of resourceful actors and outsiders<br>b) Deep in the sense that participating actors should be able to mobilise commitment and resources within their organizations and networks. |
| **Learning processes** | Learning processes have to be:<br>a) Directed at the accumulation of facts and data (first-order learning)<br>b) Enabling of changes in cognitive frames and assumptions (second-order learning)<br>c) Encompassing multiple domains. |

## 2.3 Exploring interactions of niche experiments with regime and landscape levels

SNM and MLP argue that, despite qualitative niche developments being a necessary condition for socio-technical transformations, they are not sufficient. External factors play a major role in shaping innovation patterns and therefore the broader context in which niches are inserted needs to be investigated (Van Eijk & Romijn, 2008). The third part of the research explores what other factors deriving from the predominant sanitation system (meso level) as well as the institutional, political and economic context (landscape level) influence future upscaling potential of RRSS. Combined with the information gathered during the previous research steps, it will yield the elements to answering the question of the scope for the RRS niche to contribute to the transition of wastewater management towards sustainability.

As pointed out in the previous section, the MLP and SNM fail to provide systematic conceptual tools to investigate the scope for RRSS to transcend the niche dimension and bring about changes in the established sanitation regime. Indeed, the theoretical assumptions of the theories' constructs hinder their operationalization (Berkhout et al., 2004; Genus & Cole, 2008). Hence, we conducted an explorative research based on previous empirical studies employing such theoretical perspective (full list provided in Appendix 7.2) which we have then integrated with empirical findings to derive a hypothetical list of factors at meso and macro level influencing RRS niche upscale.

### *Regime analysis*

The analysis first focused on the regime level i.e. the features of the sanitation sector in Germany and The Netherlands which explain its stability and the main challenges for RRSS to overcome. Following the MLP the three interlinked elements composing socio-technical regimes have been investigated to uncover barriers and stimulating factors to the upscale of RRSS pilots.

1. The network of actors and social groups that are part of the wastewater management sector;
2. The set of formal and informal rules that maintain the sanitation system and;
3. The material and technical elements forming the wastewater infrastructure system.

Additionally, as performed in Van Eijk and Romijn's study on the prospects of Jatropha as alternative energy source in Tanzania (2008), we have investigated the three elements of other regimes influencing the upscaling potential of RRSS pilots – i.e. the agricultural and energy regimes. Albeit not central in original formulations of the MLP and SNM, recent theoretical contributes have pointed out the relevance of different regimes' interaction for the occurrence of niche-fuelled transitions of socio-technical systems (a.o. Berkhout et al., 2009; Smith et al., 2010). Beside the assessment of these factors, we integrated our analysis with Frenken's (2013) insights on the variables that influence innovation diffusion at the industry level e.g. switching costs and market structure considerations, and Hegger's (2007) work on the specific characteristics of the wastewater sector in Western countries.

## Landscape analysis

The second part of the analysis explored the contextual dynamics that are indirectly influencing RRSS pilots and the sanitation regime. Indeed, according to MLP and SNM, regimes and niches are inserted into socio-technical landscapes – an exogenous environment that puts pressure on regimes and generates opportunities for niches (Schot & Geels, 2008). Landscape developments, however, may also reinforce lock-in trajectories, thus further constrain niche-upscaling pathways (Smith et al., 2010). Put in these terms, the theory seems suggesting that the direction of influence is unidirectional: from landscapes to regimes and niches. While the scientific community has raised a number of criticisms to the theory (a.o. Berkhout et al., 2004; Genus & Coles, 2008; Markard and Truffer, 2008; Smith et al., 2005), this point is rather overlooked. The discussion focuses on the pace at which landscapes change; early formulations conceived landscapes as stable or slow moving while more recent contributes (Van Driel & Schot, 2005) introduce a distinction between stable, slow-moving and rapid changing factors. While *reverse causality* – the study of how regime shifts contribute to landscape changes (Geels, 2011) is not addressed in depth. This would be an interesting aspect to develop since it is also connected to the broader topic on the role of individual agency within the MLP and the extent to which it influences transitions.

Given that the chosen theories provide little methodological inputs on how to structure the analysis of macro-level pressures – a category that has been criticized for being a kind of "garbage can" concept accounting for many kinds of contextual influences (Geels, 2011: 36) – the factors have been derived from empirical studies employing such theoretical perspectives and then integrated with the empirical findings. The analysis investigated influences deriving from the European Union, national, regional and municipal governments, worldwide economic trends and geopolitical factors.

## Policy recommendations

Having assessed the internal and external dynamics influencing RRSS in Germany and The Netherlands and having uncovered the main barriers and opportunities for the upscale of pilot projects, the last part of the research focuses on mechanisms to overcome challenges that projects are facing and that support further development of the RRS niche. The departure point of the analysis concerns policy and institutional strategies that improve niche-internal processes and enhance further development, such as niche protection strategies (i.e. shielding, nurturing and empowerment) (Kemp et al., 1998; Smith and Raven, 2012). Then we concentrated on facilitating successful niche-regime interactions, particularly looking at ways to foster integration between existing sanitation regimes and RRSS pilot projects. In conclusion, we explored what policies contribute to the creation of an enabling environment for sustainable sanitation projects to thrive, also considering their applicability to different contexts from Germany and The Netherlands.

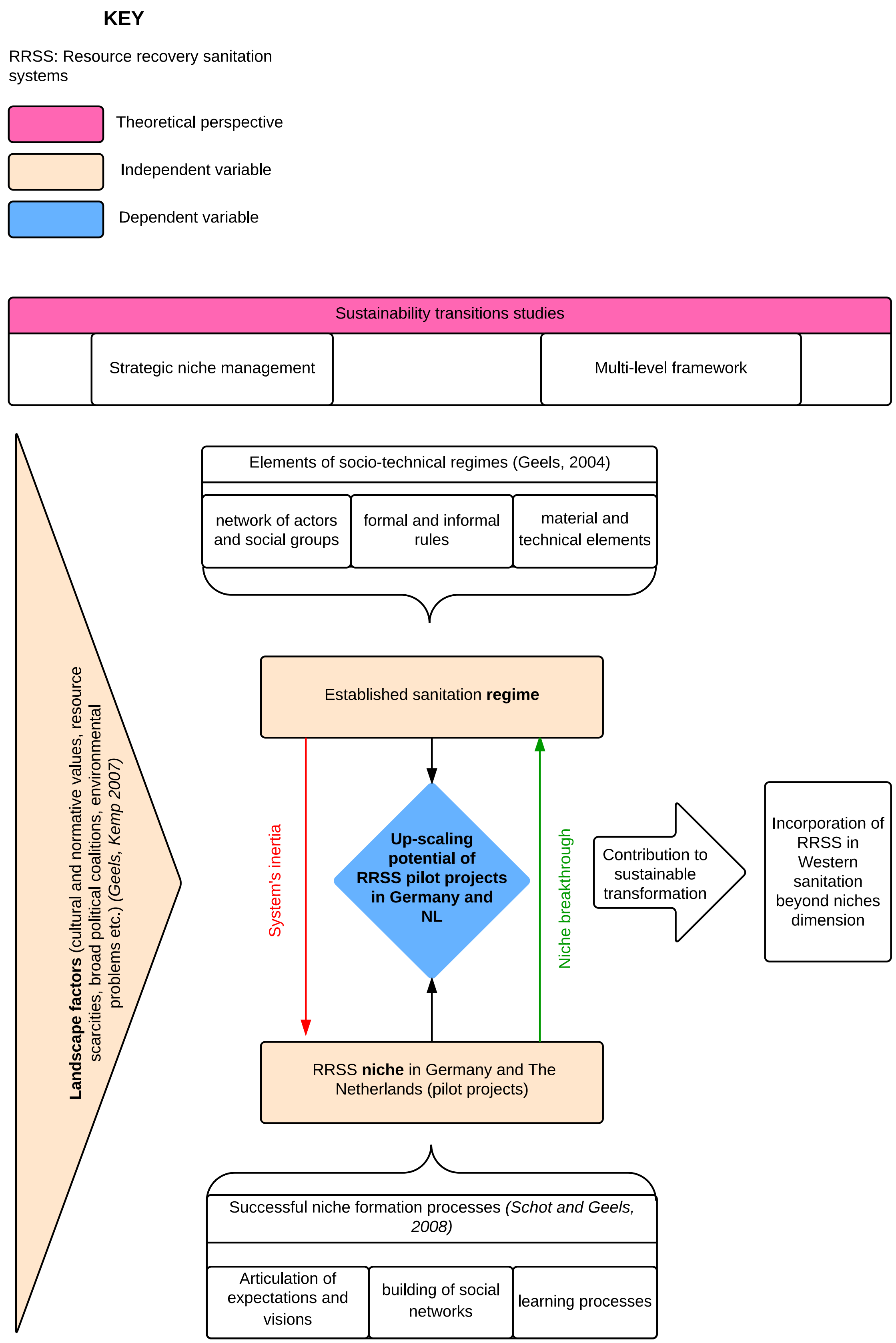

*Figure 2.4 Conceptual representation of the theoretical elements underpinning the research framework*

# Chapter 3: Research strategy

## 3.1 Case study method

The case study method has been selected as research strategy, given the exploratory and qualitative nature of the analysis (Verschuren & Doorewaard, 2010). Within this approach, the theoretical framework's construction precedes and guides the empirical research (Hegger, 2007). Empirical findings, in turn, are used to critically reflect on the theories and suggest input for further development. The empirical subject of research is RRSS niche experiments for which two cases are assessed and compared, in order to establish causal relationships between niche, regime and landscape factors and the scope for further upscale. Case study research offers the advantage of obtaining a general picture of the research object (Verschuren & Doorewaard, 2010: 184), however, external validity of the findings might be affected when the number of cases is small (*Ibidem*). Concerning external validity of this research, the results may help develop theoretical hypotheses for the upscale of the RRS niche in Germany and The Netherlands as well as other contexts that show similar regime and landscape features.

## 3.2 Case selection strategy

The research employs the embedded case study method with the larger unit being the Resource Recovery Sanitation (RRS) niche and the sub-units two local-scale demonstration projects (Verschuren & Doorewaard, 2010). For the purpose of this research a pilot project is intended as a *geographically restricted project where socio-technical experiments with resource recovery sanitation systems (RRSS) are carried out*. The sub-units have been studied according to the hierarchic method – initially each case has been examined independently according to the three levels of analysis and following an established pattern, and then a comparative analysis has been performed (*Ibidem*). The comparative analysis is intended to shed light on the projects' evolutionary path in order to draw conclusions on the upscaling prospects of the RRS niche – i.e. the larger unit.

The rationale behind case selection is to compare projects that show different socio-technical configurations (e.g. technical and management scale, involvement of end-users) and verify to what extent the observed niche, regime and landscape factors (independent variables) determine their future pathways (dependent variable). The field of research is restricted to projects that perform some kind of resource recovery activities in either energy, nutrients or water flows (or the three of them). The selection of cases is not be based on the scale of the project (e.g. number of actors involved, reach, quantity of flows recovered etc.) because the research's aim is not to assess up-scaling in mere terms of size, but the evolution and general improvement of projects and the future prospects of the RRS niche.

In order to operationalize these concepts, the following principles have been developed. Firstly, with *up-scaling* referring to the process that socio-technical innovations undergo when shifting from prototypical state to viable market niche (Caniels & Romijn, 2008. See p. 24 for detailed definition), a necessary condition for it to take place is that projects are in their implementation phase already. Projects that are in the conception phase[11] have not yet reached prototypical state and therefore are not yet confronted with potential upscaling processes. Secondly, since an important part of the research focuses on internal learning processes, projects have to be (or have been) operational and data on their past performance should be available. Western European countries with the highest amount of RRS projects are Germany, Sweden and The Netherlands (Hegger, 2007). Since data accessibility and time availability are important case selection criteria, Swedish cases are not part of this research due to the researcher's residence in The Netherlands with subsequent time and resources constraints. In conclusion, since the case studies are compared across countries and across typology (cross-unit research), only two cases are selected. Nevertheless, the small number of units is appropriate given the intensive study needed for each unit (Gerring, 2004). In order to select the two case studies I have conducted a preliminary research on the on-going projects in RRS. A comprehensive review of worldwide pilots is provided by the German International Cooperation Agency (GIZ – *Gesellschaft fuer Internationale Zusammenarbeit*). This document (Worldwide List of Documented Ecosan Projects by Various Organisations, GIZ, 2012) served for making a first selection of 10 possible case studies. Subsequently, I have analysed each project in more depth and have informally discussed them with experts from Metabolic – where I was doing an internship. This led me to the identification of two suitable case studies – De Ceuvel in Amsterdam (The Netherlands) and DEUS 21 in Knittlingen (Germany). In support of this choice are the following elements:

- Both projects are in their implementation phase and have been operational for at least 1 year;

- Both projects are "second generation" - they are new and have not been extensively assessed yet. Nevertheless, sufficient technical and social data are already available;

- Despite showing different technical configurations, both projects perform *(semi)-decentralized* resource recovery (i.e. small scale). The relatively similar scale of the projects enhances the comparability of their technical performance and the constraining and stimulating factors deriving from it (e.g. small-scale of the installations, small quantities of recovered products);

- The projects present different social configurations (e.g. management models, degree of involvement of end-users). This helps deriving more generalizable hypotheses concerning success (failure) factors connected to a specific social configuration;

- De Ceuvel and DEUS 21 share similar regime features (similarity of infrastructural, organizational and administrative structures of wastewater sector)

- My internship at Metabolic grants privileged access to data sources for De Ceuvel.

## 3.3 Data collection methods

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[11] For instance Jenfelder Au in Hamburg http://www.jenfelderau-info.de/

Data collection relies on several sources to ensure an in-depth understanding of the topic and greater reliability of information gathered; the combination of desk and field research allows for triangulation of information from different sources. Primary data obtained through interviews were supported and tested with secondary data on regime and landscape dynamics. Given that this research was combined with a part-time internship at Metabolic, leading organization in sustainable urban development and nutrient recycling systems from (human) waste, and whose partners are involved in sustainable sanitation projects in The Netherlands, an important part of knowledge and data were accessed through this source.

### 3.3.1 Desk research

Desk research focused on scientific papers and academic publications on RRS, sustainability transitions and strategic niche management in order to identify the factors (i.e. barriers and opportunities) that were tested during the empirical research. Additionally, I conducted an analysis of legal, policy and technical documents to assess the context surrounding the case studies and conduct the regime and landscape analyses. Organizational reports from Metabolic and Fraunhofer Institute formed the basis of the case studies description, which was integrated with information from the interviews.

### 3.3.2 Semi-structured interviews

I conducted 12 semi-structured interviews during the months of May and June 2015. Additionally, in the framework of a university research assignment on the topic of RRS, I have conducted 7 interviews during the month of October 2014 – reaching a total of 19 interviews. Interviewees are representatives of the following categories:

- Research Centres (Eawag, Fraunhofer Society, Wageningen University Research Centre, Wetsus);
- Technology developer/private firm (Desah, Metabolic);
- Municipalities (City of Amsterdam, Town of Knittlingen);
- Water utility companies (Hamburg Wasser, Waternet);
- Networking organizations (Nutrient Platform);
- Farmers' association (ZLTO);
- Ministries (Dutch Ministry of Economic Affairs).

*Table 3.1 List of respondents*

| Period | Name | Affiliation and title | Method of interview |
|---|---|---|---|
| May – June 2015 | Hugo Cortial | **Metabolic**<br>Research Coordinator and Sustainability consultant | Personal interview |
| | Thomas Eschenbacher | **Municipality of Knittlingen**<br>Watermaster | Personal interview |
| | Volker Just | **Municipality of Knittlingen**<br>Building Department Director | Personal interview |

| | | | |
|---|---|---|---|
| | Kujawa Katarzyna | **Wageningen University Research Centre**<br>Sanitary and Environmental Engineer | Personal interview |
| | Marius Mohr | **Fraunhofer IGB**<br>Group Leader Water Technology | Personal interview |
| | Wenke Schoenfelder | **Hamburg Wasser**<br>Quality Management and Technology Development | Phone interview |
| | Felix Tettenborn | **Fraunhofer ISI**<br>Competence Center Sustainability and Infrastructure Systems | Personal interview |
| | Elizabeth Tilley | **Eawag**<br>Water & Sanitation in Developing Countries (Sandec) | Skype interview |
| | Jan Peter Van der Hoek | **Waternet**<br>Head of Strategic Centre | Personal interview |
| | Guus Van der Ven | **Metabolic**<br>Community Coordinator | Personal interview |
| | Sanderine Van Odijk | **Metabolic**<br>Chief Financial Officer | Personal interview |
| | Bas Van Vliet | **Wageningen University Research Centre**<br>Assistant Professor and Educationla Coordinator | Personal interview |
| **October 2014** | Wouter De Buck | **Nutrient Platform**<br>Secretary | Personal interview |
| | Marc Heijmans | **Southern Agriculture and Horticulture Organization (ZLTO)**<br>Project Leader Water and Soil | Personal interview |
| | Enna Klaversma | **Waternet**<br>Water and Energy Advisor | Personal interview |
| | Philipp Kuntke | **Wetsus**<br>Researcher Centre of Excellence for Sustainable Water Technology | Skype interview |
| | Brendo Meulman | **Desah**<br>Project Coordinator | Skype interview |
| | Harm Smit | **Ministry of Economic Affairs**<br>Policy Coordinator | Personal interview |
| | Edgar Zonneveldt | **Municipality of Amsterdam**<br>Advisor Circular Economy and Sustainability | Personal interview |

The purpose of the semi-structured interviews was to uncover the key (perceived) obstacles faced in the implementation and management of the projects as well as possible leverage points, and to assess the potential for further development. In order to obtain a comprehensive and realistic set of factors, I targeted experts involved in RRS experiments (e.g. Metabolic, Waternet, Fraunhofer Institute), informants (e.g. Wageningen Environmental Policy Group, Dutch Nutrient Platform) and end users/residents. Interviews also contributed to collect up-to-date factual information that was not available in literature and documents. Consultations were mainly face-to-face and by skype when respondents where located outside Germany and The Netherlands. The identification of respondents was an iterative process throughout the research which led to modifications in the list of interviewees. For De Ceuvel, most of interviewees were suggested from Metabolic, which had had prior contacts with them. In the case of DEUS 21, interviewees were identified via a snowballing process where further contacts were suggested by already identified respondents (e.g. Dr. Marius Mohr suggested Dr. Felix Tettenborn). Experts have provided knowledge and data for more than one case study, especially when investigating regime and landscape variables. With the participants' prior consent all the interviews were tape-recorded; when required, they were shared with interviewees. With the exception of two interviews that were held in German, the language was English. Beside formal interviews, a series of informal discussions on the research topic have taken place during the months I have spent at Metabolic (February-July 2015). Daily interaction with sanitation experts has enhanced my overall understanding of RRSS.

The questionnaire for the interviews was based on the theoretical framework and consisted of a set of open-ended questions on the topics summarized in table 3,2. The questionnaire was structured in four parts. The first three explore key enabling and constraining factors at niche, regime and landscape level that are derived from System innovation theory, MLP, SNM and empirical studies employing such theoretical perspectives. The questions' design left space for discussing elements that were not part of the theoretical framework but nonetheless considered relevant for the scope of this research. A fourth part concerned a brainstorming section on potential strategies for supporting upscale of projects.

*Table 3.2 Overview of the questionnaire's topics*

| Level of analysis | Topic | Theoretical foundation |
|---|---|---|
| Niche analysis | **Quality of endogenous niche processes**<br>• Vision<br>• Expectations<br>• Learning processes<br>• Social network (Relationships between stakeholders - e.g. frequency of meetings; role of different stakeholders) | SNM |
| | **Social acceptability**<br>• Required level of behavioural change<br>• Psychological barriers<br>• Cooperation mechanisms | System innovation theory |
| | Successful management structures | - |
| Regime analysis | **Economic barriers and opportunities** | Similar |

| | | |
|---|---|---|
| | • Long-term economic viability<br>• Distribution of extra costs<br>• External funding<br>• State of market for recovered products<br>• Promising business models | empirical studies |
| | **Reuse of recovered products**<br>• Limits (e.g. health concerns, legal provisions)<br>• Opportunities (e.g. emergence of sanitation value chains) | - |
| | **Behavioural inertia of regime actors**<br>• Role of habits, routines and cultural meanings in slowing down transitions | MLP |
| | Role of other regimes' actors for success of pilots<br>• Agricultural sector<br>• Energy sector | Similar empirical studies |
| | Compatibility of innovation with existing regime (e.g. infrastructure) | SNM |
| **Landscape analysis** | National public policy | MLP, SNM and similar empirical studies |
| | EU policies (e.g. environmental regulations) | |
| | **Macro trends**<br>• Phosphorus peak<br>• Fertilizers market trends<br>• Energy prices trends<br>• Demographic trends | |
| | **Environmental awareness**<br>• International conferences<br>• International agreements | |
| **Upscaling strategies** | Creation and support of market for recovered nutrients | SNM |
| | Pros and cons of centralized RRSS vs. (semi)-decentralized RRSS | - |
| | Modification of relationships between stakeholders of sanitation sector | |
| | Economic instruments (e.g. incentives, tax credits, subsidies) and their impact | SNM |
| | Role of water utility companies as initiators of RRSS pilots | - |

The questionnaire was divided into two main parts - the "case studies" section was meant for interviewees that participated in the DEUS 21/De Ceuvel projects or are knowledgeable about them while the "experts" section is directed towards interviewees that have expertise in sustainable sanitation in general and are not directly related to DEUS 21/De Ceuvel (see Appendix 7.3). The questions were always previously adapted to each respondent's role, position and expertise.

Participants were contacted by email and phone and were provided with a fact sheet of the research project including information on my identity, affiliation, research questions and research goals (see Appendix). When they requested it, I also sent along the interview questionnaire. Interviewees were told that the questionnaire had to be used as guideline and not as checklist. Hence, they could concentrate on specific topics, according to their expertise and interest, while neglecting other aspects. Interviews took the form of structured discussions;

on one hand the flexible questionnaire was useful to make sure all the relevant topics were covered, on the other it allowed for inductive processes to take place within the interviews.

### 3.3.3 Site visits

In order to gather firs-hand observations I visited both case studies and received special explanatory tours conducted by representatives from Knittlingen's municipality for DEUS 21 and Metabolic for De Ceuvel. The visits greatly contributed to a more accurate description, analysis and explanation of each case study.

## 3.4 Data analysis

The information gathered through in-depth interviews was mostly qualitative. Some respondents provided quantitative data on technical components. The use of the same questionnaire for all interviews ensured that answers were (to some extent) comparable. Data analysis followed an iterative process; interviews were transcribed and colour-coded into groups corresponding to specific questions or specific themes (Creswell, 2007). This method allowed the identification of patterns in respondents' answers.

## 3.5 Overview of the empirical chapters

The presentation and discussion of empirical findings is structured as follows. Chapter 4 is divided into three parts according to the analytical levels of the research framework.

The first section presents the *niche analysis* for each case study. It includes a comprehensive description of the projects with an overview of the wastewater system installed and the study of the three key processes of vision and expectations dynamics, actor network building and learning processes. Text boxes are used to elaborate on project-specific technological aspects that are interesting for better understanding RRSS.

The second section is dedicated to the *regime analysis*. Given the similarity of wastewater regime features in Germany and The Netherlands, the findings are presented together for De Ceuvel and DEUS 21. Where the analysis yielded relevant differences, these are highlighted.

The final section comprises of the *landscape analysis*. It focuses on national and super-national mechanisms that have an influence on wastewater regimes and niche projects. Specific attention is given to relevant policy developments at European level.

Chapter 5 derives implications from the analysis of the two case studies (sub-units) for future pathways of the RRS niche.

# Chapter 4: Case studies analysis

## 4.1 Niche analysis

According to the research framework (Chapter 2), the first step of the empirical analysis concerns the study of the endogenous niche elements and processes that influence the projects' success. The analysis is based on the hypotheses developed within SNM, which identify a successful niche as one that shows (1) a robust and supportive social network, (2) shared and solid vision and expectations, and (3) comprehensive learning processes (Schot & Geels, 2008) (see p. 37). We have assessed their presence at De Ceuvel and DEUS 21 through in depth interviews and the study of project documents with the aim of understanding whether and to what extent those factors play a role in determining the project's success. An overview of the factors is provided in table 4.1. We have found that the theoretical factors alone were not specific enough to explain the projects' success. In fact, the analysis revealed additional factors (table 4.2) that are not captured in the theory's hypotheses, which could be used to further develop them in order to improve their accuracy and applicability to real-world niche experiments. For each case study a description of the project precedes the analysis. The discussion of findings follows the order of vision and expectations dynamics, social network and learning; where applicable, the analysis distinguishes between resource recovery and resource reuse phases.

*Table 4.1 Overview of factors contributing to successful niche formation according to SNM*

| | Hypothesis | De Ceuvel | DEUS 21 |
|---|---|---|---|
| **Vision & Expectations** | Robust and shared | ✓ | ✓ |
| | Specific to provide guidelines | ✓ | Partly |
| | Based on project experiences | Partly | Partly |
| **Social network** | Broad and inclusive (diverse) | ✓ | ✓ |
| | Deep (able to mobilise commitment) | ✓ | ✓ |
| **Learning processes** | Accumulation of facts and data | ✓ | ✓ |
| | Enabling changes in cognitive assumptions | ✓ | Partly |
| | Encompassing multiple domains | ✓ | ✓ |

*Table 4.2 Overview of additional success factors identified with the empirical analysis*

| | Success Factor | De Ceuvel | DEUS 21 |
|---|---|---|---|
| **Vision & Expectations** | Long-term, flexible planning | ✓ | - |
| | Participated planning process | ✓ | ✓ |
| | Stakeholder champion | ✓ | ✓ |
| | Media coverage | ✓ | Partly |
| **Social network** | Favourable local legal framework | - | Partly |
| | Frequent interaction – maintenance of communication flows between stakeholders | ✓ | Partly |
| | Support from institutional channels (e.g. research programs) | - | ✓ |
| | Early involvement of stakeholders (esp. end users) | ✓ | - |
| | Hosting of events | ✓ | - |
| | Stable (trusted and approachable) central network node | ✓ | Partly |
| | Involvement of utilities (i.e. regime actors) | ✓ | ✓ |
| **Learning processes** | Workshops and educational activities to enhance cohesion | ✓ | Partly |
| | Formalised learning sharing mechanisms (e.g. reporting) | ✓ | - |

### 4.1.1 De Ceuvel: a pioneering urban regenerative project in Amsterdam

De Ceuvel is a creative and (almost entirely) self-sufficient office park located in Amsterdam North that was built in April 2013 and officially opened in June 2014. It consists of 15 up-cycled houseboats placed on land, a café and a biorefinery. The project has been described as one of the most sustainable urban developments in Europe due to its unique approach to water and energy management. The De Ceuvel site is part of a broader program – the Cleantech Playground (CTP) – that also includes Schoonschip, a floating neighbourhood with 47 households currently approaching the construction phase . The CTP, as the name suggests, is a living lab that stimulates experimentation with clean technologies in urban developments with the aim of closing material flows at local scale (Innovatie Netwerk, 2013). Metabolic – a systems consulting and development firm based in Amsterdam – first introduced the CTP concept and was then joined by several partners to achieve its concrete implementation at De Ceuvel.

*Figure 4.1 De Ceuvel render (Source: Metabolic, 2015)*

De Ceuvel is a socio-technical experiment in its very essence; innovative technologies, products, management structures and lifestyle practices are being tested on the site with the goal of achieving energy self-sufficiency and local closure of water and sanitation cycles.

The history of this project is very peculiar, starting with the choice of its location. De Ceuvel is situated in the area called Buiksloterham, in Amsterdam North. This plot of land bears the scars of rapid urban expansion and uncontrolled industrial activities witnessed by the city of Amsterdam during the 19th and 20th centuries. In fact, it has been used first as landfill for sludge and other wastes, and then as heavy industry hub due to its strategic position on the river IJ canal. These past land uses have left a gloomy legacy made of heavily polluted soils and surface waters, incidental asbestos and abandoned buildings (Innovatie Netwerk, 2013). In the years 2000s industrial activities had ceased, and the municipality of Amsterdam took the occasion to launch a redevelopment program aimed at transforming Buiksloterham from neglected brownfield into a model showcase for circular urban development (WUR, 2015). De Ceuvel emerges in this context as pioneering urban regenerative project.

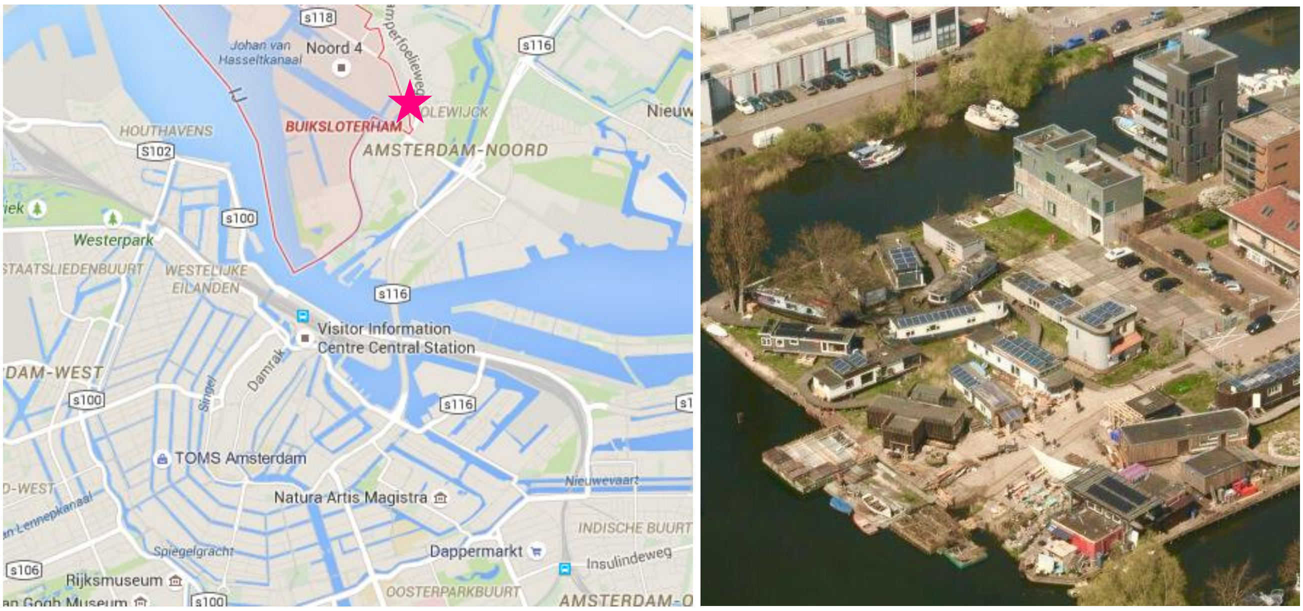

*Figure 4.2 Buiksloterham area in Amsterdam Noord (left; star sign indicates De Ceuvel) and aerial view of De Ceuvel site (right)*

De Ceuvel occupies a total area of ca. 5000 m$^2$ that was used as shipyard in former times and lies within a scarcely populated neighbourhood – 646 people as of January 2010 – with high population growth expectations (11,000 people in 2030) (Innovatie Netwerk, 2013). The project was initiated by three parties – Metabolic, space&matter, and Delva Landscape Architects – who in 2012 jointly participated to, and won, the tender to secure the site for a 10-year lease. Special conditions concerning rental fees applied to the stipulated contract, aimed at boosting the redevelopment efforts of the municipality by attracting (groups of) citizens to set up their offices in Buiksloterham. Nevertheless, one restriction was posed regarding the typology of businesses allowed to become De Ceuvel renters; these should have a Kawa license, which is granted to artists (with a broad definition, including filmmakers, architects etc.) with a certain income threshold (Van der Ven, personal communication, June 19, 2015). The Kawa clause is meant to safeguard a vulnerable category of tenants that might not afford Amsterdam's high rents in other areas and to ensure that the redevelopment program is truly inclusive. While the three commercial parties own their boats, other occupants are tenants.

After acquiring the land, the parties reclaimed and renovated the houseboats that would later become the offices. This process was performed off-site with the aim of achieving high levels of eco-efficiency in order to reduce the need for external energy inputs. The radical choice for employing land-based houseboats was dictated primarily by the prohibition to dig into the soil – a necessary step when laying building's foundations – due to its high contamination (Van der Ven, personal communication, June 19, 2015). However, what was originally a constraint has been turned into an opportunity for enhancing creativity and uniqueness of the project; renters have been given the opportunity to customize the design of their boats, which now reflect "personality" of the businesses they house. Furthermore, using reclaimed boats – a remarkable waste stream in Amsterdam – resulted in economic savings[12]. Using houseboats instead of newly constructed buildings also better fits with the temporary nature of the development, with the site only leased for 10 years. Indeed, once the location will be returned to the municipality, the offices can be moved elsewhere leaving minor traces behind and, thus, not undermining the opportunities for future land uses. Given the "regenerative" nature of the project, De Ceuvel also hosts experiments with land phytoremediation (Innovatie Netwerk, 2013). These are carried out by Delva Landscape Architects and the University of Ghent and employ soil-cleaning plants to extract pollutants in a less invasive and more economical way than conventional approaches based on removal and transfer of contaminated soil layers. The phytoremediation process uses different types of plants and grasses (e.g. willow and reed) that are harvested every year and biodigested to obtain energy. The digestate that is left over contains the pollutants extracted by the plant in a compacted format of few cubic meters that can be treated in different ways e.g. using fungi (Van der Ven, personal communication, June 19, 2015). The goal of such project (so-called "forbidden garden") is to return the site to the municipality in a cleaner status than it received it in 2012 by treating the soil as much as possible directly on site.

## *Wastewater system's overview*

De Ceuvel is a system of quasi-autarkic units scattered on a plot of land and connected by a raised wooden boardwalk. For the purpose of this research we will focus on wastewater management aspects, but it has to be reminded that the project has an important energy component as well (see box 1). Water management and sanitation interventions at De Ceuvel are developed within the framework of the CTP water research program, which is jointly overseen by Metabolic, Waternet, the Watercycle Research Institute (KWR) and Advanced Waste Water Solutions (AWWS) (Metabolic, 2014).

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[12] In Amsterdam, disposing of old houseboats costs between 2,000 and 3,000 Euros to the owner. Metabolic and its partners tapped into this waste stream and obtained all the boats at De Ceuvel for a price between 0 and 1,000 Euros (Van der Ven, personal communication, June 19, 2015).

## De Ceuvel’s small-scale, de-centralized energy production system

*Description*

- Electricity is generated on-site through solar panels installed on houseboats’ roofs with the most convenient sun exposure. Generated electricity is then fed back into the grid and evenly distributed among all the offices.
- Each boat has its own heating system. Heat pumps extract heat from outside air and, at De Ceuvel, they are entirely powered by the electricity produced with solar panels. The heating system works with an outside temperature up to 0 degrees and potentially even lower. The efficiency of the heating system is further enhanced by the fact that the boats are retrofitted according to Passive House standards, which through better insulation substantially reduce heating needs.

*Performance comparison with conventional offices:*

Dutch offices energy demand in 2008 (Energie Nederland, 2011; Innovatie Netwerk, 2013):

- 15 m$^3$ of gas per m$^2$ of office space (primarily for heating).
    - ✓ Entirely replaced by locally generated renewable energy.
- 205 kWh of energy per m$^2$ used for lightning (21%), electronic equipment like computers and printers (12%), servers and decentralized ICT (7%), remainder for transport, ventilation and other functions.
    - ✓ Half of it is covered by the PV system and the other half by the grid.

*Targets*

- Reduce electricity demand by 50-70% compared to conventional offices through optimization of usage patterns and efficiency of devices.
- Achieve 100% renewable energy supply.

The wastewater system has been designed by Metabolic and, following a DIY (do-it-yourself) approach, built by Metabolic itself and the community of prospect renters. It comprises several technological elements and can be further divided into four sub-systems[13]:

1. Offices’ greywater system, consisting of a wastewater stream from the sink treated with biofilters;
2. Offices’ excreta system, consisting of a faeces and urine stream collected through dry composting toilets;
3. Metabolic Lab’s and De Ceuvel Café urine-diverting system, consisting of a separated urine stream collected through UDDT.
4. Rainwater module, consisting of a separately collected rainwater stream.

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[13] Additionally, there is a fifth sub-system. This is installed at Café De Ceuvel only and it consists of 2 conventional flush toilets. This sub-system has been excluded from the analysis since it does not present innovative elements with regards to sustainable wastewater management.

The sub-systems are entirely off-grid and do not rely on sewage infrastructure that, given the digging restrictions, cannot be built. Therefore, they require a high end user involvement. Recovered products are treated on-site in the waste treatment community platform located in Metabolic's biorefinery boat. Reuse aspects will be further discussed in the regime analysis section (p. 78).

The first sub-system treats greywater from the sink[14] through halophyte filters. Despite the high price of obtaining a halophyte filter – as high as 17,000 Euros per unit – Metabolic succeeded in DYI it with the precious help of the community and by closing extremely convenient deals for materials. The halophyte filter that is adjacent to each houseboat purifies the wastewater that is then discharged into the soil. Periodically, the plants inside the filter are harvested and either used as biomass for energy production or as additive for concrete production (see box 1). Each houseboat has one filter that is able to absorb 200l per day.

*Figure 4.3 De Ceuvel's alophytic filters*

The second sub-system relies on dry composting toilets installed at each office to collect and store faeces and urine. These are then jointly treated in Metabolic's biorefinery boat to produce compost. The composting toilets have been purchased from a Canadian company for the price of 1500 Euros; they do not use any water but require the addition of carbon material and periodic tumbling to enhance the composting process[15], whose first phase occurs directly in at the toilet level. The collection model rests on active participation of users, who, every 1-2 months depending on the toilet's use, have to empty the storage tank and transport it to the community platform at Metabolic's biorefinery boat. The process is safe, simple and quick and with the users wearing protective gloves, there are no risks of contamination. De Ceuvel's peculiar collection model works because of specific reasons, which may not apply to other contexts:

- Composting toilets produce dry material to dispose of that is easy to handle compared to flushing toilets;

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[14] Note that greywater normally also includes wastewater from shower and washing machine. However, since De Ceuvel houses offices, the production of wastewater only originates from the sink.

[15] The addition of material is needed to maintain a balanced ratio between Carbon and Nitrogen.

- Waste production is limited in quantity as the houseboats host businesses and not households and therefore toilets usage is limited;
- The biorefinery has to process waste of only 15 units.

### Halophyte filters (saline constructed wetlands)

- Constructed wetlands are biofilters used to treat wastewater from different sources and contamination levels. They use either freshwater helophyte plants or salt-tolerant (i.e. halophyte) species (De Lange et al., 2013).
- Biofilters purify wastewater through a series of biological, chemical and physical processes (e.g. sedimentation of suspended solids, nutrient uptake, microbial transformation) and are able to simultaneously reduce a vast rage of contaminants (nutrients, pathogens, pesticides, suspended solids) (De Lange et al., 2013; Gude et al., 2013; Imfeld et al., 2009).
- They are an ecological and low-cost alternative to conventional wastewater treatment which can be situated at household level close to the wastewater source and provide further benefits such as the improvement of microclimate and aesthetic aspects. Moreover, they allow for reuse of water and nutrients (Gude et al., 2013).
- Beside treating wastewater, wetland vegetation can be used as biomass for energy generation, for insulation and roofing purposes as well as livestock and human consumption (De Lange et al., 2013; Ciria et al., 2005; Maddison et al., 2009).

*De Ceuvel's greywater system*

- De Ceuvel's greywater system employs reed, willow, bamboo, elephant grass, and cat tail. It consists of a passive biofilter (i.e. does not require pumping) composed of two elements installed at each houseboat.
- Through a 40 mm connection, greywater flows to the first three-layered filter. The first layer is made of perlite to enhance plants growth; the second layer is made of sand and the third of gravel.
- Plants and bacteria first take up the nutrients and the remaining pollutants and solids are absorbed or mechanically trapped through physical filtration.
- By law of communicating vessels, water flows through the three layers and reaches the second filter. After flowing through the second filter, the purified greywater percolates in the soil.
- The fast-growing plants are periodically harvested and used as biomass or additive in concrete production.
- The system requires low maintenance and is built with commonly available material – a sealed container to avoid water leakages and a coat of insulation material to prevent freezing of plants during winter.
- The system requires minimal but peremptory behavioural change: users are only allowed to use ecological detergents in their sink.
- The system is able to treat up to 200l/day.

The third subsystem encompasses the two urine-diverting devices, installed at Café de Ceuvel and Metabolic Lab houseboat. Albeit small inflows size, the system is interesting to study because it is connected to a struvite reactor. After collection, urine flows through a buffer and then to the reactor situated in the biorefinery houseboat (also called Metabolic Tech boat) where it is further processed into fertilizer (i.e. struvite). In order to perform local closure of nutrient cycles, tests concerning reuse of struvite and compost for food production will be performed in the newly built greenhouse that is placed on top of Metabolic houseboats. Besides producing struvite from urine, Metabolic's biorefinery hosts events and workshops aimed at creating awareness on sustainable sanitation themes as well as a laboratory where water tests are performed. Furthermore, a sensor system is being developed to monitor resource use and production of each houseboat; live readouts of the sensor system in the biorefinery will provide additional support to educational and research aspects.

Finally, a rainwater module has been installed at Metabolic Lab with the aim of pre-treating rainwater in light of future reuses for irrigation or drinking water purposes. The module is intended as a first experimental set-up to test the performance of bio-sand filtration and collect data on water quality. Suspended solids, nutrients and microbiological agents are removed through sand filtration by mechanical trapping and absorption (Metabolic, 2014a) and the system requires periodic backflush depending on the quality of the input water (roughly every 30-35 days of operation).

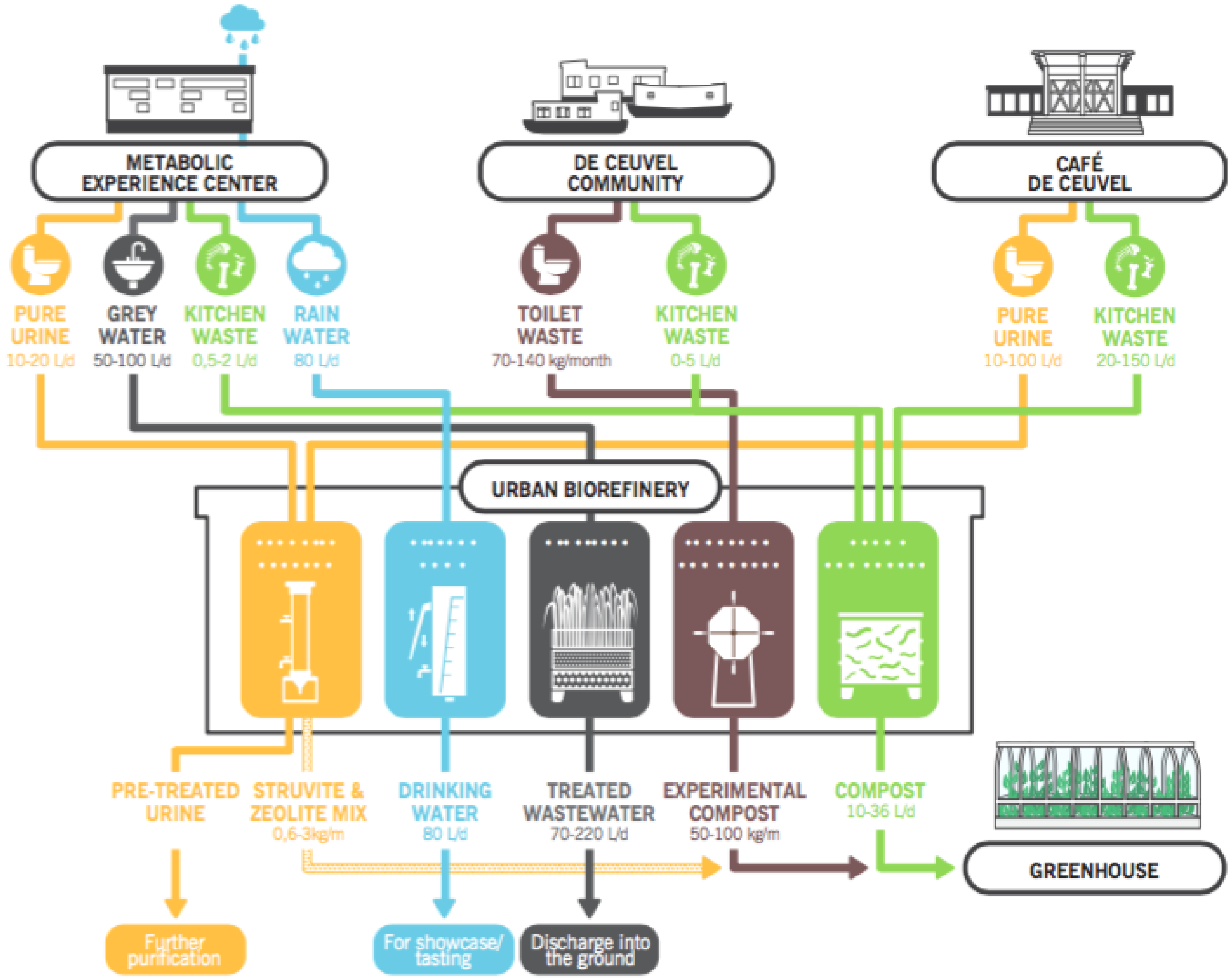

*Figure 4.4 Schematic representation of the interconnected wastewater and kitchen waste streams at De Ceuvel (Source: Metabolic, 2015)*

# Niche Analysis

## *Vision and expectations*

The development of a common vision for De Ceuvel is an essential element of the project. The fundamental concepts of urban flows' circularity and experimentation with alternative cleantech utility models are extensively described in openly available project documents (e.g. Innovatie Netwerk Report, 2013). The overarching framework set by the CTP program is well elaborated and detailed; it contributed articulating De Ceuvel's vision, which was shared among the stakeholders since the beginning of the project. Metabolic has had a prominent role in the vision shaping process by introducing a series of core ideas that had to form the basis of De Ceuvel – I am referring, among others, to the regenerative and productive approach to the development, the onsite treatment of wastewater, the self-sufficiency of the site in terms of energy, and the educational and awareness aspects. Despite anticipating numerous changes to the project's components during the implementation phase, these principles had to remain unchanged since they are De Ceuvel's distinctive trait. A participated planning process ensured that other actors' opinions were discussed and embedded in the project strategy. A series of plenary meetings has taken place during the initial phase, which indicates stakeholders' awareness concerning project goals and development path.

*Table 4.3 De Ceuvel's main stakeholders*

| | Name | Type |
|---|---|---|
| **Initiators<br>Design, construction and operation of the system** | Metabolic | Business |
| | Space&matter | Business |
| | Delva Architects | Business |
| | Community of renters | End-users |
| **Partners Water research program** | Waternet | Public water utility company |
| | KWR Watercycle Research Institute | Research Organization |
| | AWWS Advanced Waste Water Solutions | Business |
| **Technology developers** | TU Delft | University |
| | I love Biogas | Business |
| **Research partners (fito-remediation and sanitation)** | University of Ghent | University |
| | Wageningen University | University |
| **Material and workforce provider** | Blom | Business |
| | Individual volunteers | |

The overall project goals are ambitious and need continuous performance improvements; therefore the system is in constant evolution. The dynamic character of De Ceuvel is defined in the three-phase deployment plan developed by Metabolic and Innovatie Netwerk (2013). After retrofitting the houseboats (phase 1) and the building of the communal infrastructure (phase 2) comes a flexible development and maintenance phase (*Ibidem*: 58) spanning the period from July 2014 until 2023 – the year marking the end of the lease contract. During this phase De Ceuvel will experience techno-social upgrades according to the community priorities and depending on the success of previous phases. Such long-term yet elastic approach sets general guidelines while respecting the desires of the users; it enables De Ceuvel's evolution towards the achievement of its goals preventing bottleneck situations deriving from too stringent planning. Experimentation greatly benefits from flexibility: low-performing systems and technologies can be replaced with more desirable ones, thus avoiding lock-in conditions.

Creating an appealing and inspiring image of De Ceuvel was crucial in bringing together the community of prospective renters and gathering support from institutional actors (e.g. Amsterdam's water utility company Waternet) (Van der Ven, personal communication, 2015). The visioning process brought legitimacy to the project from the general public as well as professionals from the architecture and wastewater management sectors – as it can be seen by the extensive media coverage during the years 2014-2015 and the awards received (Dutch Design Award 2014 in the Habitat category and Frame Public Dutch Design 2014) (dutchdesignawards.nl, 2015).

According to SNM hypotheses, the elements concerning expectations dynamics are promising because we identified significant convergence among stakeholders. Community, project initiators and research partners are aligned in their opinions about De Ceuvel's development, and a sound dialogue among them enhances expectation-sharing mechanisms. Expectations of project participants for the resource recovery phase are generally high and positive, while they are still unclear and rather hypothetical in the resource reuse phase. One possible explanation of such difference is that experiments with resource *recovery* are more widespread in The Netherlands and offer tangible results, while resource *reuse* experiences are proceeding at a slower pace. Hence, expectations of the research partners and the community concerning resource recovery are based on on-going project experiences and are therefore more robust than expectations on reuse of recovered products from sanitation. Based on the information gathered during the interviews:

- Expectations of the projects initiators concerning water reuse have proven too optimistic due to unforeseen financial and technological constraints. The initial attempt of creating an off-grid drinking water net using purified rainwater has been downsized to one single installation (the so-called village pump) used for demonstration and research purposes (Van Odijk, S., personal communication, 2015). In the meantime, the research consortium is investigating alternative solutions for drinking water production unit that fits with De Ceuvel's technical and financial requirements (e.g. it should be able to operate at small water flows, given the low water demand of the site) (Metabolic, 2015a).
- Expectations of Metabolic concerning biogas production have been revised; the co-digestion of excreta and kitchen waste originally planned has proven troublesome and too expensive in terms of maintenance. Moreover, composting toilets were found not producing the appropriate input for an anaerobic digester. Nevertheless, on-site energy production in the form of biogas was not dropped but transformed into a different initiative led by Café De Ceuvel. The Café is currently crowdfunding the "biogas boat", a bio-digester that transforms the Café's kitchen waste into biogas which is then in turn used to cook (cafedeceuvel.nl, 2015).
- Expectations of nutrients reuse did not take entirely into account some intermediate steps and were therefore slowed down. The goal of achieving local food production (10-30%) overlooked the testing phase required for using compost and struvite from excreta on crops. While the testing phase for struvite has recently taken off,[16] there are still uncertainties concerning the use of compost – which for the time being is stored at the biorefinery boat. The tests performed on the compost after 6 months were not satisfactory and it was therefore decided to extend the storage time and postpone application on crops (Van der Ven, G., personal communication, 2015)[17]. However expectations about the use of locally produced compost on small-scale food production are still high from Metabolic's side. The team is confident of meeting the required health standard and being able to use it in the near future (Cortial, H., personal

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[16] Metabolic team is currently carrying out trials on tomatoes seedlings for research purposes.

[17] The WHO guidelines suggest a storing period of 2 years (WHO, 2006).

communication, 2015). It is uncertain whether these expectations are fully justified because of possible legal bottlenecks that may impede its use as well as technical hurdles that may render it unsafe.

- Expectations about possible business models arising from the commercialization of recovered products seem to be positive but uncertain and more probabilistic/visionary than pragmatic. Factors explaining this might be: a) lack of consistent results deriving from previous experiences concerning wastewater outputs; b) in light of local closure of nutrient flows, local reuse is favoured when possible; c) the quantities produced are small to be reused in mainstream agricultural channels; d) the market for recovered products from sanitation is almost inexistent and hard to enter for small-scale independent producers[18].

### Expectations concerning future prospects

As one of the project initiators, Metabolic has well-defined expectations concerning the future of De Ceuvel. These were adjusted during the execution of the project, based on lessons learned. De Ceuvel's replication elsewhere or expansion, is not envisaged given the ad hoc nature of the wastewater system installed – specifically designed for the local context. Instead, Metabolic wants to use the knowledge accumulated and the network of partners to develop alternative sanitation systems for more impactful future projects such as Schoonschip and Buiksloterham (Cortial, H., personal communication, 2015).

### Social network

De Ceuvel brings together a broad and diverse actor network – groups of citizens, research organisations, private and public companies, technical universities (see table4.3). The network has been expanding during the past two years given the actors' participation to other similar projects. One emblematic example is the signing of the Circular Buiksloterham manifesto in March 2015, where the parties have publicly committed to a common vision and action plan for the redevelopment of Buiksloterham. This has been perceived as further confirmation of the actors' intentions to pursue the same goals and has reinforced the ties within the network. For some actors, De Ceuvel represents the seed of long-term cooperation (e.g. Metabolic and Waternet). We have identified a series of elements that enhanced network formation processes in particular in bringing together the three main stakeholders of the wastewater components – the community, Metabolic and Waternet. Numerous other parties have contributed to De Ceuvel with involvement at different stages, to different extents and different time periods (Metabolic, 2014a: 5).

De Ceuvel's group of prospective renters was the main driving force for initiating the project; its early and extensive involvement during "volunteer days" strengthened the sense of community and deepened the ties within participants. What is now called *community* was at first a group of citizens that did not know each other and had signed a rental agreement before the site was even built. Their involvement started with the symbolic step of signing the sustainability

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[18] As we will see in the "regime dynamics" and "landscape influences" sections, this point is debatable.

manifesto (August 2013) and the sustainability agreement (January 2014), where they committed to changing their lifestyle towards the achievement of De Ceuvel sustainability goals. Their symbolic commitment was then backed up by active participation in the construction process. Given the DIY (do-it-yourself) nature of the wastewater system, future renters engaged in voluntary days building and assembling the installations designed by Metabolic. On that occasions they would also be explained the functioning of the components and the reasons for choosing a specific design. Not only this process fostered the sense of ownership of the technology – important element in stimulating its proper use – but it also brought together people, giving rise to a strong and united community. As described by one of the respondents (Van der Ven, G., 2015):

> *"Cross connections came up between people doing similar projects – they bonded. This created a sort of village-like feeling that is now also in place. The setup is very connected also physically – you can enter each other's boats easily".*

The second element refers to the establishment of trusted and approachable network nodes – strategically placed entities whom most of the information run through (Borgatti, 2006; Latour, 1996). Central nodes enhance network cohesion by *quickly diffuse information, attitudes, behaviours or goods and/or to quickly receive the same* (*Ibidem*: 23). At De Ceuvel, Metabolic was an important catalyst, whose role was to convey applied research knowledge and funds to translate the community's vision into reality. It acted – and still does – as central node, keeping alive the connection between otherwise distant actors. Metabolic has frequent interaction with the community through meetings, workshops and troubleshooting interventions and is seen as main contact point. It also receives feedback from houseboats that are often used as input for performance improvements[19]. Simultaneously, it is the main interface for the water research program thereby producing and receiving technical information and assistance concerning the wastewater system that forms the knowledge base of the research consortium. As it appears from the interviews, the figure of a knowledgeable and reliable focal point has fostered trust-building mechanisms among project participants.

The third element enhancing network building at De Ceuvel is the involvement of Waternet. Waternet is Amsterdam's water utility company, responsible for both water provision and sanitation – in SNM terms, one of the most important regime actors. Waternet can be regarded as a powerful actor for De Ceuvel's network for at least three reasons:

- High expertise with (waste)water management;
- Access to state-of-the-art infrastructure and to funds;
- Credibility and legitimacy with other institutional actors (e.g. municipality).

Besides providing 50,000 Euros for the water research program and technical assistance, Waternet has been crucial in obtaining legal exemptions needed for on-site treatment of

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[19] With systems that require high end users involvement there is a risk that central entities like Metabolic take on part of the tasks to be performed by end users because they posses more knowledge and experience. Metabolic tackles this issue by continuously stimulate users' active engagement and strengthen their sense of responsibility; it favours explaining and assisting rather than substituting itself.

greywater. Being able to mobilise commitment and resources indicates that the network ties are deep and the project is progressively reaching out to new actor networks.

In conclusion, an important mechanism for expanding De Ceuvel's actor network is the organization of events. Since construction the site has hosted a large number of workshops, festivals, trainings, educational programs. These have allowed De Ceuvel to connect with a variety of actors such as universities, private firms and policymakers that contribute raising awareness and sharing knowledge about sustainable urban development.

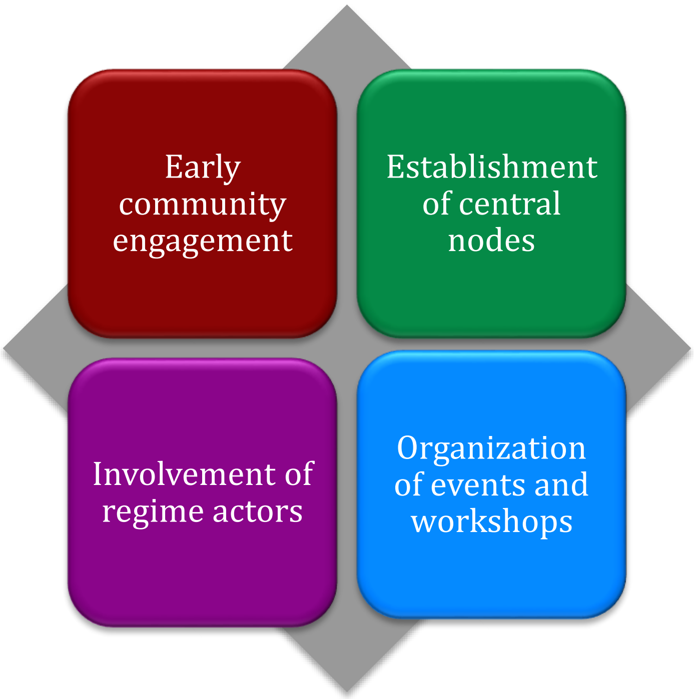

*Figure 4.5 Key actor network formation processes at De Ceuvel*

Establishing what we can safely define a well-functioning network proved key in achieving project goals. De Ceuvel's wastewater system indeed requires high degrees of cooperation and expertise from different fields – making a strong and inclusive actor network an absolute necessity. Due to budgetary restrictions, the system is for the most part DIY (do-it-yourself), and without the material help from the community, construction phase would have lasted longer. At the same time, partners from the water research program provided fundamental assistance and public legitimacy to the project while attracting other resourceful actors. It will be crucial in the long-term to either maintain Metabolic as central node or develop alternative mechanisms that ensure constant information flows among network actors.

### Learning processes

De Ceuvel has generated many learning experiences for the stakeholders, encompassing technical, institutional and social aspects surrounding the introduction of the new wastewater management system. For actors like Waternet and Metabolic gaining first-hand experience with alternative sanitation systems represented one of the main drivers for participating in the project. Sharing of lessons learned among stakeholders appears high given that the research partners produce detailed and easy-to-read quarterly reports on the status of the project. Providing the reader with a list of specific lessons learned is not our aim in this section; we will instead discuss a few emblematic experiences reported by the interviewees in order to give a general overview about the type of learning mechanisms that have taken place.

On the technical side learning processes directed at the accumulation of facts and data (first-order learning) concerning the performance of greywater biofilters, composting toilets and the struvite reactor occurred. In the framework of the water research program, tests on water quality – rainwater and greywater modules' outputs – and compost have been performed to ensure compliance with environmental regulations. Initial tests on the outflow of the greywater filters were confusing – some filters seemed to be discharging more nutrients than what contained in the inflow. The reason for that was found in the perlite layer used in the filters: the material had been previously used in industrial tomatoes production and was therefore full of nutrients. Since the plants in the filters had not grown yet, they were not able to take up the nutrients from the perlite layer with the result of high nutrients release in discharged water. This temporary phenomenon is called "flushing" and does not impair the filters' efficiency in purifying water over the long-term. Additionally, design optimizations were performed in order to reduce overflows and smells. The positive experience of the first testing phase was shared with Metabolic Foundation – a subsidiary of Metabolic by that time operating in Thailand – which installed the same system in Thailand. In relation to the reuse phase, it is still too early to identify solid learning mechanisms given that the struvite tests have just started and the compost is currently being stored. In general, the flexible and low-tech nature of the wastewater system at De Ceuvel allows for an easy implementation of the lessons learned for improving system's performance.

As for the performance of composting toilets, the most relevant learning experiences concern users behaviour. Despite counting on proactive and committed users, handling of excreta in alternative ways proved to be still somewhat problematic. As reported in the surveys administered to the community, users accept composting toilets on a theoretical level; nevertheless, they have difficulties in conforming to the required behavioural changes. Soon after installation improper use caused issues like smelling and flies – when the storage spaces were emptied too late – or poor compost quality if users forgot to regularly tumble the compost. It became an utmost priority to teach users how to properly manage their composting toilets. After trying several approaches (emails, phone calls, written instructions), the most effective strategy was to tackle improper use through dedicated workshops; talking face-to-face instead of handing out instructions was the key (Van der Ven, G., personal communication, 2015). For that purpose Metabolic informally designated a "composting toilets" contact person that would directly engage with the community for any toilet matter. Having regular and direct interaction with the community proved successful – to date only minor issues related to improper use are reported.

Institutional learning processes mainly focused on legal aspects. Understanding the legal framework and the exact applicable regulations required almost 3 months of investigation (Metabolic, 2015a). It was calculated that acquiring the full set of permits for construction and operation of decentralized utilities takes at least nine months, and that the procedure demands specialized knowledge. These elements should be taken into account for future projects. An interviewee reported of an issue with the environmental authority (NZKG) due to insufficient knowledge about the institutional context. In particular, project leaders where unaware of the fact that the environmental authority does not make any distinction between small-scale and industrial-scale when granting waste(water) collection and treatment licenses. Subsequently, when commercial parties apply for licenses for decentralised utilities in urban areas – regardless of the size of the installations – the procedure turns out being more meticulous than if the community applies. The procedure for obtaining the necessary permits from the environmental authority was therefore slowed down because it had been filed from the commercial parties and required Waternet's mediation.

### 4.1.2 DEUS 21: an alternative to conventional water and wastewater management in Knittlingen (Stuttgart, Baden-Württemberg)

The Knittlingen pilot project is part of a research program launched in 2003 and sponsored by the German Federal Ministry for Education and Research (BMBF) aimed at developing alternative methods of municipal (waste)water management. The program, dubbed DEUS 21 (Decentralised Urban Infrastructure System of the 21st century), encompasses two projects – Knittlingen and Heidelberg-Neurott – and has gained international attention thanks to its promising results. Indeed, the concepts developed within the DEUS 21 framework have inspired similar projects in Timisoara (Rumania) and Namibia, among others (Fraunhofer IGB, 2012; Stadtblatt Heidelberg, 2007). DEUS 21 is being developed by a broad and diverse range of partners who, through their experience and expertise, have proven the feasibility of decentralized wastewater infrastructure. The Fraunhofer Institute for Environmental Biotechnology and Bioprocessing Engineering (IGB) has a prominent role among the program's contributors, which also comprise the Fraunhofer Institute for System and Innovation Research (ISI), the Chair and Institute for Environmental Engineering[20] (ISA) of the Department of Civil Engineering of the Rhineland-Westphalian Technical University in Aachen (RWTH) and 7 industry partners.

The two DEUS 21 projects are based on semi-decentralized membrane technology wastewater treatment – which we will further discuss in the following sections. Nevertheless, despite a similar technologic approach, the different state of the chosen sites – Heidelberg Neurott was an existing settlement, while Knittlingen a new development area (Schliessman & Mohr, 2015) – called for adjustments in the system installed. The fact that the same research program encompasses different, albeit conceptually akin, installations highlights the importance of developing wastewater solutions that are designed to meet the specific needs of each site (M.Mohr, personal communication, 2015). DEUS 21 embodies this innovative approach to wastewater management, which favours flexibility, suitability to local conditions and minimal environmental footprint. Moreover, it allowed the research team to experiment with different technologies and draw important lessons for future projects.

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[20] The ISA is also known as the Institute for Urban Water Management (Fraunhofer IGB, 2013).

Knittlingen is a small town of almost 8,000 inhabitants situated near Pforzheim, in Baden-Württemberg. Albeit small, it has historical relevance, as it is the birthplace of Georg Johann Faust, who was born there in 1480 and whose figure inspired numerous literary and artistic works (Knittlingen, 2015). The construction of the wastewater system started in 2005 and was put into operation at the end of the same year, while official opening occurred on October 12, 2006 (Fraunhofer IGB, 2013). It was design to cater to the needs of 100 households part of a new development area called "Am Römerweg", which in 2008 amounted to 175 inhabitants. The new housing complex spans two areas facing each other (Fig. 4.6) – only one of which is served by the DEUS 21 wastewater system.

*Figure 4.6"Am Roemerweg" residential development in Knittlingen. In red: parcel served by DEUS 21. The star indicates the location of the Wastewater treatment plant (i.e. the Waterhouse ) (Source: Stadt Knittlingen, 2015)*

In the DEUS 21 parcel, prospective homeowners were asked an additional sum of 1, 972 Euros per household to connect to the rainwater cistern and the service water network that brings treated rainwater back to the users (Stadt Knittlingen, 2015). The price bonus did not discourage homeowners who, instead, proved eager to participate in the project (Mohr, personal communication, 2015). By 2010 40 households housing 120 people were effectively connected to the system (Mohr, Tettenborn, 2015). Furthermore, given the positive experience with the vacuum sewer system, the municipality decided to install such system also on the housing plot not covered by the DEUS 21 project (Just, personal communication, 2015).

*Figure 4.7 Am Roemerweg" residential development plot in 2011 (right) (Source: Stadt Knittlingen, 2015)*

During the first phase of the project (2006-2010), the system was operated by the Fraunhofer IGB and then it passed into the hands of Knittlingen's municipality under the lead of Mr. Eschenbacher, the town's Water Master (*Wassermeister*) and Mr. Just, the Building Department Director (*Bauamtsleiter*). The testing period (2006-2010) served to collect operational data, optimize the technologies installed and perform the required adjustments. When it reached standard functioning and entered the competence sphere of Knittlingen's municipality, the research partners continued testing additional technical modules (e.g. for nutrient recovery) whose optimization was funded by the Fraunhofer Society (2009-2013). As we will see in the next section, the vacuum sewage network connects households to the so-called Waterhouse (*Wasserhaus)* – a modern-looking wastewater treatment plant that contains all of the project's technology (Fraunhofer IGB, 2013).

Unfortunately, after successful operations for 9 years (2005-2014), the wastewater treatment plant of DEUS 21 in Knittlingen temporary – and only partly – ceased operations. To date (June 2015), wastewater of the Am Römerweg community is collected through the vacuum sewage system but treated in the local conventional wastewater treatment plant – in practice bypassing the Waterhouse. As for rainwater, this is treated within the Waterhouse and discharged into the river despite the original plan of reusing it as service water (i.e. for gardening, toilets, washing machines, showers and dishwashers). Nevertheless, this fact should not lead to the wrong and rushed conclusion that the project was unsuccessful; on the contrary, the different stakeholders interviewed during this research have expressed high appraisal of the innovative wastewater management system (Eschenbacher,T.; Just, V.; Mohr, M.; Tettenborn, F., personal communication, 2015).

### Wastewater system overview

The regenerative water management system of DEUS 21 in Knittlingen encompasses three areas: vacuum black- and greywater collection, rainwater harvesting and reuse as service water, and wastewater treatment with resource recovery in the form of biogas and potentially nutrients.

Instead of conventional waterborne pipes, a vacuum sewer system serves the newly built housing plots on the Römerweg – amounting to 40 in 2010. Vacuum systems of the kind that can be found on ships and planes have multiple advantages; they allow for considerable water saving and are more economical to build compared to conventional infrastructure (Eschenbacher, personal communication, 2015). In terms of volume, water used to transport excreta constitutes the biggest share of wastewater flows. Since this is drastically reduced when using vacuum systems, the resulting volumes to transport are smaller, and, as a consequence, so are the pipes. Smaller sewage pipes require less material and can be built closer to the surface, bringing about important economic savings (*Ibidem*). Vacuum canalizations are also more flexible for both expansion and reduction of users, requiring less extensive infrastructural works (Troesch, 2006). In Knittlingen, single households are connected to a central vacuum station located in the Waterhouse that creates a vacuum of 0.5-0.7 bar (Schliessmann, 2013). Users may decide whether to connect to the vacuum sewage directly inside their house – which requires the installation of vacuum toilets – or using the conventional wastewater collection system up to a subterranean transmission chamber (acting as a buffer) that is connected to the vacuum network (Kotz et al., undated). Vacuum toilets drastically reduce water consumption; using 0.5-1litres per flush instead of 5-7litres of conventional toilets, they produce savings in the order of 5000 litres per person per year[21] (DEUS 21, undated; Mohr, Tettenborn, 2015). In addition, it is possible to install kitchen waste disposers (e.g. grinders) over the sink, whose output is collected through the same vacuum sewerage.

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[21] Considering 6 flushes per day.

*Figure 4.8 vacuum toilet*

Offering alternative options to end-users is an important feature of DEUS 21 in Knittlingen. The project was in fact conceived as to have some degrees of customizability according to the level of comfort, economic investment and environmental performance desired by each household. Nevertheless, regardless of the users' particular choices, the basic infrastructure (e.g. the rainwater distribution network) has been built throughout the site in order to ease future changes.

The black- and greywater stream collected through the vacuum canalization is transported to the Waterhouse, where it receives treatment. This stream also contains grinded kitchen waste from houses equipped with food waste disposers. The Waterhouse is the operational centre of DEUS 21; it is built at the edge of the housing plot and contains the central vacuum station, the 10m³ cistern collecting rainwater, and the waste- and rainwater treatment modules. Given the progressive nature of the estate development, the wastewater treatment plant was designed to initially cater for 50 households with the possibility for future expansion. The Waterhouse employs an innovative anaerobic membrane bioreactor (MBR)[22] that produces less sludge for disposal[23] and requires less energy than conventional wastewater treatment plants (Troesch, 2006). Aeration, which is not required in anaerobic technologies, is an important share of WWTPs energy consumption, accounting for 50-80% over an estimated total energy consumption of 30kWh/person/year [24] (Mohr, 2013).

*Figure 4.9 The subterranean collection chamber*

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[22] DEUS 21 in Neurott-Heidelberg uses *aerobic* membrane technology – a relatively more common twastewater treatment technology.

[23] Microorganisms living in anaerobic conditions produce less waste than those living in aerobic conditions (Mohr, 2014).

[24] This figure is more than double for small WWTPs (Mohr, 2013).

*Figure 4.10 DEUS 21 Waterhouse , containing the wastewater treatment modules*

*Figure 4.11 The anaerobic MBR for biogas production*

The microorganisms contained in the anaerobic MBR transform waste components containing carbon into biogas. The Fraunhofer Society estimated that biogas production of conventional WWTP amounts to about 20-25 l/cap/d whereas DEUS 21 reaches 60 l/cap/d with an energy content of 150 kWh/cap/a (Mohr, Tettenborn, 2015). Biogas is an electricity and heat source that can be directly reused to power WWTP operations or injected into the grid after transformation into biomethane. Being a methane substitute, it can be alternatively used as car fuel (*Ibidem*). The small size of Knittlingen's installation only allows for direct reuse of the thermic energy – obtained by burning biogas and used to provide heating for the bioreactor (Fraunhofer IGB, 2013).

Anaerobic microorganisms do not break down the nutrients present in wastewater; hence, the digested biogas effluent is reach in Phosphorus and Nitrogen. These nutrients are recovered through struvite precipitation (P) and ammonia stripping (N) not only to prevent them entering water bodies but also to (possibly) put them to further use in agriculture. After this last treatment step, purified wastewater meets all the limits for discharge, which happens in a local river.

*Figure 4.12 The water filters for upgrade of wastewater to service water*

The third element of DEUS 21 in Knittlingen concerns rainwater harvesting and treatment. Rainwater from roofs and roads is separately collected in a subterranean system of storage drains (Kotz et al., 2006: 3) and then directed to a central cistern located in the Waterhouse. Conventional wastewater systems usually handle stormwater as household wastewater i.e. with collection through the sewage system and then treatment at WWTP. This is quite an inefficient method since rainwater increases the volumes of – and heavily dilutes – flows to be treated, resulting in higher energy consumption during the treatment process. Moreover, the two streams present different contamination levels, with rainwater already showing drinking water quality for most of the chemical parameters prior to treatment (Fraunhofer, 2013). Hence, rainwater has to undergo a simpler treatment process to reach reusing standards. In Knittlingen rainwater is treated with a membrane process that is able to purify it up to drinking water standards and shows a very low hardness that make it suitable for households hot water applications.[25] The system was designed to supply households with treated rainwater to be used for non-potable applications in the form of "service water". Service water refers to gardening, toilets, washing machines, dishwashers and showering purposes. With this regenerative approach the only external input required is drinking water for exclusively *drinking* purposes, which is supplied through the existing potable water network. In case of rainwater shortages (e.g. prolonged drought), a back-up connection to the existing drinking water network ensures continuous supply (Troesch, 2006). Service water produced on-site is supplied to DEUS 21 households free of charge and users are free to decide what uses to cover with it. Three alternatives are possible – either using reclaimed rainwater for gardening, or for gardening and washing machines, or for the first two and for showers and dishwasher as well (Eschenbacher, T.; Just, V., personal communication, 2015).

DEUS 21 rainwater reuse scheme is an absolute innovation for the German context, although this step has encountered some obstacles (see section 4.1.3).

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[25] The use of Soft water also reduces the need for descaling agents as well as detergents (Kotz et al., 2006). Knittlingen's treated rainwater showed 2.7-4.3 dGH compared to 20.4 dGH of externally supplied drinking water (Mohr, Tettenborn, 2015).

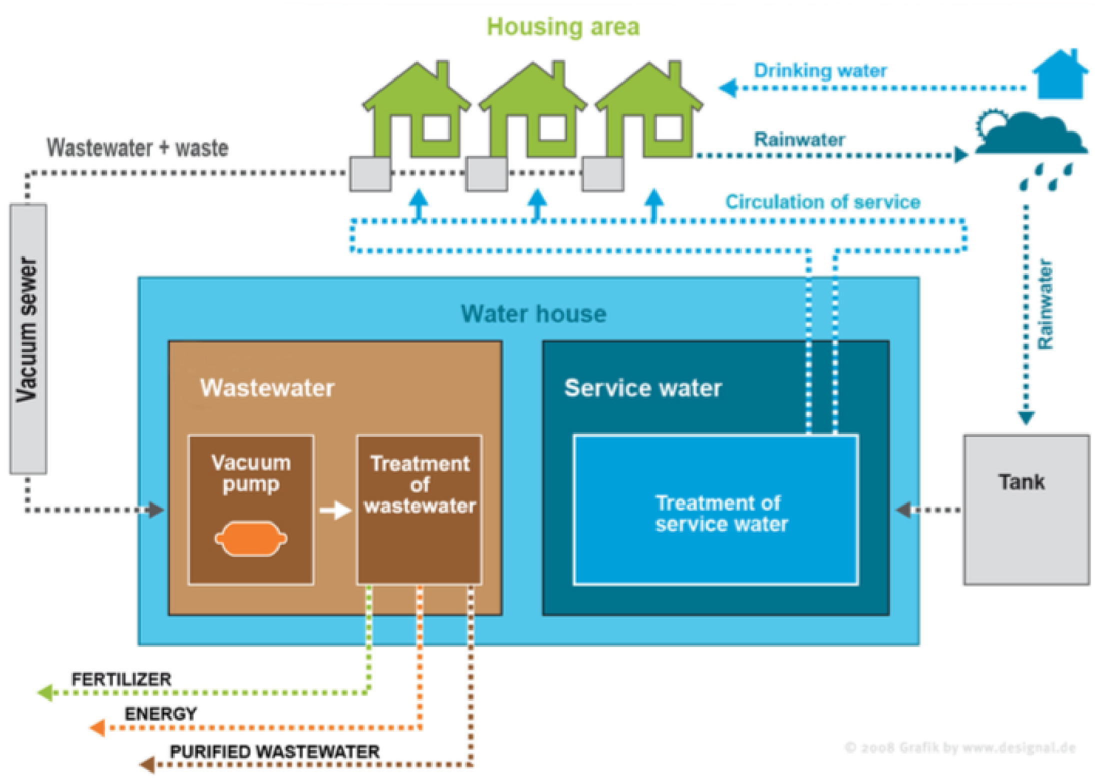

*Figure 4.13 Graphic representation of the regenerative water cycle concept of DEUS 21 in Knittlingen (Source: Fraunhofer IGB, 2013)*

# Niche Analysis

## Vision and expectations

Professors Troesch and Hiessl from Fraunhofer IGB and Fraunhofer ISI have developed the core elements of the vision of the DEUS 21 pilot project in Knittlingen. They had the idea to realize an applied research project in the field of decentralized urban infrastructure systems where they could test a series of innovative technologies that their institutes had been developing. The visioning process started in the early 2000s with the aim of demonstrating the technological feasibility of new techniques for sustainable wastewater management and stimulate future investments in that direction. Contrary to similar contemporary projects like Luebeck-Flintenbreite, flexibility of the system and the use of cutting-edge technologies were the main pillars of DEUS 21 (Mohr, M., personal communication, 2015). Rainwater and wastewater treatment (anaerobic membrane bioreactor) represented the most innovative modules and they were intended since the beginning of the project as experimental elements to be tested. This was possible because the community was served by drinking water infrastructure and thus supply of potable water was not at risk in case of technological failure. For wastewater collection, instead, the project had to employ a technology with minimal risk of failure, since the system had to be safe for residents. That is the reason for choosing a vacuum sewage network – a well-known technology – and for installing a backup connection to the existing (conventional) sewage infrastructure (Tettenborn, F., personal communication, 2015).

DEUS 21 is an applied research demonstration project – a showcase of alternative municipal (waste)water management techniques. It was not intended as a system to be exactly reproduced elsewhere but as a means to advance knowledge and improve performance of a set of technologies. Therefore, proving economic viability was not one of the key priorities. The project's vision was not based on similar past experiences, which increased the risk of failure. Despite uncertainties, however, the vision proved appealing since it succeeded in mobilizing consensus and resources from a broad range of actors.

Our analysis of expectations dynamics shows contrasting elements. In particular concerning the rainwater treatment module, expectations from both project team and users have not been entirely fulfilled.

Groundwater in Knittlingen is very hard, enhancing limestone formations in household appliances that use water (dishwashers and washing machines). Purified rainwater instead is of a softer nature. DEUS 21 was meant to provide households with softer water than the one supplied through the existing infrastructure, producing benefits such as longer life span of appliances and reduction in use of descaling agents. However, shortly before DEUS 21 was built, the city of Knittlingen installed a unit decreasing the water hardness for the whole area – affecting the need for the rainwater component (Tettenborn, F., personal communication, 2015). Service water produced with DEUS 21 was expected to be cheaper than regular water provided through the existing infrastructure but instead the technology proved too costly for such a small scale in terms of operation and maintenance costs. Therefore, despite feasible, treating rainwater did not take place since the high costs were not justified in an area without water scarcity and already served by drinking water infrastructure. At the same time, users' had developed high expectations for rainwater reuse and thought they would have been supplied by DEUS 21 service water. These facts indicate that expectations were mostly based on laboratory experiences and uncertain forecasts. Actors had high and positive expectations that certainly understandable but not entirely justifiable as they were not based on tangible results from previous experiences. Users' wrong expectations are connected to communication issues that will be discussed in the *learning processes* section.

We have identified other interesting mechanisms concerning expectations of the municipality and private investors. Both actors seemed fearing that if DEUS 21 had required too many changes in residents' lifestyle, the market value of the houses would have suffered. In fact, interviews highlight that the municipality demanded to leave the choice of whether installing vacuum systems inside the house to the house owners; and private investors were more reluctant to install vacuum systems thinking they might have trouble in selling or renting out the house later on (*Ibidem*). From our analysis these negative expectations concerning the level of behavioural change that residents are willing to take on are based on wrong assumptions. One sanitation expert from Wageningen Research Centre (WUR) highlights that there is a tendency to underestimate the users' environmental awareness and willingness to engage in sustainable practices. He points out that:

> *[...] in my experience with consumers, in Sneek[26] and in other projects, make them realize that they flush a toilet with 6 litres of precious drinking water will make them upset about it. And I'm talking about ordinary consumers who are not green or particularly environmentally conscious. So, they see that as a problem once you tell them and show them.*
> (Van Vliet, B., personal communication, 2015)

There seems to be a gap between what end users are ready to change and what other stakeholders think they are willing to change. This leads to wrong assumptions concerning value of properties that make use of alternative sanitation systems. Lienert and Larsen (2009) have investigated this aspect for Germany, Switzerland, Austria and Sweden. They found in their study that 80% of 1200 respondents would move into an apartment with sustainable sanitation technology (in their case, urine diverting toilets). Although this aspect should be further investigated, we can cautiously affirm that citizens are becoming more aware of their environmental impact and (household) features that allow sustainable practices tend to be associated with positive qualities.

### *Expectations concerning future prospects*

DEUS 21 in Knittlingen was developed with an eye to the future. Since the very beginning the project was intended as stepping-stone for further implementation of technologies in larger scale. Initially it was expected that the technologies would have been reproduced elsewhere, while in reality the project became a place where to show what is technologically possible –

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[26] Sneek is a sustainable sanitation pilot project in The Netherlands http://waterschoon.nl/project.htm.

since some of the technologies are still too experimental to be implemented elsewhere. The justification for implementing small-scale projects even if economic viability is not achieved is that they are necessary for testing promising technologies and processes that can be scaled up in the future – investment costs and risks of testing at larger scales would indeed be too high.

DEUS 21 is intended as a learning-based experiment whose components can be up-scaled. Currently there are no future plans for the project, which is stalling due to a lack of funds to pay for operation and maintenance. Interviewees report that an eventual bigger scale realisation of sustainable wastewater management in Germany would not employ all the elements demonstrated in Knittlingen. For instance, rainwater upgrading to drinking water would not be implemented. However, other elements are promising also in the current German context. In fact, DEUS 21 has created awareness in the whole sector and triggered similar developments; it has inspired two other cities to install vacuum systems and influenced other (large) projects such as Hamburg-Jenfelder Au (Mohr, M., personal communication, 2015).

## Social network

DEUS 21 is supported by a broad range of social network which encompasses public and private actors. The project involves two research institutes of the Fraunhofer Society (*Fraunhofer Gesellschaft*), the technical university of Aachen (RWTH), the municipality of Knittlingen and 7 private firms. These included a variety of entities from energy, engineering, industry and construction sectors that were interested in testing their technologies in real-world contexts. (see table 4.4). When the project was being developed the different stakeholder groups were involved through a series of meetings. The gatherings are described as fruitful talks where a lot of different ideas and perspectives came together (Mohr, M., personal communication, 2015). This process is a positive signal for the quality of the actor network as it highlights that actors had the opportunity to voice and discuss their opinions.

*Table 4.4 DEUS 21 main stakeholders*

| | **Name** | **Type** |
|---|---|---|
| **Initiators Conception, design and implementation of the system** | Fraunhofer Institute for Environmental Biotechnology and Bioprocessing Engineering (IGB) | Applied Research Organization |
| | Fraunhofer Institute for System and Innovation Research (ISI) | Applied Research Organization |
| **Research partners** | Chair and Institute for Environmental Engineering of RWTH University (ISA) | Research Institute |
| **Technology developers** | EnBW Energie Baden-Wuerttemberg AG | Public energy utility company |
| | Eisenmann Maschinenbau KG | Business |
| | Kerafol GmbH | Business |
| | Roediger Vacuum GmbH | Business |
| | GEMU Grebrueder Mueller | Business |

|  |  |  |
|---|---|---|
| **Funders** | Apparetebau GmbH & Co. KG |  |
|  | Gebr. Bellmer GmbH Maschinenfabrik | Business |
|  | German Ministry of Education and Research (BMBF) | National Ministry |
|  | Municipality of Knittlingen | Local government |
|  |  |  |

The actor network is stable in the sense that since the project launch, no new parties have been involved in the implementation. However, it has gained international spotlight since its initiators have presented it in a variety of conferences, workshops and panels throughout the world – including Helsingborg 2015, Budapest 2015, Sharm el Sheik 2014, Bangkok 2013, Timisoara 2012[27]. Thus, we can consider it a growing social network in the extent that new actors are being indirectly involved. These ties are nonetheless weaker than those of the initial project stakeholders. Despite the biggest share of funds being provided by the German Research Ministry, DEUS 21 partners co-financed parts of the system; the mobilization of resources is a positive indication of their strong commitment.

Our respondents highlighted the crucial role of social capital for kick-starting the project; in particular they referred to professors Troesch and Hiessl from Fraunhofer IGB and Fraunhofer ISI respectively as project champions – core figures in establishing the project and enabling its implementation (Farrelly & Brown, 2011). The visionary duo proved critical in mobilizing resources for the project in terms of funds and partners – they convinced rather sceptical stakeholders to engage in DEUS 21, and they managed to do it without basing their argumentations on actual project experiences but on groundbreaking ideas. The motivational traction was backed-up by the solid figure of the Fraunhofer institutes. The Fraunhofer Society has a high reputation since its establishment in 1973, and acted as trusted facilitator of the DEUS 21 project. Fraunhofer IGB was the leading figure for overall infrastructural design, operation and optimization of the technical units. Fraunhofer ISI conducted several analyses concerning institutional, social and legal framework as well as an LCA (Life cycle assessment) and economic assessment of different wastewater infrastructure concepts (Fraunhofer IGB, 2013). However, the institute was also the main contact point for the other stakeholders – what we have named the *central network node* in De Ceuvel's section. For the community, in particular, the combination of indisputable knowledgeability and approachability – given by the continuative presence on site – of the institute generated deep trust building mechanisms. The sound relationship between Fraunhofer and other actors is regarded as critical success factor of the project (Mohr, M.; Tettenborn, F., personal communication, 2015). In fact, when in 2011 professor Troesch retired, the project suffered since it had lost its guiding figure. Even if other figures from Fraunhofer IGB stepped in at his place, it has been difficult so far to catalyse the same amount of resources for the project to continue operations. Furthermore, from our

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[27] IWA Swedish seminar on source separating sewage systems (Helsingborg); EWA Spring Days 2015 Budapest Water Conference (Budapest); Integrated Resource Management in Asia cities: the urban Nexus (Bangkok); Sustainable Integrated Wastewater Treatment and Reuse in the Mediterranean (Sharm el Sheik); Semi-decentralized water and wastewater management for peri-urban areas (Timisoara).

interview with the municipality it appears that direct contact with Fraunhofer has slowed down during the past year, affecting communication processes (Eschenbacher, T.; Just, V., personal communication, 2015). The municipality is unclear concerning the future of the project and this general uncertainty might lead to deterioration of the relationship with the institute. We conclude that it is important to substitute contact figures of central network nodes as little as possible and to maintain communication flows throughout all phases of the project.

Beside research and commercial parties, DEUS 21 was actively supported by Knittlingen's municipality. Knittlingen was chosen after a long search, being one of the decisive arguments the town's interest in participating to the project (Tettenborn, F., personal communication, 2015). Active cooperation of the local government was a very valuable element; the town's Watermaster (i.e. Mr.Eschenbacher) provided technical assistance throughout the project course and is now the main responsible person of the system. Engaging with the municipality is a win-win situation for DEUS 21: the project gained institutional legitimacy and at the same time Knittlingen's image benefitted from taking part to a nationally-funded innovative research project. Indeed, the town received growing attentions from international experts, policy-makers, researchers (and students!). Contrary to the municipality's enthusiastic approach, the community showed milder, albeit positive, interest. Future residents did not "run away" from DEUS 21, but they did not actively engage in the project either. This is demonstrated by the fact that when deciding where to build within the redevelopment area several residents decided for the plot dedicated to DEUS 21. However, only a small fraction of them actually installed a fully vacuum system within their houses. Moreover, we were not able to find evidence of active involvement of the community, in particular in early stages. The lack of active participation of end users might have affected social acceptance of the system and hampered the sense of ownership of the technology (see *learning processes* section).

### Learning processes

DEUS 21 has been a real learning ground for the Fraunhofer Community and the town's municipality. Despite the project's strong focus on technological features, learning processes have gone beyond the technical sphere. Important lessons for future experiences have been drawn from social and institutional aspects – in particular regarding strategies for enhancing communication and users acceptance. As pointed out in the *social network* section, DEUS 21 experiences have been discussed in several international conferences, which indicates that lessons learned have reached out to many actors. Nevertheless, the extent to which learning has been shared among the project stakeholders is unclear; we were unable to find follow-up documents on the status of the project. Up-to-date performance data of the system's components had to be extrapolated from presentations given in different occasions by the project team[28]. This section is therefore entirely based on personal interviews.

Important learning mechanisms took place concerning the functioning of the whole system and its single components. Overall the technical performance of DEUS 21 was successful – it was

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[28] The most comprehensive presentation with performance data was personally shared by the authors upon request.

possible to operate all the components without major issues and the technology proved feasible. However, the high-tech nature of the project demands high operations and maintenance costs to sustain the system over the long run. It was realized that, in order to break the dependency from external funds and reach economic self-sufficiency, the system should be implemented at a larger scale (between 1,000-10,000 people). This way the costs could be divided among more end users (Mohr, M.; Tettenborn, F., personal communication, 2015). Concerning the rainwater treatment module, biocides and pesticides were unexpectedly found in rainwater. These are difficult to treat with the membrane technology installed in the Waterhouse and represent a barrier to achieve high service water quality for reuse in households. The explanation for that most likely resides in the occurrence of a rebound effect: highly insulated houses prevent heat transfers from the inside to the outside. This leads to colder and more humid outer walls – making them a natural breeding ground for algae and bacteria. As a consequence the paintings of such walls contain biocides and pesticides that are absorbed by rainwater (Mohr, M., personal communication, 2015). If this is the correct explanation, rainwater collected from roofs will be cleaner and more suitable for reuse in households because it requires less treatment to achieve drinking water standards. Therefore to enhance reuse potential in future applications it is suggested to separate rainwater from the roofs and from the streets with the latter being either treated and discharged (which requires lower quality standards compared to reuse) or reused for irrigation purposes only.

The project encountered some communication issues that yielded key lessons. In general it was found that information flows were often not reaching future renters – they were lost at the level of investors building the house. This also applied to people that started construction works before DEUS 21 officially started. As a result of poor communication, the project lost an important share of potential supporters (Tettenborn, F., personal communication, 2015). Additionally, it was understood that end users should have been better informed concerning the experimental nature of the system in order to decrease the chances of future complaints. This aspect is evident in the case of rainwater reuse. Indeed, it appears from our interviews with Fraunhofer IGB and Knittlingen's municipality that rainwater reuse suffered from miscommunication – households were hoping to actually use reclaimed water and were not fully aware that the module had been primarily designed as showcase for technical feasibility and was too costly to operate in a water rich area.

> *I think rainwater reuse was not so well communicated in the beginning. People were really hoping that they could use the rainwater as drinking water. But in an area where we have such good groundwater, it will never be economical to use rainwater. Especially if you collect it from the streets.*
>
> (Mohr, M. personal communication, 2015)

Therefore, an important learning for future experiences is that acceptance of the system is enhanced if end users receive constant and high quality information as early as possible, and that it is in the project team's interest to track down all potential end users (*Ibidem*). Another crucial lesson is to engage with well-trained companies for the installation of vacuum sewers. This is regarded as a critical step – the functioning of the whole system is affected if one household does not work properly. Despite intense communication with local installing companies, minor problems took place during first installations. In order to minimize their occurrence, it is fundamental to establish knowledgeable contact persons within those companies that households can easily resort to when encountering technical problems/doubts (Mohr, M., personal communication, 2015).

Concerning the institutional domain, it was understood that the strategy of leaving complete freedom of choice to the users whether installing conventional or vacuum toilets was not very successful. Even with Fraunhofer encouraging the use of vacuum toilets – beside water savings, a more concentrated stream improves the anaerobic process – a survey held in 2010 found that only 20-25% of the households had installed vacuum toilets and kitchen grinders. The strategy was not effective because users had no legal obligations and in some cases they had already installed a conventional system. One respondent from Fraunhofer ISI suggested as a remedy for future experiences to develop an ad hoc legal provision in the local law that makes the installation of vacuum toilets binding[29].

Our analysis revealed that learning processes in the reuse phase were limited to the technical sphere. Beside rainwater reuse, there is no evidence of social and institutional lessons for biogas and nutrients reuse. We explain this absence by the fact that DEUS 21 focused on testing alternative wastewater treatment, while local closure of nutrients and energy cycles was not a priority. Once it has been demonstrated that the techniques employed are working but require larger scale to be efficient, exploring reuse opportunities became less interesting since the amounts locally produced are very small.

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[29] For Knittlingen, the local law (*Satzung*) concerning the DEUS 21 development area had already been granted by the municipality when Fraunhofer chose to implement DEUS there. It was therefore too late to modify it.

## 4.2 Regime dynamics

According to the research framework (Chapter 2), the second step of the empirical analysis is to explore the interactions of the niche dimension with the broader environment it is inserted in. We are therefore proceeding towards the second level of analysis (meso level) – the socio-technical regime. The MLP posits that socio-technical regime consist of a) network of actors, b) formal, informal and normative rules guiding actors' activities, and c) material elements such as infrastructures (Rip & Kemp, 1998; Truffer et al., 2008). The explorative analysis we have conducted focuses on the elements from wastewater, energy and agricultural regimes that are more relevant for the RRS niche with the aim of uncovering constraining and stimulating factors influencing upscaling potential of De Ceuvel and DEUS 21. Since the MLP and SNM do not provide a clear and well-defined list of factors for this level of analysis, they are derived from previous empirical studies employing such theoretical perspective (e.g. Van Eijk & Romijn, 2008; Loorbach, 2007. Full list provided in Appendix 7.2) and integrated with interviews' and desk research findings. As a result, the set of factors identified in the research for this level of analysis is of an explorative and hypothetical nature. The findings are a first step towards the formalisation of MLP and SNM methods, in that they can be used to further develop the theories' hypotheses.

*Table 4.5 Overview of regime factors influencing upscale potential of De Ceuvel and DEUS 21*

| **Stimulating factor** | **Constraining factor** |
|---|---|
| High investment costs of conventional wastewater infrastructure | Dependency from past public capital investments favouring incremental innovation (improvement and extension of existing infrastructure) |
| Target of new development sites not yet served by conventional wastewater infrastructure | Inflexibility of schemes regulating relationships between sanitation actors in terms of<br>• Investment costs<br>• Management and responsibility |
| Compatibility of RRSS elements with existing infrastructure<br>• Possibilities to upgrade existing systems with RRSS technological modules<br>• Design of hybrid systems combining conventional and innovative elements | Resistance to change in institutional patterns and practices<br>• Risk adverse behaviour of governments and utilities<br>• Standard and rigid industry protocols (e.g. water quality sampling procedures)<br>• Fear of failure of institutional actors<br>• Disincentivizing tax schemes<br>• Public policy slow in incorporating innovations |
| Projected improvement of cost-efficiency performance of RRSS technologies as an outcome of more widespread implementation<br>• Technological learning curves<br>• Increased number of investors | |
| **Re-use of wastewater products (water, energy, nutrients)** | |
| High potential for energy recovery (heat and biogas) and reuse | Safety concerns |

| | |
|---|---|
| • Minimal health risks<br>• Use of existing energy infrastructure<br>• Direct reuse reducing need for external energy inputs<br>• Increased profitability of the system | |
| Struvite recovery at centralized level<br>• Lower production price due to economies of scale<br>• Use of product as compound for conventional fertilizers | Regulations forbidding reuse |
| | Psychological attitudes of other regimes actors (e.g. farmers) |
| | Lack of water scarcity justifying wastewater reuse |
| | Low pricing mechanisms for water provision |
| | Low competitiveness with conventional (fertilizing) products<br>• High production costs<br>• Absence of market (lack of demand, market saturation<br>• Over-supply of nutrients (e.g. in the form of manure) |

We have already discussed the main features of Western-style sanitation systems (see chapter 1) – waterborne, centralized infrastructure that uses great amounts of drinking water and energy to collect, transport and treat wastewater for disposal; and we have already introduced the factors explaining the fundamental stability and resistance to change of prevailing wastewater regimes (see chapter 2.1). This wastewater model applies to both De Ceuvel's context as well as DEUS 21. Indeed, the former is located in The Netherlands, where during the period 1890-1930 conventional sewage systems became the predominant wastewater disposal method (Geels, 2006[30]). Similarly, the latter is located in Germany, which experienced the general introduction of sewers in urban centres from the year 1867 (Lofrano & Brown, 2010). Since then, water-based sanitation infrastructure has undergone tremendous expansion in both countries reaching levels of 96 and 99 percentage of population connected (Fraunhofer ISI, 2012; Hegger, 2007). An overview of the main features of wastewater regimes in The Netherlands and Germany is given in table 4.6.

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[30] The paper offers an insightful historical analysis of the transition from cesspools to sewer systems in The Netherlands.

| The Netherlands | Germany |
|---|---|
| Sector regulated by Water Supply Act (2005), Water Boards Act (1995 and 2007) and EU Urban Wastewater Treatment Directive (91/271/EEC) | Sector regulated by Wastewater Ordinance, Water Resources Management Act and EU Urban Wastewater Treatment Directive (91/271/EEC) |
| Regional Water Boards are in charge of wastewater services and controlled by the State via the Rijkswaterstaat (Ministry of Infrastructure and Environment) | Wastewater services are provided by municipalities or private-public partnerships with the supersvion of state governments (Laender). There are more than 6,900 municipal wastewater disposal companies (Umwelt Bundesamt, 2014). |
| Amsterdam's municipality is an exception where one integrated company, Waternet, provides water supply and sanitation (Waternet, 2014). | In Knittlingen, wastewater services (and drinking water supply) are provided by a consortium of 3 local municipalities. |
| There are **361 WWTPs** and total length of the sewer system is roughly **150,000km** | There are **10,000 WWTPs** which consume 3,200 GWh of electricity per year emitting 2.2 million tons of CO2. Total length of the sewage network is **540,000km** |
| Wastewater tariff scheme:<br>1. Households: flat rate according to fixed pollution levy ("waste unit") and sewer connection. Multi-person households are charged 3 waste unit. Charges amounted to **127 E/cap/year** in 2007.<br>2. Companies: the tax is calculated according to their consumption of drinking water. There are different sub-categories depending on population-equivalent (p.e.) and concentration of pollutants e.g. hotels: low concentration; factories: high. | Wastewater tariff scheme:<br>1. Tariffs are approved at state level and regulated by the Local Rates Act<br>2. In 2007 they averaged at 2.47 Euro/m$^3$ and **115.62 E/cap/year** |
| Average capital investment per m3: **0.93 Euros** | Average capital investment per m3: **1.18 Euros** |
| Total investment in sewerage management (network maintenance, expansion, WWTPs): **2 billion euros** (2008) | Total investment in sewerage management: **4.8 billion euros** (2014, provisional) |
| Per capita water consumption **132/l/day** | Per capita water consumption **121/l/day** |

*Table 4.6 Main features of Dutch and German wastewater regimes*

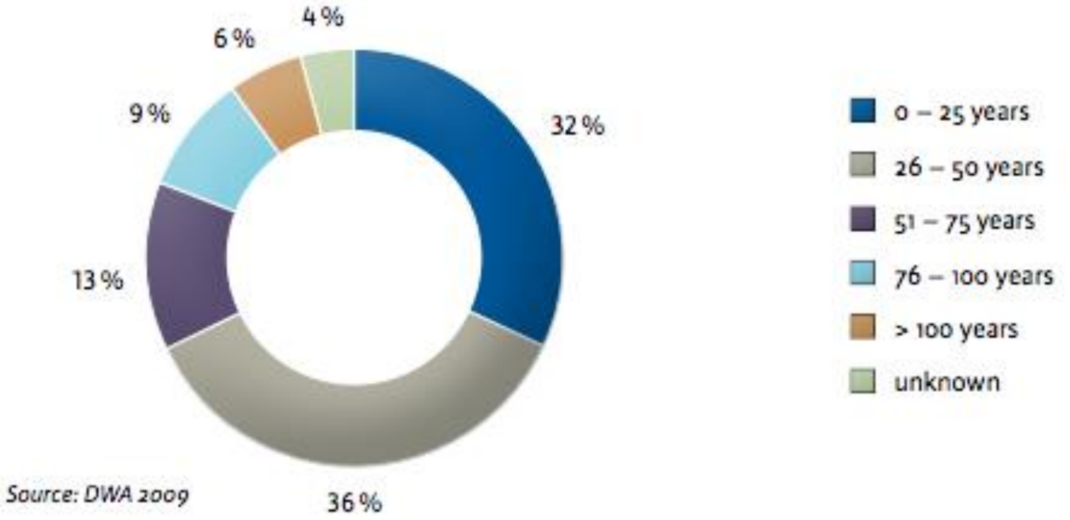
*(Sources: ATT et al., 2015 & 2011; BDEW/DWA, 2009; Bressers and Lufols, 2002; EUREAU, 2008; Umwelt Bundesamt, 2014; Van Riel et al., 2015; Vewin, 2008; VEWA 2010; ZLWK, 2001)*

### 4.2.1 Stimulating factors

Our empirical analysis has identified a series of viable entry points for future upscale of RRS experiments within current wastewater, energy and agricultural regimes.

#### *Significant and continuing public investments for construction and maintenance of conventional wastewater infrastructure*

In Germany and The Netherlands, as well as most of the other European countries, existing wastewater infrastructure is getting aged (fig. 4.13). Sewer lines sections are growingly in need of renovation or replacement, demanding high investment costs. These costs are so high that installing sustainable sanitation technologies represents in some cases an economically competitive alternative (Kujawa, K., personal communication, 2015). It is estimated that capital expenditures for sewers amount to 8,000 Euros/km/year in German contexts and 15,000 Euros/km/year for Dutch cities (ATT et al., 2015; Van Riel et al., 2015). Amsterdam's municipality has a higher budget available of 17,000 Euros/km/year and the total length of the sewerage network is 3,811 km (*Ibidem*). Total costs of sewerage management, including network maintenance, expansion and WWTPs operation, amounted to 2 billion euros in 2008 and 4.5 billion euros in 2014 for The Netherlands and Germany respectively (ATT et al., 2015; Vewin, 2007).



Source: DWA 2009

*Figure 4.14 Age pattern of the sewer network in Germany (Source: ATT et al., 2015; DWA, 2009)*

Resource recovery sanitation systems are less cost-intensive in terms of infrastructure compared to conventional wastewater systems based on extensive waterborne sewage networks and centralized treatment plants. In both DEUS 21 and De Ceuvel, albeit for different reasons, there have been some economic savings in terms of infrastructural costs; DEUS 21 relies on vacuum pipes, which are smaller and less expensive to install (see p. 68), while De Ceuvel is an entirely off-grid system. Therefore, regardless of the performance of the treatment technologies installed, which, being still in their early development might be less cost-efficient than conventional systems, they bring about economic gains in the collection and transportation phase (Mohr, M., personal communication, 2015).

Another situation where RRSS might be favoured to conventional systems is in new residential or isolated areas where infrastructure is not (yet) in place. In these contexts (semi) decentralized collection and/or on-site treatment of wastewater might be preferred since it relieves from building wastewater infrastructure ex-novo. In the framework of DEUS 21, in fact, providing the town of Neurott (Germany) with its own wastewater treatment infrastructure resulted more convenient than extending the sewer lines to connect with the existing centralized system.

We conclude that targeting places where wastewater infrastructure renovation has to take place or new development areas not yet served by sewer networks is a concrete opportunity for testing innovative wastewater systems.

### *Compatibility of RRSS elements with existing infrastructure*

Our analysis revealed that designing hybrid systems that integrate with existing infrastructure is a promising pathway to unlock future developments towards sustainability at the regime level. It appears from our interviews that RRSS that combine conventional and new sanitation concepts have greater opportunities to thrive within a stable regime (Kujawa, K., personal communication, 2015). Sustainable wastewater management solutions may become more attractive in terms of economic and technical performance if combined with existing systems (*Ibidem*). According to one respondent from Fraunhofer Institute IGB, upgrading of existing conventional infrastructure to enhance source separation is an opportunity to reproduce niche-based experiments at a higher institutional level. He reported of a project in which regular overflows of the sewage lines caused by the simultaneous collection of rain- and wastewater had led to the contamination of local water bodies. The solution proposed by the Fraunhofer Institute was to use the existing pipes exclusively for rainwater collection, while installing new vacuum pipes for wastewater collection. This new, integrated, system reduced overflows and subsequent pollution in an efficient way. At the same time it opened opportunities for heat recovery from the wastewater fraction that was no longer diluted with rainwater (Mohr, M., personal communication, 2015). Another example of advantageous complementarity between conventional and innovative systems is given by an interviewee from Fraunhofer IGB. He points out that heat recovery from wastewater combines a well-established technology (heat exchanger) with innovative RRS concepts. It can be achieved without deep modifications to infrastructure and operating models, thus resulting a viable economic, technical and social solution within current regimes (Tettenborn, F., personal communication, 2015).

Similar developments are taking place in The Netherlands, where still 80% of wastewater is combined but diversion of rainwater from household wastewater is being encouraged in certain municipalities (e.g. Wageningen) (Kujawa, K., personal communication, 2015). Furthermore, efforts to enhancing biogas generation and nutrient recovery in the form of struvite (see p. 20) at existing wastewater treatment plants are becoming more widespread (Van Vliet, B., personal communication, 2015;). An opportunity for upscaling niche experiments is thus given by the application of certain concepts and technologies to enhance efficiency of existing infrastructure. While complementing existing regimes might come at the cost of developing systems that are less radically innovative, it contributes to enhance their institutionalization and wider implementation.

These recent developments indicate that improving the sustainability performance of the current wastewater regime needs to follow a stepwise approach, with hybrid solutions combining conventional and innovative elements representing important stepping-stones for future more radical changes. This finding is supported by the theory; the higher the compatibility of new technologies with existing infrastructure (and regulations), the lower switching costs (Frenken, 2013). Low switching costs increase the adoption rate of new technologies (*Ibidem*).

### Improvement of cost-efficiency performance of RRSS technologies

Currently, RRS technologies are less efficient than conventional systems. However, as an effect of learning curves, more implementation will lead to lower costs. A good example of such future development is membrane technology. As pointed out by a respondent from Wageningen WUR, membrane technology used to be an expensive technology introduced for wastewater treatment roughly 30 years ago. Its high potential attracted investors and within a few decades the cost-efficiency performance became so interesting that the technology is now applied in an ever-increasing number of WWTPs (Kujawa, K., personal communication). The high involvement of private technology firms in DEUS 21 and De Ceuvel indicate that businesses are investing in alternative treatment technologies. Support from the private sector is key in improving attractiveness of RRSS and opens up opportunities for future larger scale applications of these systems.

### High potential for energy recovery and reuse

According to Fraunhofer ISI (2012), water supply and wastewater disposal in Germany consume 6.6 TWh/a of electricity – corresponding to the annual electric power demand of 1.6 million 4-person households. These figures indicate that there is a high potential for energy efficiency improvements and to progressively transform WWTPs into energy producers, and not only energy consumers. Among the various products recoverable from wastewater, energy in the form of heat and biogas appears to be the strongest case for European contexts at present (Mohr, M.; Van der Hoek, J.P.; Van Vliet, B., personal communication, 2015). Transforming wastewater into energy eliminates the health risks that are associated with reuse of other sanitation products (e.g. water, nutrients). Moreover, reuse opportunities are facilitated by the fact that producers can make use of existing energy supply systems (e.g. the gas grid) (Van Vliet, B., personal communication, 2015). This is different from the case of nutrients, for instance, because reuse is more dependent on the establishment of new distribution channels.

There are different perspectives about the energy content of wastewater – water experts are generally more optimistic than energy professional concerning the potential of wastewater as energy source. What we understood from our analysis is that compared to current energy consumption, generation from wastewater is a small fraction that does not have the potential to achieve households' self-sufficiency. Nonetheless it can contribute reducing the need of external energy inputs (Kujawa, K.,; Mohr, M., personal communication, 2015). Biogas yields can be enhanced adding kitchen waste to wastewater; developing efficient organic waste collection mechanisms from households therefore increases profitability of the system. Recently heat recovery has gained increasing attention. Heat is the largest part of energy in wastewater – in energy efficient buildings, wastewater represents the biggest heat flow leaving the house. Recovered heat can be integrated with conventional sources to provide heating. In both cases (biogas and heat), recovery is more efficient from concentrated streams (low water content). Separation of rainwater – that dilutes and cools down wastewater – is an advisable step to increase energy production yields.

If suitable to the local context, coupling sanitation with energy production is an opportunity for enhancing the attractiveness of RRSS. Indeed, it is an activity that requires little or none modification of current sanitation and energy regimes to be performed, and it brings about concrete benefits for system's users. Moreover, there is a market demand for biogas and heat that can further stimulate improvements in supply performances (Tettenborn, F., personal communication, 2015).

### 4.2.2 Constraining factors

Despite these promising dynamics, there are a series of regime elements that limit upscaling prospects of RRS experiments.

#### *Dependency from past public investments*

Conventional wastewater systems are based on incumbent technologies and well-established operation models. Hence, they are more efficient within current regimes compared to experimental sustainable systems that are still technically, institutionally and socially under development. This is particularly evident for urban areas for which residents and municipalities have already contributed to the construction of wastewater infrastructure. Indeed, wastewater infrastructure is the result of huge past capital investments. This dependency creates favourable conditions for incremental innovations (improvement and extension of existing systems) while it hampers radical modifications (Mitchell et al. 2012). In these contexts it is difficult to implement alternative systems because there is little justification for substituting a functioning system (i.e. conventional) with an experimental one. For locked-in trajectories to be breached, new systems would have to demonstrate economic competitiveness in the long term (Maurer, 2013).

#### *Inflexibility of schemes regulating relationships between sanitation chain actors*

As Tilley et al. (2008) suggest a sanitation system is a management system that processes different waste streams from the point of generation to the point of use or ultimate disposal. A variety of actors interact along this chain, with roles and responsibilities regulated by formal and informal regulations.

The implementation of decentralized resource recovery sanitation systems alters well-established relationships between residents, municipalities, water bodies, technology developers, national governments etc., substantially modifying hierarchies, roles and responsibilities. Our interviews have uncovered that there are still a lot of uncertainties concerning how the new relationships along the sanitation chain would look like in terms of investments, tax regimes and responsibility. Some respondents have recognized that current schemes are not fair for completely off-grid systems as they do not put any load on existing infrastructure (Van der Hoek, J.P; Van Vliet, B., personal communication, 2015). However there are different configurations of RRSS, and most of them are partly connected to the infrastructure. Standard and inflexible schemes are not suitable for such hybrid wastewater systems; they discourage implementation since users cannot benefit from potential economic gains. Therefore, until new schemes will be put forward, RRSS will be less attractive in areas where wastewater systems are in place.

### *Resistance to change in institutional patterns and practices*

Resource recovery sanitation systems disrupt equilibria of wastewater regimes. One obstacle to their upscale is the resistance to change in institutional patterns and practices. Wastewater management is dominated by risk adverse behaviour of governments and utilities. This attitude is justified by concerns regarding public health implications of alternative systems, which hampers innovation processes. For the past hundred years our society has tried to create as much possible physical and psychological distance from wastewater – such a powerful disease vector (Van Vliet, B., personal communication, 2015). Indeed, infrastructure in urban contexts is pervasive yet invisible and treatment takes place in isolated locations. New wastewater systems challenge these principles; wastewater is reframed as valuable resource to be recovered and reused. The small scale of the installations brings infrastructure back into our sight and our lives; reuse of sanitation products is encouraged potentially leading to pathogen contamination. This proximity is regarded as extremely risky for the entities in charge of safeguarding public health, which therefore are less prone to modify the sector's standards as to allow innovation (Van Odijk, S., personal communication, 2015). Rigid and standard protocols are hostile to RRSS and in some cases they pose insurmountable barriers to their implementation. Fear of failure decreases the chances of institutional actors to sponsor pilot projects[31] and thus slows down their institutionalization process.

Legal frameworks are also resistant to change; innovation processes are faster than governments' ability to regulate them (Innovatie Netwerk, 2013). Out-dated regulations create barriers for RRSS, whose implementation often requires long negotiation procedures and the granting of special status (e.g. De Ceuvel). The sampling procedure for on-site wastewater treatment is an emblematic example: German and Dutch law does not distinguish between

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[31] One example is the first sustainable sanitation project in Wageningen in the framework of the EET-DESAR research program which was cancelled during the planning phase (Hegger, 2007; Kujawa, K., personal communication, 2015).

small and large-scale wastewater treatment operations and therefore sampling becomes very costly for small-scale installations. They are required to perform the same amount of tests on effluents, whose cost is very onerous if distributed among small communities. The problem is not the law per se but how the law is conceived. It is justified to require strict sampling procedures – it safeguards human health and the environment. What is to be changed is the inflexibility. National regulations should start incorporating the possibility to have wastewater treatment at different scales. If different sampling requirements and procedures are set according to the scale of the operations – as to ensure safety is respected but the costs are not prohibitive – then RRSS might gain competitiveness. Another example is the fee for sewer connection: users are charged for wastewater services even if they have onsite treating systems that do not rely on municipal sewers (Hegger et al., 2008; Klaversma, E., personal communication, 2014). This system disincentivizes the use of RRSS because it reduces potential economic savings of residents, who have to pay for sewer charges and the RRSS.

It appears from our interviews that legal frameworks in certain utility sectors (e.g. energy) are undergoing an evolution that is not foreseeable in the near future for the sanitation sector. This field is different from other urban infrastructures, and more resistant to change given that it interferes with senses, private spaces and health aspects (Van Odijk, S., personal communication, 2015; Van Vliet, B., personal communication, 2015). Public policy in the energy sector responded to the introduction of innovations in ever-growing contexts and has become more reactive in incorporating and providing institutional support to new technological developments. A similar acceleration in wastewater policy has not taken place yet; adaptation of regulations and policies is still uncertain.

## *Obstacles to water and nutrients reuse*

The majority of respondents agree that current sanitation and agricultural regimes in The Netherlands and Germany hamper reuse of recovered water and nutrients from wastewater. Recovery and reuse of such products is context specific, and these countries lack the necessary drivers for performing it.

### Safety concerns, regulations and consumers' psychological attitudes

Reuse of wastewater products is hindered by uncertainties regarding potential threats to human health. For domestic wastewater the presence of micro-pollutants (MPs) such as pharmaceuticals, personal care products and hormones – which are not trapped by membrane technologies – is still an open question for the scientific community (Mohr, M., personal communication, 2015; Winker et al., 2009). Measuring of such contaminants is complicated and requires advanced technical equipment (Ellis, 2006). In fact, to date, studies on MPs concentrations in sanitation end products have been carried out only on urine (Tettenborn et al., 2007) and struvite (Ronterltap et al., 2007). These uncertainties concerning potential risks of wastewater products hamper their reuse – an impasse that may be unlocked with further research. The presence of pathogens is another constraint for reuse, which may facilitate the transmission of infectious diseases. Since pathogens are mainly found in faeces (Feachem et al., 1983; Hoeglund, 2001), source separation of wastewater streams reduces risks of contamination

(Mohr, M., personal communication, 2015). Separated streams are reduced in volume, allowing for easier handling, and prevent pathogen contamination of urine and greywater which can thus be reused with less treatment[32] (Winker et al., 2009).

Since the main task of wastewater systems is to protect citizens' health, uncertainties concerning potential risks of wastewater products are reflected in the sector's regulations. Using human-waste products as agricultural inputs is not legally allowed in many cases. The use of sewage sludge is regulated at European level but Member States have the power to implement higher limits[33]. In fact, the limits of heavy metal and pathogens concentrations in The Netherlands are so strict that its use is basically prohibited – sludge is instead incinerated (De Buck, W., personal communication, 2014; Eurostat, 2011). German legislation for sludge allows for its reuse on agricultural lands, which is however decreasing due to thermal disposal procedures (e.g. incineration) gaining in significance (ATT et al., 2011). The high efficiency of wastewater treatment ensures that pollutant concentration in sludge comply with the German Sewage Draft Ordinance and the EU Directive 86/278/EEC (Sludge Directive).

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[32] Note that the risk of contamination with bacteria, viruses and parasites exist for urine as well. That is why a miniumum of 6 months storage is recommended as treatment (Schoenning et al., 2002; WHO, 2006)

[33] This aspect is further discussed in the *Landcape influences* section.

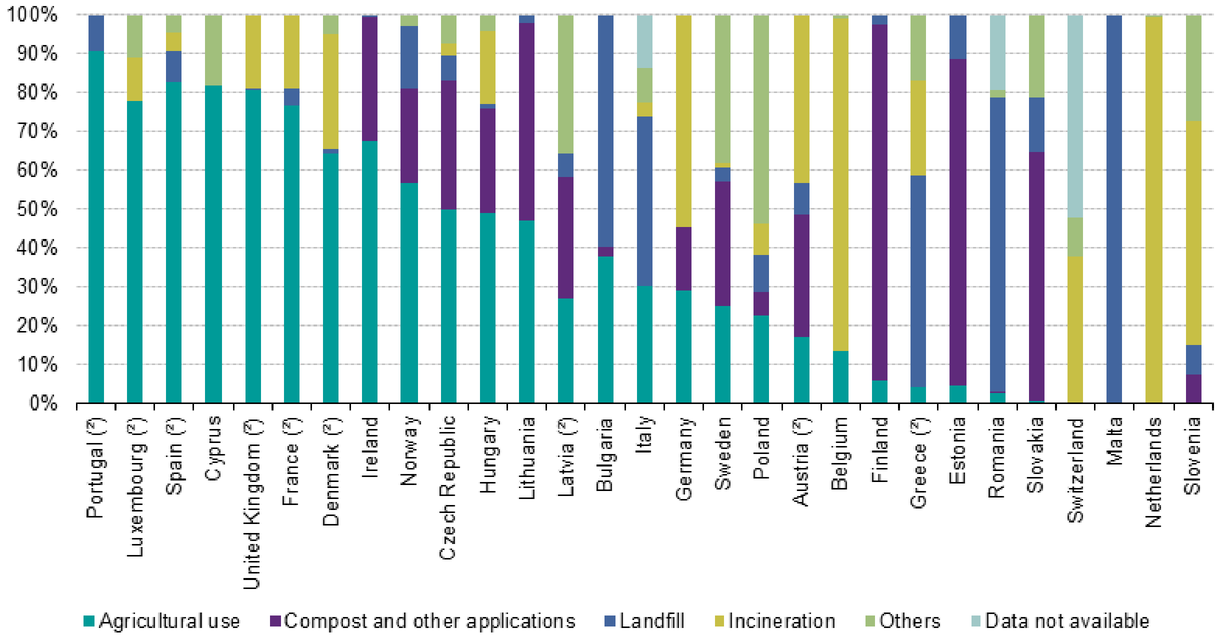

*Figure 4.15 Sludge disposal methods in EU countries (Source: Eurostat, 2011)*

There are uncertainties also concerning attitudes of final users towards recycled wastewater products. Respondents have pointed out fear of risk for reuse (Kujawa, K., personal communication, 2015) and farmers' reluctance to use human waste as agricultural input (Hijmans, M., personal communication, 2014). However, a study conducted by Pahl-Wostl et al. (2003) seems pointing in a different direction; when asked about consuming goods produced with urine based fertilizers, 72% of the respondents answered positively. Clearly, these findings cannot be generalized and final customer acceptability of recovered products should be further investigated.

### Water

Both the Netherlands and Germany have great availability of high quality drinking water. Water provision is not only efficient but also cheap. Purifying grey- or rainwater requires technologies that have high operation and maintenance costs (in terms of energy use, filter changes etc.). At present these systems are less competitive compared to conventional provision and the need for purified wastewater as source of drinking water is not strong enough to justify higher expenses (Van der Hoek., J.P, personal communication, 2015). Low pricing mechanisms are a relevant hurdle for the implementation of water recovery systems:

> [A viable business model] *is really hard to achieve with current water prices. If this is a water-saving technology, as it is the one we're talking about, you don't get a business case out of it because water is too cheap to make a business.*
> (Van Vliet, B., personal communication, 2015)

Water reuse also encounters legal barriers; in both countries drinking water has to be supplied to households by official drinking water supply companies (Dutch Water Supply Act of 2005, Water Boards Act of 1995; German Drinking Water Ordinance TVO). While it is authorized to produce drinking water for personal use, it is not legal to distribute it. One key informant from Waternet reported that discussions are taking place at ministerial level on the possibility of adapting legislation in the future in order to incorporate alternative drinking water supply systems (*Ibidem*).

**Nutrients**

> *Circular sanitation is just so logical – we eat food, the food needs nutrients and in fact we produce as much nutrients that we can recycle to produce our own food – it is so logic.*
> (Kujawa, K., personal communication, 2015)

Recovered nutrients in the form of fertilizer and soil conditioner have the potential to generate two-faceted benefits: reduction in the need for external (synthetic) nutrient inputs as well as prevention of hazardous environmental nutrient over-enrichment (Winker et al., 2009). In 2005 the EU produced 9.4 million tonnes of dry matter from sewage sludge, containing 300,000 tonnes of potentially recyclable nutrients[34] (Fraunhofer ISI, 2012). Unfortunately, agricultural reuse of nutrients recovered from domestic wastewater encounters economic, legal and technical barriers in Germany and The Netherlands.

<u>High production costs, lack of demand and stringent regulations</u>

With the current technologies, the cost of recycling nutrients from wastewater is higher than acquiring them in conventional ways. One respondent from Eawag points out:

> *In South Africa the cost of urine was 20 cents/litre* [which] *makes it 10 dollars per kg of recovered nutrients – and that was the cheapest we could do it because of the transport, the labour, the energy. So, if you're looking for selling something for 10$/kg, I mean, that's outrageous. Right now you can buy probably 20 kg for 5$. So, the distance that we have to go still is pretty huge.*
> (Tilley, E., personal communication, 2015).

Nitrogen recovery through ammonia stripping is more energy intense than fixing it from the air (Haber-Bosch process) (Kujawa, K., personal communication, 2015). Mining and importing Phosphorus (P) and Potassium (K) is also more convenient than recovery within current regimes. Additionally there is a mismatch between the scale of current RRSS – in the order of hundreds of people – and the scale that would be needed to produce appreciable quantities of nutrients. One respondent from Fraunhofer IGB suggested that wastewater of at least 10-20,000 people is needed to produce amounts of nutrients needed to actually support a market demand (Tettenborn, F., personal communication, 2015). The lack of cost-competitiveness from recycled fertilizers is to date a relevant barrier for the development of a market.

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[34] As a reference, the EU consumption of phosphate amounted to 1.34 million tonnes/year in 2005 (Fraunhofer ISI, 2012).

Beside high costs of production processes, German and Dutch contexts experience lack of demand for recycled nutrients. This is caused by a combination of factors. (Western) European countries are experiencing nutrient imbalances due to P and N surpluses (Liu et al., 2008). The high rates of fertilizers use have led to diffuse pollution of water bodies and soils. In response to that, the European Union (EU) has progressively developed stricter application standards (Nitrates Directive 0676/1991). Lower legal limits coupled with campaigns stimulating more efficient application procedures[35] (less input per hectare) have translated in a decrease in fertilizer consumption within the EU (Theobald et al., 2015; Fertilizers Europe, 2011).

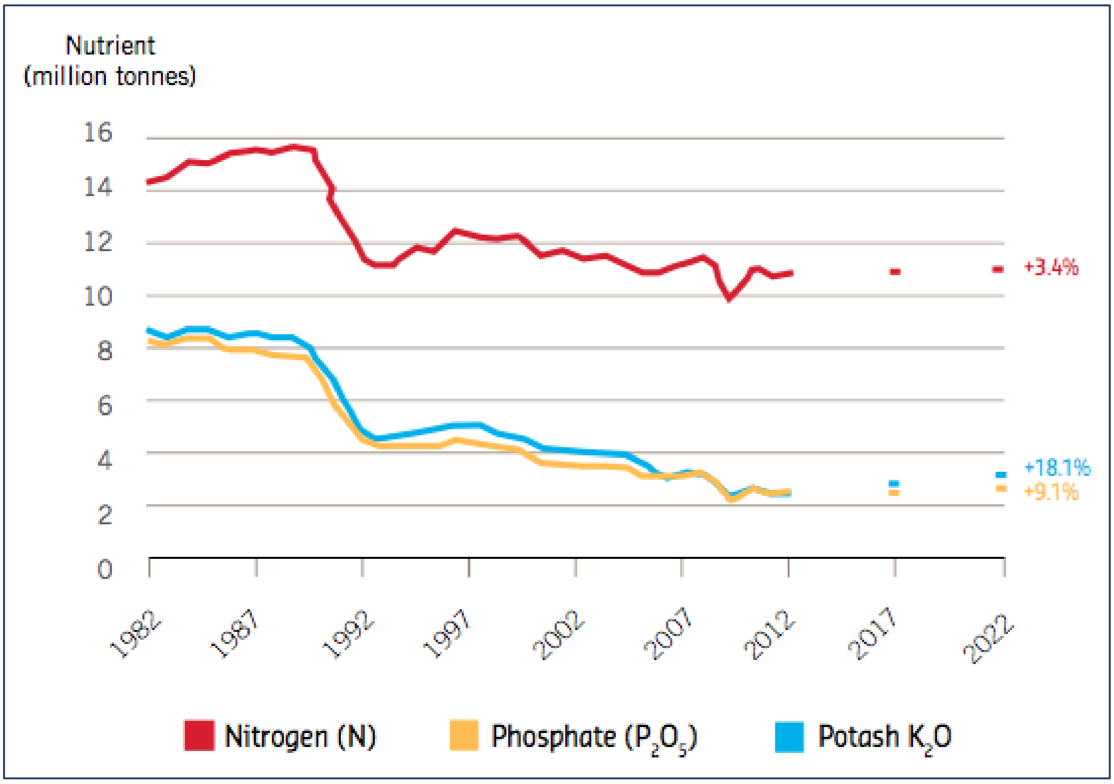

*Figure 4.16 Fertilizer consumption in Europe (EU-27) by nutrient (Source: Fertilizers Europe, 2015)*

In Germany and The Netherlands fertilizers are highly available and there is over-supply (fig. 4.16). In a context of decreasing prices of artificial fertilizing products (see *landscape influences* section) farmers can easily afford the needed quantities. The need to recycle nutrients is thus not perceived. Moreover, intensive livestock husbandry produces great amounts of manure, which is widely used – and accepted – as agricultural input. This dynamic is particularly evident in the Dutch context – a small country with one of the most intensive livestock production sectors in the world (Erisman et al., 2011; Liu et al., 2008). The Netherlands host 12.2 million pigs and 96.9 million poultry, producing 170 million kg of phosphate in the form of manure per year (Dutch Ministry of Economic Affairs, 2013). With application standards allowing 149 million kg only, the surplus has to be disposed in costly ways. This trend is less dramatic for Germany, where livestock density is lower (average mineral P inputs of 6 kg/ha versus 10 kg/ha for The

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[35] EU agricultural policy supports "Sustainable intensification" programs aimed at stimulating more efficient use of mineral fertilizers while maintaining or increasing productivity (Fertilizers Europe, 2015).

Netherlands) (Theobald et al., 2015; Smit et al., 2009; EU 2009). However, with the exception of Nord-Eastern regions, Germany experiences fertilizers surpluses as well (Theobald et al., 2015).

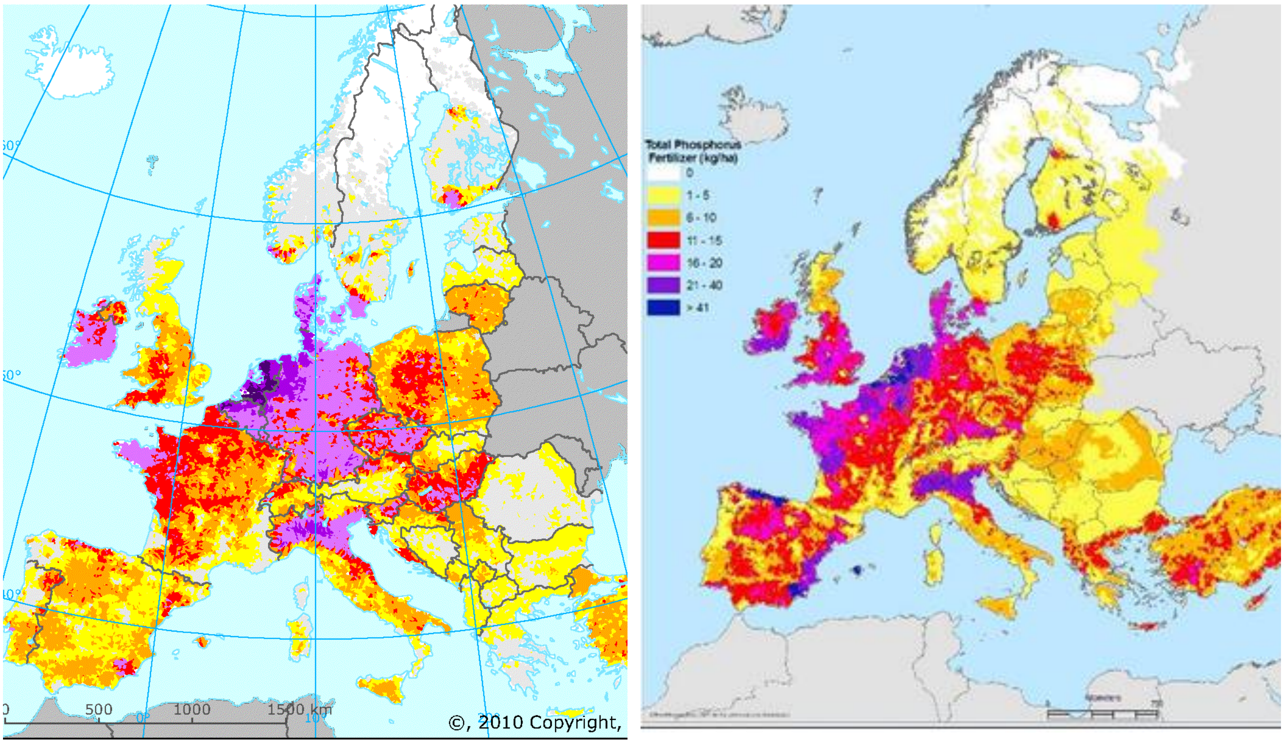

*Figure 4.17 Nitrogen (left) and Phosphorus (right) surplus in EU countries – particularly evident for Germany and The Netherlands. Dark purple areas indicate a surplus of > 150 kg/ha, medium and light purple between 40 and 150 kg/ha, red 30-40 kg/ha. (Source: EC JRC, 2010)*

With policies encouraging (and mandating) less use of fertilizers and national over-production of nutrients in the form of manure, the market seems already saturated. This trend hinders the opportunities for recycled nutrients to enter national and European markets since demands tend to be covered by cheaper artificial products and alternatively ready available manure. Institutional support for recycled nutrients in the form of EU regulations could encourage the creation of a market. As discussed in the *landscape influences* section, there are first signals that developments in such direction may take place in the future[36]. In such environment RRS projects are struggling to commercialize their output, especially if their produce at small scales. As one respondent pointed out:

> *There's no clear commercial party or utility provider that wants our compost. If you want to sell it you need to certify it and demonstrate it is meeting standards in terms of organic matter, nutrient content and pathogens* [Ed. a long and expensive procedure]
> (Cortial., H., personal communication, 2015).

With commercialization being not viable at the moment, local reuse would seem the only option for pilot projects. Nevertheless, this is hampered by hostile regulations prohibiting use of human waste-based fertilizers. Difficulty in actual reuse of nutrients discourages the recovery of

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[36] We refer to the amendment proposal of the EU Fertilizers Regulation 2003/2003.

nutrients in the first place, as it is happening in DEUS 21, and poses a serious barrier to the evolution of RRS pilots. In fact, there is no incentive for developing more efficient production processes which make it more challenging to exit the vicious cycle of low economic competitiveness.

### A promising outlook for nutrient recovery in the form of struvite?

One exception is for the case of struvite recovery at centralized WWTPs. Stuvite is a slow-release P-based fertilizer that showed promising results on vegetables, flower boards and ornamental plants as well as sugar beet (Rahman et al., 2014). Struvite builds up spontaneously (precipitation) in WWTPs due to the chemical composition of wastewater. Struvite deposits cause clogging of pipes and result in increased pumping costs and expensive maintenance operations[37] (Tilley, E., personal communication, 2015; Doyle & Parson, 2002). Recovery of struvite for centralized plants is a win-win situation - it prevents the formation of deposit and lowers the concentration limits of P in effluents, allowing to comply with discharge limits (Tilley, E., personal communication, 2015). The market for struvite is still very limited but some characteristics of the product point in an encouraging direction. Struvite is easy to transport thanks to its low density and high concentration of nutrients – which is not the case for compost or sludge. This quality enables exports from contexts with high nutrient availability (e.g. The Netherlands) to regions that have high demand for P-based fertilizers. Therefore it opens a business opportunity for struvite producers in countries with nutrients oversupply. Additionally, the external appearance of struvite does not resemble in any way to human waste – a factor that may foster social acceptance. Nevertheless, there seem to be high uncertainties concerning the market price of struvite; given the absence of an established market, the price is not determined by supply and demand dynamics. The literature suggests different approaches to derive the market price of struvite (e.g. price of single components, agronomic value, a combination of production, transportation and packaging costs) but the final estimates are highly inconsistent:

- Doyle & Parson (2002) propose a price range of US$ 9 – 1883/ton.
- Maas et al. (2014) propose a price range of E 830 – 1000/ton.

Our interviews suggested considerably lower values. The manufacturing company ICL Fertilizers Europe C.V – a business unit of ICL Fertilizers based in Amsterdam – is willing to pay E 50/ton for struvite (Zanelli, A., personal communication, 2014). An informant from Desah reported the price to be of E 250/ton in Belgium, albeit he referred to struvite directly used as fertilizer while ICL would use it as component for industrial fertilizer production (Meulman, B., personal communication, 2014).

### Fosvaatje in Amsterdam

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[37] Doyle & Parson (2002) estimated that a WWTP with a capacity of 100,000 $m^3$/day spends on average US$ 100,000 per year to tackle struvite build-ups.

The Netherlands has recently (January 2015) included struvite and other recovered phosphates in the Dutch Fertilizing Substances Act[38], allowing their use as fertilizer or as compound within national territory. Waternet has ceased this opportunity and has upgraded one of its plants with struvite reactors. Fosvaatje is currently Europe's largest phosphate recovery installation (Dutch Water Sector, 2013); it brings about annual savings of 400,000 Euros and produces struvite able to fertilize an area equivalent to 10,000 soccer fields yearly (Waternet, 2013). According to Dr. Van der Hoek, head of Waternet's Strategic Centre, the key for transforming P recovery from wastewater into successful business is to do it at a large scale because:

- In order to be a player on the phosphate market you need to produce volumes comparable to traditional suppliers of such resource – and phosphate producers are very large;
- With high costs of recovery technology, large installations can benefit from economies of scale and therefore reach profitability.

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[38] The Act implements European legislation on fertilizers and sets limits for heavy metals and organic micro-pollutants concentrations in fertilizing products.

## 4.3 Landscape influences

Having analysed the micro (niche) and meso (regime) levels, the following section explores the factors influencing RRS niche upscale deriving from the broad institutional, political and economic context – what MLP and SNM identify as *landscape level*. As pointed out in Chapter 2, the definition of which elements are part of this level is quite evasive. Different theoretical contributes include macro-economic patterns, demographic changes, broad political developments, socio-cultural attitudes and other contextual elements that exert influence on regimes and may create window of opportunities for niches (Berkhout et al., 2009; Geels, 2011; Rip & Kemp, 1998; Smith et al., 2005). Our explorative analysis identified through interviews and the study of relevant documents a series of landscape pressures on the wastewater regime that influence upscaling prospects of RRS niche. As for the regime level, the set of factors is of a hypothetical nature and may serve to further elaborate the MLP and SNM's methodology. The analysis distinguishes between factors at different spatial levels (European, national and regional), economic and market-based factors, and geopolitical factors.

### 4.3.3 European level

#### *Water quality within the EU – Micro-pollutants & the Water Framework Directive*

**Micro-pollutants**

As pointed out in chapter 1, effluents from WWTPs contain substances that are a threat to receiving water bodies. In particular there is raising concern for the impact of micropollutants[39] (MPs) such as pharmaceuticals and hormones on aquatic ecosystems (De Graaff et al., 2011). Conventional WWTP technologies are not efficient in removing them, since they were designed for eliminating organic matter and nutrients (Clouzot et al., 2013; Schwarzenbach et al., 2006; Ternes & Joss, 2006). Recent studies point out that MPs in source separated streams are found at higher concentrations, therefore separate treatment of each stream may be more efficient in reducing their discharge to the environment compared to conventional WWTPs[40] (de Mes, 2007; Larsen et al., 2004; Winker et al., 2008). However, there are still fundamental uncertainties regarding the fate of MPs and options for optimizing treatment as to minimize their impact on aquatic life. These uncertainties are reflected in the lack of regulations setting specific WWTPs effluent limits for MPs (Clouzot et al., 2013).

At present the matter is (partly) regulated by: 1) the EU Directive 2008/105/EC that lays down maximal concentrations tolerated in receiving waters of 33 priority substances (EC 2008); 2) the

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[39] MPs are defined as inorganic and organic trace chemicals present at concentrations from to µg/L to pg/L (Clouzot et al., 2013).

[40] Separate streams are considerably smaller and easier to handle - sewage 200 L/p/day; urine 1.5 L/p/d when collected undiluted, black water 7.5 L/p/d when using vacuum toilets (Kujawa-Roeleveld et al., 2008).

EU Registration, Evaluation, and Authorization of Chemicals (REACH) that regulates chemical toxicity and uses of high concern chemicals. However, these provisions are not connected to municipal discharging standards. With the scientific community identifying MPs as one of the greatest challenges of wastewater management (a.o. Kujawa-Roeleveld et al., 2008), more stringent regulations are expected in the future. In Switzerland, already, legal provisions have been developed to upgrade 100 WWTPs with MPs removal technologies (OFE, 2012). Such developments increase the economic burden of conventional wastewater treatment and question incumbent technologies. Alternative wastewater management concepts may benefit from it.

### The Water Framework Directive (WFD)

The WFD (2000/60/CE) is the overarching European water policy aimed at protecting and restoring the quality of European water bodies. Its innovative approach puts aquatic ecology at the centre of water management (Hering et al., 2010), addressing pollution issues deriving from improper urban wastewater management and agriculture (EU, 2015). The Directive sets targets to achieve "good ecological and chemical status" of surface and groundwater and it is failing to reach such objectives mainly for diffuse eutrophication phenomena [41] (Klauer, 2014). Eutrophication is caused by nutrient overloads – also resulting from inefficient wastewater treatment. As for the case of MPs, stricter regulation of WWTPs discharging standards is likely to be developed (Van Odijk, S., personal communication, 2015), since it is crucial to achieve the goals set by the WFD. In order to comply with regulations imposing more stringent effluent limits, additional treatment has to be performed at WWTPs. In this context, RRS may attract attention of actors looking at alternative treatment systems that do not require costly upgrades.

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[41] The other reason is the water structure and morphology (Klauer, 2014).

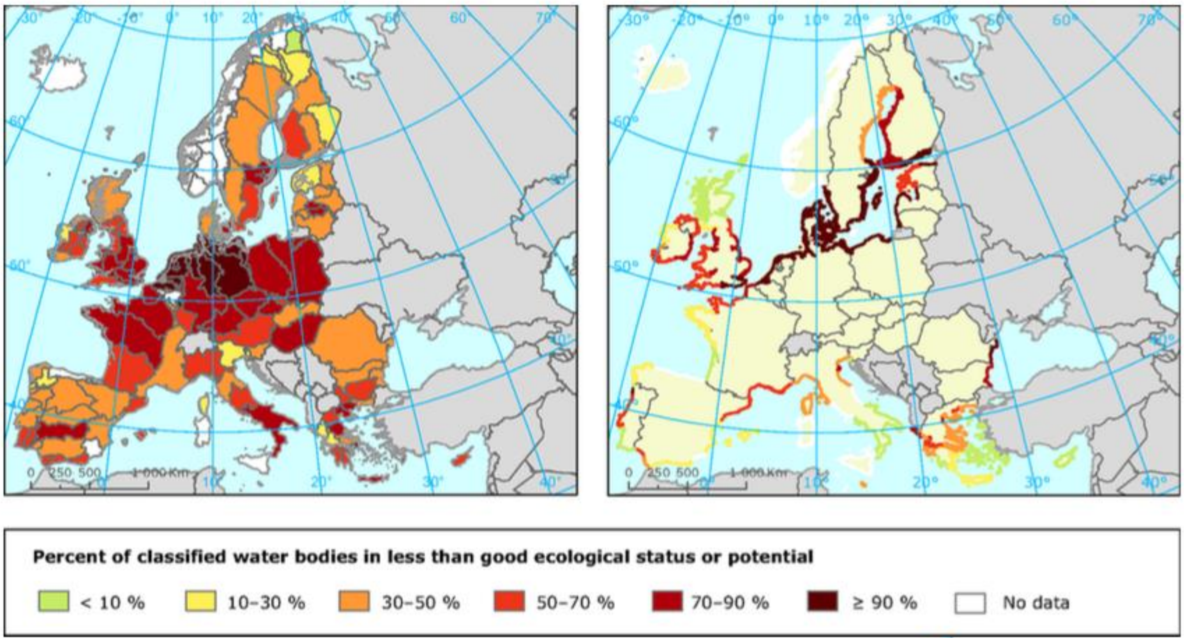

*Figure 4.18 Percentage of water bodies currently (2012) failing good status (Source: ITC/ICM, 2012)*

## Developments of European legislative framework for use of nutrients as agricultural input

Below is an overview of EU legislation affecting agricultural reuse of recovered products from sanitation. Our analysis identified a legislative gap for products other than sewage sludge – which are not regulated at EU level. The Fertilizers Regulation, in fact, only applies to mineral (inorganic) fertilizers, thus excluding organic fertilizers, soil improvers and other bio-stimulants (Fertilizers Europe, 2012). The procedure for introducing new mineral fertilizers and products may take up to 7 years – a relevant barrier to innovation (CSES, 2010). These aspects of European provisions pose relevant hurdles for an upscale of the RRS niche because they impair the possibilities for pilot projects to develop profitable mechanisms based on reuse of their products.

*Table 4.7 Overview of EU legislation influencing RRSS*

| Regulation | Key features |
|---|---|
| **EC Regulation 2003/2003 – Fertilizers Regulations** | • Annex I lists fertilizers that can be marketed within the EU ("EC Fertilizers")<br>• Lays out procedure and conditions for inclusion of new fertilizers in Annex I<br>• Does not include fertilizers from human waste other than sludge |
| **EC Regulation 1774/2002 – Regulation on the use of animal by-products** | • Prohibits agricultural use of organic fertilizers and soil improvers other |

| | |
|---|---|
| | than animal manure |
| **Directive 86/278/EEC – Sludge Directive** | - Allows application of sewage sludge to agricultural land<br>- Sets maximum concentrations of pathogens and heavy metals for use<br>- Allows Member States to set higher values of maximum concentrations |
| **Directive 91/676/EEC – Nitrates Directive** | - Aims at reducing and preventing water pollution caused by nitrates from agricultural sources<br>- Member States have to establish action programmes establishing application standards for nitrate fertilizers (and indirectly phosphorus) |
| **Council Regulation EC No 2092/91 – Organic Agriculture Regulation** | - Defines types of fertilizers allowed in organic agriculture<br>- Does not include fertilizers derived from human waste |
| **Directive 2009/28/EC – Promotion of the use of energy from renewable resources** | - Considers biogas from treatment plants as renewable source<br>- Encourages Member States to increase share of energy produced from renewable sources |

In 2010 an evaluation of the Fertilizers Regulation pointed out the legislative gap concerning human waste-based products and recommended the Commission to amend the document in order to include this category. A key informant from the Dutch Ministry of Economics has reported that the matter had been taken forward and an amendment proposal to the Regulation is currently being discussed – with a new regulation expected in 2017 (Smit, H., personal communication, 2014). The proposal aims at (quoting from EU, 2013):

- Extend the scope of the Fertiliser Regulation to cover also other organic fertilising materials in addition to inorganic fertilisers.
- Reduce the time required for the inclusion in its Annex I for new fertiliser and fertiliser additives which are the main area of innovation for the sector [*in order to*] speed-up the placing on the market of innovative fertilisers in line with the agricultural needs in different regions of the EU.
- Achieve full harmonisation of the legislation [...] and contribute to a more resource-efficient Europe by fostering the safe recycling of waste materials into fertilising materials.

In light of these recent developments, it seems that RRS concepts are starting to receive some support within European institutions.

### 4.3.4 National and regional level

#### *Nationally funded research programs*

In the past, German nationally funded research programs were targeted towards end-of-pipe solutions, mainly aimed at developing high-tech solutions to improve sustainability performance of conventional wastewater systems (Tettenborn, F., personal communication, 2015). These programs have achieved remarkable results but did not really question the underlying wastewater management model. With DEUS 21 the German federal government is promoting radically new urban wastewater systems.

We identified a similar trend in the Dutch context. As part of a shift in the (waste)water management discourse – from "fighting water" to "facilitating water" (Hegger et al., 2008) – an encompassing research project on Decentralized Sanitation and Reuse (DESAR) has been launched with the aim of implementing innovative technologies in real-world contexts. Similarly to DEUS 21 and somehow the Cleantech Playground, DESAR is part of a multi-disciplnary research program funded by the Dutch Programme EET (Economy, Ecology, Technology) – a joint initiative of the Ministries of Economic Affairs, Education, Culture and Sciences and of Housing, Spatial Planning and the Environment (*Ibidem*). The program is aimed at stimulating socio-technical innovations with ecological and economic benefits for society.

Given that one of the critical hurdles to the implementation of RRS pilots is their dependency from funding programs (Tilley, E., personal communication, 2015), the engagement of national governments in such projects creates a favourable alignment between niche and landscape level. With national governments sponsoring broad RRS research programs, we can expect more such projects to be implemented. Moreover, this type of institutional support indicates that the systems tested in RRS niches are considered as promising potential breakthrough in future wastewater management paradigms (Hegger et al., 2008).

#### *Environmental building certifications and building codes*

The environmental impact of the built environment has attracted increased attention over the last 10 years (Frischknecht et al., 2015). Buildings are important resource consumers, accounting for 30-40% of energy use and 30% of $CO_2$ emissions worldwide (UNEP, 2007; WBCSD, 2007). This spotlight has fostered the development of a series of tools for evaluating buildings' environmental performances and for designing solutions aimed at reducing resource consumption over their life cycle. Among these instruments the Leadership in Energy and Environmental Design (LEED) developed in 1998 by the U.S Green Building Council (USGBC, 2013) is one of the most internationally widespread third-party rating systems. Similar systems have also been developed in Europe (e.g. BREEAM, UK; DGNB, Germany; and HQE, France). LEED is a credit-based system; depending on their performance in several categories – including water efficiency – buildings are granted a certificate (ranging from platinum to base). The system incentivizes water use reduction by assigning extra credits for the installation of water-saving appliances, equipment and processes. These also include composting and vacuum toilets, waterless urinals (USGBC, 2013: 270). Moreover, the standard lays down prerequisites concerning maximum installed flush and flow rates of toilets (*Ibidem:* p. 272). These measures can be implemented in new as well as in existing buildings.

Building rating systems are voluntary, yet an increasing number of local regulatory bodies are embracing their requirements - *labels such as LEED are becoming quasi-compulsory in some jurisdictions* (Fuerst & McAllister, 2011). Additionally, there is growing evidence of direct correlation between labels and market value (Eichhotz et al., 2013): LEED-certified buildings obtain rental and sale premia of 5-9% (*Ibidem*). The Inclusion of water efficiency measures in such schemes is an incentive for investors to employ water-saving technologies, thus it indirectly supports the growth of the RRS niche into mainstream applications.

### *Demographic changes in Germany*[42]

Demographic changes are pressures that are not targeted at any specific regime, but which can bring about selection pressures on regimes (Smith et al., 2005: 1494).

The German Federal Statistical Office estimated that the current population of 82 million inhabitants will decrease to about 65-70 million in 2060 (Destatis, 2015). In particular Eastern Germany is experiencing a combination of decreasing birth rates and high migration outflows causing reduction in population among the highest in Europe - on average population fell by more than 8.0 per thousand inhabitants per year over the period 2008-2012 (Eurostat, 2014). Decrease in the users of wastewater infrastructure is a serious problem causing higher maintenance and operation costs (Hollaender, 2014; Tettenborn, F.; Van der Hoek, J.P., personal communication, 2015). With infrastructure ageing and population decreasing maintaining conventional systems in operation is very expensive; firstly, new capital investments are spread within smaller number of inhabitants, secondly since the network is over dimensioned for the number of people served, operators have to artificially pump water through the pipes to keep the required level of flows and prevent stagnation of raw sewage. Considering such issues, semi-decentralized systems may become more attractive to future urban planners compared to large-scale infrastructures.

## 4.3.5 Economic and geopolitical factors

### *Artificial fertilizers market trends*

The dynamics of the global fertilizers market indirectly influence the competitiveness of recycled nutrients. Conventional processes to obtain P and N – the two key macro-nutrients required in agriculture – are energy intensive. In the past increasing energy prices have led to a continuous increase in fertilizers prices, threatening the livelihoods of farmers in poorer countries who could no longer purchase those vital agricultural inputs (Winker et al., 2009). After reaching a price peak in 2008, fertilizer prices are now steadily decreasing (-11.5% in 2014) reflecting, inter alia, a reduction in US natural gas prices (FAO, 2014; World Bank, 2014). This

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[42] The trend described in this section does not apply to the Netherlands were the year 2014 has experienced rising population growth rates (CBS, 2015) and internal migratory flows are less prominent compared to the extreme case of Germany.

macroeconomic contingency creates an unfavourable environment for wastewater products, which have to compete with cheap conventional fertilizers. Nevertheless, there are a series of factors that may alter current trends and open up opportunities for recycled nutrients in the future.

1. **Increase in total fertilizers consumption**. As shown in fig. 4.18, world's consumption of fertilizers is estimated to grow at constant pace – especially reflecting an increase in Africa and Asia (FAO, 2015). Higher demand may drive fertilizers' producers to explore alternative sources for securing supply – including wastewater products. With higher investment, production processes become more efficient and economic competitiveness of recycled fertilizers is enhanced.

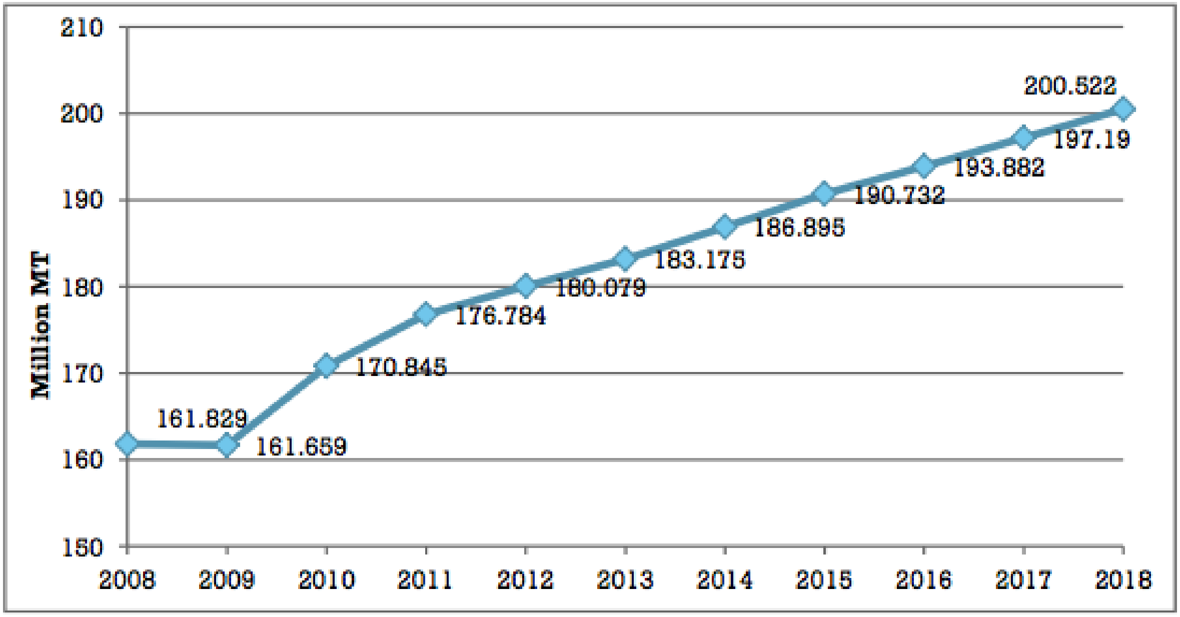

*Figure 4.19 – Estimated growth in fertilizers consumption worldwide (FAO, 2015)*

2. **EU-wide initiatives to respond to geopolitical uncertainties**. Phosphorus is mined from phosphate rock unevenly distributed around the world. The three top producers are China, the US and Morocco which make up together 68% of the total 210 million tons produced worldwide (Grontmij, 2014; US Geological Survey, 2012). The main estimated reserves of fossil phosphate are in geopolitically unstable areas – Morocco and Western Sahara, China, Algeria, Syria, Jordan, South Africa (*Ibidem*). Given that phosphate is an essential input for agriculture that has no substitutes, European countries are looking at ways to reduce dependency on imports. This effort is aimed at encouraging development of P recovery systems in order to be able to cope with potential future shortages dictated by political developments. Within this framework several steps have been taken at European level to stimulate sustainable management of P. Two emblematic initiatives are the institution of the *European Sustainable Phosphorus Platform* (phosphorusplatform.eu, 2015) and the discussion on the inclusion of alternative fertilizers in the new proposal of the EU fertilizers directive (Smit, H., personal communication, 2014). Moreover, a respondent from Metabolic mentioned the

likelihood of new EU legal obligations being developed setting minimum P recovery threshold for WWTPs (Van Odijk, S., personal communication, 2015). These mechanisms provide institutional support to RRS and can stimulate their upscale in the long term.

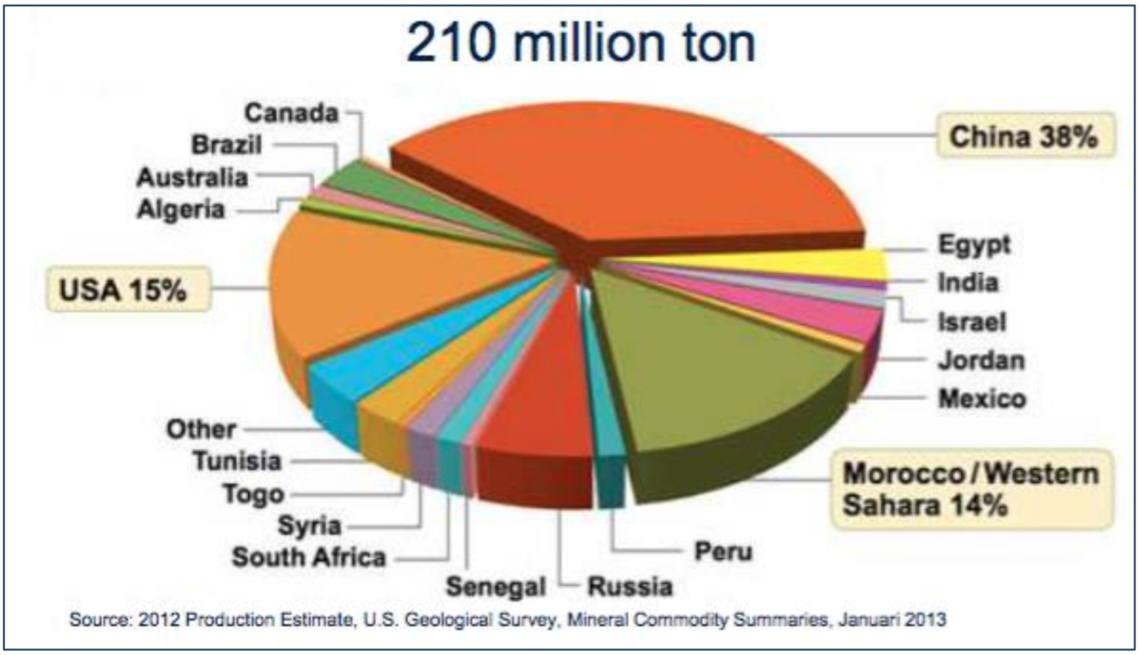

*Figure 4.20 Breakdown of global Phosphate production (Grontmij, 2014)*

3. **The occurrence of a phosphorus peak**. This topic is highly controversial. The literature suggests that finite P reserves are decreasing at fast pace and that easily and cheaply mined phosphorus will have to be replaced with more expensive and environmentally hazardous methods (e.g. sea mining) (Cordell et al., 2009). Similarly, Van Vuuren et al., (2010) calculated that by 2100 40-60% of the world's P resource base would be extracted. Other estimates point at a peak P around the year 2030 and depletion of resources within the next 75-100 years (Fraunhofer ISI, 2012). In this scenario, artificial fertilizers become progressively more expensive – opening market opportunities for wastewater recycled products. Other experts are more cautious regarding the likelihood of such developments; one respondent from Eawag affirms that potential P shortages are not so pressing. The price of artificial fertilizers will increase but not as much as to reduce its economic competitiveness. The economic gap between P recovery systems and conventional production processes is still too wide and the price increase that is likely to take place due to slow diminishing reserves is not enough to cover it (Tilley, E., personal communication, 2015). In any case, both scenarios feature *an increase* in price of artificial fertilizers in the future – which opens up opportunities for generating a market for recovered nutrients.

4. **Increase in energy and material costs.** Similarly to what has been discussed in the previous section, there are predictions concerning a future increase in fossil fuel prices (Akbari & Habib, 2014; Lipson, 2011). This phenomenon is caused by geological reasons – fossil fuels extraction is becoming more expensive because easily accessible reserves

have been depleted (Bardi, 2014) – but also political factors. Stricter environmental regulations on non-renewable resources (e.g. emission caps and permits, carbon tax) increase the cost of mining, processing and shipping of minerals (Cordell et al., 2008). Secure and cheap access to fossil fuels is a key production factor for artificial fertilizers – if it goes missing, it might become profitable to resort to alternative nutrient sources.

# Chapter 5: Conclusions and Discussion

## 5.1 Conclusions

This research has investigated transition pathways in the field of wastewater management with the goal of contributing to foster the adoption of sustainable socio-technical innovations developed within niches into more mainstream settings. By conducting an in depth-analysis of two case studies based on a an analytical framework employing the Multi-level Perspective (MLP) and Strategic Niche Management (SNM) as theoretical underpinning, and semi-structured interviews, desk research and site visits as data collection methods, we have been able to answer the following research question:

*What are the main factors influencing the success of two leading niche experiments in resource recovery sanitation systems (RRSS) in Germany and the Netherlands, what are promising pathways for further up-scaling of these niche experiments, and to what extent do these experiments have the potential to contribute to the sustainable transition of the current sanitation system?*

The two case studies we have analysed have different configurations and goals, yet their functions are alike: demonstrating that alternative wastewater management models are achievable. De Ceuvel is a showcase for closing urban flows circularity towards self-sufficiency, DEUS 21 a learning ground for improving the performance of a set of promising advanced technologies. The former employs DYI low-tech solutions that are progressively upgraded while the latter brings into real world a high-tech flexible system whose technical modules can be applied to different contexts.

Based on the hypotheses of SNM (see p. 37), the analysis of the niche dimension of De Ceuvel shows positive elements suggesting that sound niche formation processes are taking place. The project is based on a long-term *vision* that steers the development of the site without constraining future adaptation and flexibility. De Ceuvel's image is powerful and legitimated by a broad and diverse *actor network* able to mobilize resources in the form of expertise and funds. Sound *learning experiences* are taking place in multiple domains, which have improved the performance of the system as a whole. Additional elements contributing to De Ceuvel's success where the early involvement of the community, which created a sense of ownership of the technology, and the role of Metabolic as visionary guide and central node in the actor network. The niche processes are not yet fully developed for the reuse phase, where we have noticed that expectations are not based on project experiences but rather estimates and forecasts. The vision for reuse opportunities is solid but not sufficient to achieve the stated goals; resource reuse is lagging behind for technical and institutional reasons and therefore learning processes are still limited and fragmented.

Concerning DEUS 21, Professors Troesch and Hiessl developed a project *vision* that succeeded in drawing attention and vital resources of powerful actors on decentralized infrastructure provision. Nevertheless, the project suffered from the lack of a long-term vision – when the funding program ceased, so did the on-site wastewater treatment. *Expectations* proved too high for several aspects, indicating that they were not based on previous experiments. Even though this created bottlenecks that affected the project's overall performance – such as the impossibility of reusing rainwater as service water – it is justifiable given the ground-breaking character of the system installed. Better communication with stakeholders, and in particular the community, on the experimental nature of the project would have led to more accurate expectations. *Learning processes* encompassed several dimensions but sharing of lessons learned took place to a limited extent. In order to improve information flow mechanisms it could be beneficial to establish formal reporting mechanisms on the project status – this would enhance other stakeholders' learning. As for De Ceuvel, niche processes for the resource recovery phase show more positive elements compared to reuse phase.

A success factor for both projects (comprehensive list of factor on p. 50) was to have stakeholder champions – facilitators who provide motivational traction and visionary guidance as well as everyday troubleshooting. Metabolic and Fraunhofer IGB are approachable and knowledgeable central network nodes and resource catalysts. The role of the community is more prominent in De Ceuvel, where houseboat renters have been defined as driving engine of the project. DEUS 21's driving engine, instead, is the leading edge research institute Fraunhofer – which explains the milder participation of Knittlingen's community to the research project. As a matter of fact, the timing of community's involvement proved an important factor; DEUS 21 suffered from late engagement with citizens – as the project team pointed out, more users would have installed vacuum systems if they had been informed earlier. Community cohesion can be enhanced through educational activities, as demonstrated by De Ceuvel's experience. In DEUS 21 educational efforts did not reach out enough to the community. Actor-network formation followed a different approach: DEUS 21 has defined a robust network before the start of the project, while De Ceuvel has established three leading partners that were necessary to launch the project and then has left it open to other partners to involve during the implementation. As a result De Ceuvel's network is expanding – new partners are continuously involved – while DEUS 21 has a more stable social network at least concerning actors directly involved in the project. The institutional support of DEUS 21 is more evident since the project's main sponsor is the national government. De Ceuvel benefits from indirect institutional support provided by the participation of Waternet and the approval of Amsterdam's municipality – active in the redevelopment of Buiksloterham area. Involving water utilities proved to be a key success factor. At De Ceuvel the cooperation between Waternet and Metabolic created synergies from which both actors and the project greatly benefitted. The former has long-term expertise, infrastructure and equipment; the latter has direct connection with the community. In Knittlingen there is no water utility – a consortium of different municipalities is in charge for (waste)water services and shares one WWTP. Nevertheless, one of our respondents from Fraunhofer IGB clearly explained that if there had been a water utility that did not want to engage in the project, the town of Knittlingen would not have been chosen (Mohr, M., personal communication, 2015). Water utilities are important for negotiating applicable rules and regulations that ensure safety but allow experimentation and they provide assistance in operation of the system and research activities.

### Growing global network supporting sustainable wastewater management

Our research indicates that in Germany and The Netherlands there is growing recognition among different segments of society about the unsustainability of conventional wastewater systems. Interviews suggest that a global RRS niche is developing from the different local-scale projects. Contrary to what was happening in the 1990s – when experiments with RRSS where isolated experiences involving almost exclusively technical research institutes (e.g. Wageningen University & Research Centre) – it appears that the network of people interested and involved in sustainable sanitation is expanding across different stakeholder groups. This is an important step for encouraging higher institutionalisation and wider implementation of sustainable sanitation systems.

1. Governmental actors

Participating to RRS projects has become appealing for governmental actors. Our analysis has shown that local governments are active partners in DEUS 21 and De Ceuvel and other municipalities are engaging in sustainable wastewater management initiatives (e.g. Wageningen municipality). Sponsoring a cutting edge research project brings visibility to the town and a positive image. The commitment of the German government for the DEUS 21 project is another positive signal for the upscale of RRS experiences. As we will discuss in the *landscape influences* section, the European Union is also to supporting sustainable wastewater management initiatives.

1. Wastewater utility companies

Wastewater utility companies are key regime actors. Our theoretical approach would expect them to be unsympathetic actors with vested interest in the maintenance of conventional wastewater systems. Our respondents from Waternet and Hamburg Wasser, instead, demonstrated a different attitude towards innovation. Most importantly, they are both engaging in experimental projects with RRS. The former is a leading figure in the *Circular Buiksloterham* redevelopment project, which aims at achieving material flows circularity in urban settings, the latter is the initiator of the *closed-loop wastewater management* project in the settlement of Jenfelder Au, which is expected to cater to 600 households (2,000 residents) (Skambraks, 2015). The participation of these regime actors indicates that niche concepts are starting to gain traction in mainstream applications. From our analysis it appears that innovative (waste)water utility companies are involving in RRS pilots as part of a strategic process to ensure their long-term ability to secure high-quality service provision. They seem open to (partial) renegotiation of their role and responsibilities towards an infrastructural model that also admits semi-decentralised systems.

2. (Waste)water professionals

Expert panels dedicated to RRS are increasingly taking place, where a growing number of (waste)water professionals is sharing experiences and ideas. This process brings credibility to the RRS niche, as concepts are progressively better articulated and supported by more actors.

Moreover, it facilitates performance improvements as lessons learned are shared across countries and provide experience-based guidelines for future projects. An example of such international gatherings is the IWA (International Water Association) Helsingborg seminar held in April 2015. The seminar on source separating waste systems brought together, among others, DEUS 21 stakeholders and the Sneek project team – a Dutch pilot project that is in contact with De Ceuvel. Therefore indirect ties have been established between the two apparently distant projects DEUS 21 and De Ceuvel.

3. Other sectors and community

Other sectors are also starting to look at the developments in the RRS niche. We refer for instance to the interest raised on nutrient and water recycling in the horticultural sector. Horticulture uses great amounts of nutrients, a big share of which is not uptaken from the plants. Researchers are trying to develop systems to recycle phosphates from drainage water borrowing lessons from sanitation research (Kujawa, K., personal communication, 2015).

Our analysis showed that citizens were eager to take part to DEUS 21 and De Ceuvel. While in the past the main users of innovative wastewater systems were small groups of conscious citizens, it seems that these ideas are reaching out to broader communities. Although we cannot generalize our findings, it seems that there is a general prejudice concerning behavioural inertia of end users who are instead motivated to engage in more sustainable lifestyles.

## *The scope for a sustainable transition of wastewater management and the role of RRSS*

Resource recovery sanitation pilots are crucial means of knowledge gathering – they are playing an important role in the optimization of technical and social aspects of sustainable sanitation systems. Without such local-scale experiences the evolution of the wastewater sector towards a more sustainable state would not have gained momentum. We are entering a new phase of sustainable sanitation; Sneek, (Netherlands), Ghent (Belgium) and Hamburg (Germany) are hosting second-generation projects – improved, larger scale implementations of first pilots. However, a complete transition of conventional sanitation is not likely to take place in countries like The Netherlands and Germany. A compelling need for changing our wastewater system is not perceived; the drivers that would stimulate a more pervasive transformation – water and nutrient scarcity – are not there. Yet there are elements of these new systems that are finding their way into our regime. That is because they offer alternatives to one of the most pressing shortcomings of the conventional approach to wastewater management: *inflexibility*.

Dutch and German societies, along with others employing the same sanitation paradigm, are realising that current wastewater systems are not resilient – they are not equipped to cope with future challenges and may not be able to secure high quality service provision in the long term. Inflexible infrastructure and inflexible operating models immobilize huge sums of public money and close the way to any future possibilities of modification. This is what opens the way to embedding RRS pilots experiences into conventional systems. In fact what is most likely to occur is that future wastewater systems in Germany and The Netherlands (and countries with similar wastewater models) will integrate conventional infrastructure and clusters of (semi-) decentralized RRSS. Alternative forms of sanitation are progressively gaining legitimacy also in contexts with well-established conventional sanitation regimes and there are already specific situations in which RRSS represent and economically competitive alternative (e.g. new estate developments where wastewater infrastructure is not yet present; places where ageing infrastructure requires high investment costs to be kept in operation). The upscale of RRSS innovations into mainstream settings will nonetheless require 20, 30 or more years to take place and encounter more challenges than similar transitions in other domains (e.g. energy sector); resistance to change in institutional practices (e.g. out-dated legal provisions, absence of bold stimulating mechanisms from governmental bodies) hampers the translation of project experiences into broader and wider applications. Linking up RRS and broader sustainable urban development initiatives would provide an important stimulus for the evolution of the RRS niche. A growing number of cities are developing innovative programs to decrease their footprint and increase liveability[43]. Showcase projects like De Ceuvel and DEUS 21 are source of inspiration for designing alternative wastewater management solutions in the framework of such programs. A sustainable sanitation system does not attract investors or renters per se. But a district that offers *a series* of sustainable services in energy, mobility and water, does. Such districts are becoming appealing for an ever-larger category of citizens and represent an important evolutionary path for RRSS to transcend the niche of green-alternative consumers and pilot project settings to reach wider implementation.

In conclusion, our research highlighted that, albeit promising, the process of upscaling the RRS niche is currently in a very early stage, with RRSS projects still representing a small fraction of wastewater management solutions. Additionally, we want to stress that despite growing interest in sustainable wastewater management systems, reuse aspects are lagging behind. Reuse of sanitation products is currently influenced by a combination of unfavourable niche, regime and landscape factors. It is important to tackle such barriers because recovering without reusing is not enough to achieve full circularity of waste flows and *really* reduce our pressure on natural resources.

## 5.2 Discussion of the empirical findings

### *Diversity and context-specificity: key principles of sustainable wastewater management*

The debate on alternative wastewater paradigms is dominated by dichotomies – social vs. technical, centralized vs. decentralized, and economic viability vs. dependency on external funds. Our research has highlighted that a black-and-white dialectic does not belong to new wastewater systems; *diversity* and *context-specificity* are, instead, the concepts underpinning the approach to sustainable wastewater management.

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[43] On the concept of *Smart Cities* see for instance Hajer & Dassen 2014.

Conventional sanitation is a *socio-technical system* that is faced with complex *socio-technical challenges* the solution to which necessarily encompasses *socio-technical aspects* – it is impossible to disentangle these two aspects. Developing sustainable technologies and nurturing the social movement behind these innovations are equally fundamental. We see how this concept is not entirely captured in De Ceuvel and DEUS 21. Both projects have privileged one of these components (social innovations at De Ceuvel, technical innovations in Knittlingen) while neglecting the other. This is certainly justifiable because De Ceuvel was lacking funds to invest in advanced technologies while DEUS 21 is a top-down project where the target community has been identified once the project vision had been developed. Nevertheless, it led to issues during the implementation phase. Future RRSS would benefit from a more pronounced *socio-technical approach.*

A clear definition of centralized and decentralized has not been developed; in fact, assessing what is the optimal scale of wastewater systems is extremely challenging at the moment (Tettenborn, F., personal communication, 2015). There are attempts to calculate what scale would yield the highest economic benefits but they are highly uncertain given the difficulty of predicting future costs of water, energy and material (Kujawa, K., personal communication, 2015). Economic viability is a complex issue as it is inextricably linked with local conditions. Drawing general conclusions on the economic performance of RRSS is also complicated as each system is unique in its kind. Our research indicates that economic sustainability is easier reached with low-tech systems that have low investment, maintenance and operation costs. For high-tech systems the (small) scale affects economic efficiency since the costs are distributed among a small number of end users. Hence they depend on external funding. If technologies were to be implemented at larger scale, they would become more profitable. To date there are some particular cases in which RRSS or some of their components are economically advantageous compared to conventional systems – mainly given their lower capital investments in the infrastructure. However, in normal urban contexts served by (waste)water infrastructure, RRSS are less convenient. Unfortunately, this is the most common situation in The Netherlands and Germany.

Ideally, RRSS are designed in such a way to separate all the different wastewater streams at the source, treating them specifically as to recover a variety of resources and then reuse those resources. Sanitation thus becomes a *producing* system – instead of a *disposing* one – that reduces energy consumption and pressure on natural resources. Full circularity of all wastewater flows, however, is difficult to achieve in some contexts where it is economically or technically prohibitive. Moreover, every location has specific needs and availability of resources. This means that standard systems are not desirable solutions – even if they maximize sustainability. Resource recovery sanitation is instead a mixture of solutions specifically designed to achieve the objectives of a particular location. A flexible approach enhances the opportunities for RRSS to be implemented in different contexts and reaching wider diffusion. This is evident in the analysed case studies with regard to drinking water production. Our interviews revealed that even though upgrading of rainwater (DEUS 21 and De Ceuvel) and greywater (De Ceuvel) to drinking water quality is an important component of sustainable wastewater management, the high costs it imposes are not justified in water-rich locations. Even if this step is not (yet) performed, however, it does not imply that the systems are not sustainable. On the contrary, achieving full environmental sustainability at the expenses of financial sustainability decreases the chances of vertical upscaling. It being understood that RRS pilots have to set ambitious goals, they should not be perfect idealistic solutions regardless of the context. In many cases complete resource separation is not feasible, biogas production not necessary, nutrient recovery too energy intense; including these components could result in project failure. De Ceuvel and DEUS 21 are different in each aspect – technological, social and institutional – yet they are both inspiring examples of sustainable wastewater systems.

## *The fundamental role of water utility companies in the RRS niche*

Treating greywater at a decentralized level is an unusual activity in urban settings and the task is performed by water utilities. The participation of water utilities to RRS projects opens a debate about the role of these companies in the development of alternative wastewater management solutions. Water utilities provide fundamental societal services – safe drinking water, disposal of wastewater and management of stormwater to prevent flooding. Our interviews revealed that even in the context of a changing wastewater sector, water utilities still are and will be the most suitable entities to secure the provision of such services in the future with the level of quality that safeguards human health (Mohr, M.; Schoenefeld, W.; Van Odijk, S., personal communication, 2015). In small-scale settings other entities – Metabolic and Fraunhofer Institute in cooperation with Knittlingen's Watermaster – can take over utilities' role because risks are limited. Large-scale RRS projects require water utilities as main operators of systems. Hence the wastewater sector cannot evolve towards sustainability without the engagement of utilities. On the other hand, utilities have an interest in participating to RRS projects; conventional systems are in fact not suitable to cope with arising challenges such as climate change (water scarcity and/or increased intensity and frequency of precipitations), water pollution caused by nutrient oversupply and micro-pollutants, prohibitive economic burdens imposed by inflexible infrastructure. It is in utilities interest and capabilities to explore what systems are optimal solutions for providing high quality services in the future. As Waternet's strategic advisor Dr. Van der Hoek points out, this may require adaptation of regulations and economic schemes as well as utilities management models (Van der Hoek, J.P., personal communication, 2015). The implementation of new wastewater systems leads to new situations in which, for instance, citizens take on part of the utility's tasks or in which water utilities become also energy producers. These situations demand for adjustments in the way relationships between water utilities, citizens and other public services providers are regulated.

## *Developing better wastewater systems for the rest of the world*

At the beginning of this research I thought that the prospect of recycling wastewater products and reusing them was one of the main drivers for installing such new. However this has proven wrong. It is not the prospect of creating business models with the products that drives implementation of RRSS – not yet at least. The reuse market is still in its infancy and the scarcity of resources that would motivate recycling is not so evident in Germany and The Netherlands. Beside the need to provide alternatives for inflexibility of wastewater models, what drives these experiments is the will to develop solutions that can be exported to other countries. There are numerous countries currently experiencing water stress, lack of nutrient availability, economic pressures and inadequate sanitation. They would benefit – and in fact are already benefitting[44] – from wastewater systems that enable sustainable use of resources and offer reuse possibilities. Resource recovery sanitation is a means of expanding sanitation coverage and wastewater treatment without putting excessive pressure on scarce natural and economic resources. However new wastewater systems still require a great deal of optimization, that is only possible through the implementation of RRS pilot projects. Europe has expertise and resources for stimulating leapfrogging mechanisms in those countries – as long as it keeps investing in RRS pilot projects where innovative technologies are tested. Therefore it is important to sustain research efforts of systems that enable sustainable use of resources where these are scarce, even if they are currently not economically viable in European contexts.

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[44] For example in Windhoek, the capital city of Namibia, where ground- and surface water are insufficient, 30% of drinking water is produced from wastewater. Treating wastewater up to drinking water is in fact more convenient than filtrate and transport desalinated sea water from the coast (Van der Hoek., J.P., personal communication, 2015).

## 5.3 Critical reflection on the analytical framework

The theories underpinning the analytical framework of this research – MLP and SNM – are relevant contributions to the systematization of knowledge on system innovation processes towards sustainability (Smith et al., 2010). Nevertheless, there are a number of analytical and practical challenges that the use of such theories has posed.

### *Over-simplistic description of real-world transition processes*

This research has highlighted that the theoretical model developed by the MLP and incorporated in SNM to explain transition processes suffers from over-simplification of reality (Lovell, 2007). The theoretical construction of the three conceptual levels appears to be distant from real-world transition processes, where boundaries are blurred and interactions far more complex. In particular the theory dedicates little attention to the interaction of niches with *multiple* regimes (Van Eijk & Romijn, 2008) and to the occurrence of feedback loops emanating from niches and regimes towards landscapes (i.e. reverse causality). The theory fails to explain in depth how changes at the landscape level occur but nonetheless assigns to those very changes the critical role of opening up windows of opportunities for niches as well as exerting de-stabilizing (stabilizing) pressure on regimes (a.o. Van Bree et al., 2010). With such an understanding it appears to us that niches become mere receivers of exogenous inputs that determine their future upscaling pathways – a contradiction to the theory's departure point of considering transitions as niche-induced processes. The empirical analysis conducted during this research has shown that there are certain landscape developments (such as the institution of nationally funded research programs and the establishment of EU legal threshold for nutrient recovery) that are not completely exogenous but responses to influences generated within the RRS niche. Even though these mechanisms need to be studied further, we cautiously conclude that if niche actors develop channels to bring their ideas to broader institutional contexts, they might have chances to influence future developments at the macro level. Hence, we suggest as an interesting point for future research agenda to refine the conceptual description of inter-level interaction integrating pull factors of change at landscape level with push factors operating at niche level.

### *Difficult operationalization of conceptual levels*

This research has encountered difficulties in operationalizing the concepts of regime and landscape given their ambiguous definition. The concept of regime has been originally defined[45] (Rip & Kemp, 1998) in *material* terms as actors, artefacts and practices practices developing and

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[45] A technological regime is 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" (Rip & Kemp, 1998: 340).

reproducing specific rule sets (Markard & Truffer, 2008). Later Geels[46] (2004) frames regimes in *institutional* terms, identifying them as the complex of cognitive, normative and regulative/formal rules. Similarly, elements belonging to landscapes have not been punctually defined – this category becoming a kind of "garbage can" (Geels, 2011) including residual contextual factors. With regimes and landscapes lacking unequivocal definition and not reflecting spatial scales (Smith et al., 2010) their boundaries overlap and render the empirical identification and study of factors influencing transitions pathways challenging.

### *Insufficient explanation of niche upscaling mechanisms*

Strategic Niche Management posits that there are three internal niche formation processes that influence their chances of success – the articulation of common expectations and visions, the building of an inclusive and robust social networks and the occurrence of broad learning mechanisms (Elzen et al., 1996; Kemp et al., 1998; Schot & Geels, 2008). Connected to these processes is a set of hypotheses that define their quality; high quality of such processes leads to the formation of a high quality niche (*Ibidem*). The theory, however, does not sufficiently address the correlation between high quality niches and their potential to trigger regime changes. The mechanisms by which niche innovations transcend the initial protective space are overlooked (Caniels & Romijn, 2008; Coenen et al., 2010; Smith et al., 2010), and the question how niches (can) exert transformative influence on regimes and landscape remains unanswered. Therefore, SNM provides limited insights on the processes by which future upscaling pathways of niche experiments take place. The static character of SNM, caused by the theory's focus on endogenous processes while neglecting their interaction with other levels (i.e. niche breakthrough) conflicts with its aim of explaining systemic transitions – which are, by definition, dynamic processes[47]. The theory could benefit from insights from institutional entrepreneurship literature (Battilana et al., 2009; Greenwood & Suddaby, 2006; Mair & Marti, 2006). This research strand studies the way groups of actors (so called institutional entrepreneurs) seek to change institutional arrangements to serve an interest they highly value (DiMaggio, 1988; Dorada, 2005; Hermans et al, 2013), which, applied to SNM, would be the widespread application of niche-based socio-technical innovations (Lounsbury and Crumley, 2007).

### *Questionable appropriateness as ex-ante policy tool*

In connection to the previous point, we noted that SNM provides few insights on how to steer towards niche-fuelled systemic changes. The theory claims to be an appropriate tool to foster the creation of thriving niches, offering insights on how to break locked-in technological trajectories (Kemp et al., 1998; Nill and Kemp, 2009). Nevertheless its descriptive approach is

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[46] I understand *regimes* as semi-coherent sets of rules, which are linked together. It is difficult to change one rule, without altering others. The alignment between rules gives a regime stability, and 'strength' to coordinate activities (Geels, 2004: 904).

[47] As Caniels and Romijn (2006) put it: *The main preoccupation of the SNM researchers has clearly been on the initiation and management of niche creation. Little attention has been given to the stages where a clear technological niche has been developed, and the main task is shifting to the creation of a viable market niche* [i.e. upscaling] (p. 14).

more useful for ex-post analysis (Caniels & Romijn, 2006); indications on how to manage niches to foster their upscale are methodologically weak. Indeed, the proposed governance activities to enhance niche upscale derive from a series of individual empirical case studies, affecting their applicability to different contexts. We were unable to find thorough analyses on strategies and instruments to foster upscale of niche innovations; the policy measures provided are not accompanied with in depth studies of their potential impacts – as appropriately pointed out by Smith and Raven (2012), for instance, protective mechanisms incur in the risk of being seized by actors that are not interested in niche development but rather withhold the benefits provided by them. The general lack of systematic guidelines affects the appropriateness of SNM as ex-ante policy tool for supporting the translation of niche ideas and practices into mainstream settings and thus accelerating transitions (*Ibidem;* Hoogma et al., 2002).

### *Weak methodological structure*

MLP and SNM lack rigorous methodological coherence for conducting empirical studies (Haxeltine et al, 2008; Loorbach, 2007). Notably, the theories do not provide formalised criteria against which to assess niche processes (SNM) nor a set of hypotheses concerning regime and landscape factors influencing transition processes (MLP). Concerning the first point, the hypotheses developed for the three endogenous processes leading to successful niche formation have proven incomplete or too superficial to identify meaningful success factors in real-world experiments. If we consider for instance the *building of social networks,* the theory takes into account extension and depth of ties but leaves out timing. Nevertheless, the temporal dimension of stakeholders' involvement has proven a critical factor for the success of the analysed case studies[48]. Another element that is not addressed by the theory is the importance of entities within the social network acting as main interfaces for information flows between the various actors (what we have called "central nodes") – again critical factor in our case studies. The consistency of empirical analyses would improve if more precise criteria – derived from the systematization of the empirical knowledge gathered thus far – were developed. This also applies to the second point we have raised i.e. the lack of a set of hypotheses. Researchers applying the MLP necessarily resort to explorative research since the perspective does not provide precise indications on *what* are the regime and landscape factors influencing the scope of a sustainable transition and *how* they influence it. The three-tiered analysis results less methodologically coherent and more subjective – how to decide what factors to study and what to disregard for each level of analysis? How to justify such choices theoretically? In agreement with Smith et al. (2010) and Haxeltine et al. (2008) we conclude that a necessary step for improving coherence and quality of future empirical studies is to formalising the MLP into more detailed methods.

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[48] We refer to the fact that De Ceuvel benefitted from early involvement of the community while the lack of it in DEUS 21 led to significant issues during implementation (see Chapter 4 – niche analysis).

## 5.4 Policy recommendations

The first part of this section provides recommendations for fostering the upscale of the RRS niche. Since the research has highlighted that resource reuse in particular is encountering resistance at all levels, the second part focuses on possible interventions for enabling reuse activities.

### 5.4.1 Measures for stimulating upscale of resource recovery sanitation projects[49]

1. **Introduce flexible regulatory schemes allowing de-centralized treatment of wastewater.** Current legislation is modelled on centralized large-scale wastewater treatment. National legislative frameworks should be revised as to ensure that public health and the environment are not at risk and that wastewater treatment complies with EU standards but that provisions are adequate for small-scale systems (e.g. they do not pose prohibitive costs in terms of sampling procedures).

2. **Redesign roles and responsibilities of actors along the sanitation chain.** Actors involved in wastewater services (e.g. municipalities, local utilities, water authorities, technology developers, end users) should renegotiate organizational structures and management models that are more suitable to cope with new situations arising from the implementation of resource recovery sanitation systems, ensuring that:

    a. These new schemes are applicable for all the steps of the sanitation chain (construction, collection, treatment, recovery/disposal, reuse);
    b. Formal and informal rules regulating actors' relationships are amended as to allow for these new schemes to be enforced.

3. **Include mandatory requirements for water efficiency in building regulations and incentivize water savings in tax schemes.** On the one hand including mandatory provisions for installing water-efficient technologies fosters infrastructural and technological change. On the other, modifying tax regimes so that water-efficient behaviours are rewarded stimulates behavioural change. The combined action of restrictions and positive incentives acts on the technical as well as the social component of RRS.

4. **Increase governmental support for RRS in the form of research programs and innovation funds.** Resource recovery sanitation projects are highly dependent on external funds. Establishing research programs is critical for improving the performance of promising systems and it enhances their legitimacy. Moreover, it opens up

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[49] These recommendations integrate insights from what SNM suggests as measures for supporting the development of niche innovations (i.e. shielding, nurturing and empowerment - Smith & Raven, 2012) with findings from interviews and desk research.

opportunities for exporting successful technologies to other countries that are facing bigger sanitation challenges. In order to mitigate the risk averse behaviour of public (waste)water utilities, it is also suggested to devote more of their budget to innovation activities so that they can invest in RRSS with less financial constraints.

5. **Embed RRS in sustainable urban development initiatives.** Urban development initiatives targeted at reducing environmental footprint and enhancing liveability are gaining momentum; sustainable neighbourhoods are becoming more attractive for a larger category of citizens. Connecting sustainable wastewater system concepts adapted from RRS pilots with broader innovation in urban energy and mobility fosters upscale of the former.

6. **Promote awareness raising campaigns and educational activities.** This research indicated that there is a growing network of frontrunners supporting the RRS niche. However, there is still a knowledge gap between "insiders" and broader society concerning the negative impacts of conventional wastewater paradigms. Information on key issues like water savings, eutrophication and phosphorus peak can stimulate greater involvement of end-users. Not only social acceptance of RRSS would increase, but also citizen demands for achieving more sustainable wastewater management may trigger broader developments in such direction at institutional levels. Establishing knowledge-sharing platforms and networking organizations may further enhance the effectiveness of awareness raising and educational activities. These foster contacts between different categories of stakeholders and enhance cooperation and cross-learning mechanisms.

7. **Conduct further research on strategies to mitigate micro-pollutants discharge and lobby for more stringent EU effluent regulations.** It is of prime importance to advance knowledge on key topics such as the impacts of micro-pollutants on receiving environments and strategies to minimize their discharge. It appears that RRSS are more effective than conventional wastewater treatment plants in treating such pollutants but there are still many uncertainties. The current EU legislative framework is inadequate for dealing with MPs; research can shed light on appropriate concentration thresholds and discharge limitations that can be used as input for future policies.

### 5.4.2 Fostering resource reuse activities

1. **Conduct further research on safety of wastewater-recovered products.** There are relevant uncertainties on the potential risks to human health and the environment arising from reuse of nutrients and water recycled from wastewater. More research is needed to better understand the impacts of contaminants and develop more appropriate legislative frameworks.

2. **Advocate for amending the following EU legislation:**

    a. Fertilizers Regulation 2003/2003 – in order to include organic fertilizing materials and reduce approval procedure for new fertilizers;
    b. Regulation on organic agriculture EEC/2092/91 – in order to allow the use of urine-based fertilizers such as struvite and other wastewater products;
    c. Urban Wastewater Treatment Directive 91/271/EEC – in order to establish minimum nutrient recovery thresholds for wastewater treatment plants.

3. **Enhance marketing and branding strategies of recovered products.** The use of green labels for fertilizers produced with recovered nutrients may represent an entry point for a niche market composed of environmentally conscious consumers. These actors may be willing to purchase recovered nutrients even if they are more expensive than artificial fertilizers.

### *Concluding remarks on economic instruments*

Subsidies are widely used policy instruments to support the diffusion on (technological) innovations (Faber & Hoppe, 2013). These are not included in the recommendations' list because the empirical research did not highlight that such instruments would be beneficial for the upscale of the RRS niche. The long-term drawbacks of subsidy schemes are acknowledged within the scientific community: subsidies increase the burden on taxpayers and they are inefficient when additionality is low (when measures would have been implemented without the subsidy) (*Ibidem*; Hoppe, 2009). At the same time, I asked several interviewees whether they thought subsidies would be an efficient instrument and the responses were not encouraging. Mark Heijmans highlighted that apply subsidy schemes for the production of human waste-based fertilizers would have unfair consequences for farmers and affect market competition (Heijmans, M., personal communication, 2014). On the same note, when asked about subsidizing biogas production from wastewater, Felix Tettenborn (Fraunhofer ISI) pointed out that it would be difficult to justify such subsidy scheme with the greater public and that considering the current small market size of wastewater recovered products, it might prove inefficient (Tettenborn, F., personal communication, 2015).

## 5.5 Limitations of the research

This research has investigated the prospects of the RRS niche in two of the frontrunners in such field. For this reason it is possible that external validity of the findings is reduced, since sustainable sanitation developments in other countries are expected to be at an earlier stage.

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# 7 Appendixes

## 7.1 Flowstreams of sanitation systems

*Table 7.1 Flowstream composition and description (Source: Tilley et al., 2010)*

| Flowstream | Description |
|---|---|
| **Blackwater** | Products: urine, faeces, flushing water, cleaning material or beigewater.<br>Description: lack of grey water in this flowstream may limit the self-cleansing velocity in a sewer network given the reduced liquid content. |
| **Grey water** | Products: grey water.<br>Description: Grey water accounts for 50-80% of the outflow produced at household level, although this very much depends on local conditions. It contains few, if any, pathogens and 90% less nitrogen than blackwater and therefore does not require the same treatment processes as blackwater or mixed wastewater. |
| **Faecal sludge** | Products: faecal sludge.<br>Description: faecal sludge can be mostly biological (e.g. from trickling filters) or mostly raw faecal material (e.g. from pit latrines). We do not distinguish between faecal sludge and biosolids. |
| **Brownwater** | Products: faeces, flushing water, cleaning material and/or beigewater.<br>Description: brownwater results from wet-urine diversion systems. Typically, brownwater is transported through sewers and is treated offsite. It is similar to blackwater, however with the urine removed, the nutrient levels are significantly lower. |
| **Urine flowstream** | Products: urine.<br>Description: urine is collected by a urine-diverting user interface. Separately collected urine from a healthy person does not contain pathogens. However, urine may still be contaminated easily by traces of faeces. |
| **Excreta flowstream** | Products: urine and faeces.<br>Description: the excreta flowstream is collected with a dry user interface, i.e. without flushing water. Given the low liquid content (and therefore, reduced ease of transport), treatment occurs on-site. |
| **Faeces** | Products: faeces.<br>Description: faeces are collected parallel to urine in a urine-diverting user interface. This flowstream resembles the excreta flowstream but is drier (as urine is missing) and is therefore transport limited. Treatment occurs on-site. |
| **Beigewater** | Products: beigewater (anal cleansing water).<br>Description: beigewater, although very dilute, contains a significant amount of faecal material and is therefore pathogenic and should be treated appropriately. |
| **Mixed blackwater and grey water** | Products: urine, faeces, flushing water, and grey water (stormwater may or may not be diverted into the sewer and mixed with this flowstream), and cleaning material or beigewater. |
| **Brownwater mixed with grey water** | Products: faeces, flushing wate, grey water, and cleaning material or beigewater.<br>Description: this flowstream is similar to the blackwater mixed with grey water flowstream except that the urine has been separated out. With the separation of |

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|---|---|
| | urine, brownwater contains lower concentration of nutrient (as nitrogen and phosphorus is mainly contained in the urine). This aspect of low nutrient concentrations is further enhanced by the inclusion of grey water, which further decreases the nutrients concentrations. This flowstream is rare, as it is dependent on water-based urine-diverting toilets, which have not been widely installed. |
| **Excreta mixed with grey water** | Products: urine, faeces, grey water (cleansing material or beigewater).<br>Description: this is a commonly seen flowstream in the developing world, though it is not generally recommended. In dense areas with a scarcity of space, on-site sanitation technologies (e.g. pit latrines) are used for both excreta and household waste water disposal. |

## 7.2 Empirical studies employing MLP and SNM

In absence of theoretical hypotheses from MLP and SNM, the following studies were used to extrapolate a working list of factors influencing niche upscale at regime and landscape level.

| Authors | Title |
|---|---|
| **Farrelly & Brown, 2011** | Rethinking urban water management: Experimentation as a way forward? |
| **Geels & Kemp, 2007** | Dynamics in socio-technical systems: Typology of change processes and contrasting case studies |
| **Geels 2002** | Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. |
| **Geels 2005** | Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850–1930)—a case study in multi-level perspective |
| **Geels 2006** | Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). |
| **Geels 2012** | A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. |
| **Hegger et al., 2007** | Niche management and its contribution to regime change: the case of innovation in sanitation. |
| **Ieromonachou et al., 2004** | Adapting Strategic Niche Management for evaluating radical transport policies––the case of the Durham Road Access Charging Scheme |
| **Konrad et al., 2008** | Multi-regime dynamics in the analysis of sectoral transformation potentials: evidence from German utility sectors |
| **Loorbach, 2007** | Transition management: new mode of governance for sustainable development |
| **Lovell 2005** | The governance of emerging socio-technical systems: the case of low energy housing in the |

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|---|---|
| | UK. |
| **Raven 2007** | Co-evolution of waste and electricity regimes: Multi-regime dynamics in the Netherlands (1969–2003) |
| **Raven et al., 2011** | Translation mechanisms in socio-technical niches: a case study of Dutch river management. |
| **Romijn et al., 2010** | Biomass energy experiments in rural India: Insights from learning-based development approaches and lessons for Strategic Niche Management |
| **Van Bree et al., 2010** | A multi-level perspective on the introduction of hydrogen and battery-electric vehicles. |
| **Van der Laak et al. 2007** | Strategic niche management for biofuels: Analysing past experiments for developing new biofuel policies |
| **Van Eijk & Romijn, 2008;** | Prospects for Jatropha biofuels in Tanzania: an analysis with strategic niche management |
| **Verbong & Geels 2010** | Exploring sustainability transitions in the electricity sector with socio-technical pathways |

## 7.3 Questionnaire used during the semi-structured interviews

### 7.3.1 Section 1: Case studies questionnaire

#### *Part 1: Niche analysis*

#### *Brief description of the project (if applicable)*

- Missing information on number of households served and duration of the project.
- What was the reason to choose Knittlingen and de Ceuvel for this project? What are the special local conditions that made these locations suitable for this niche?

#### *Internal niche processes*

1. Who were/are the main stakeholders[50] and what was/is their role in:
    a. The feasibility/start-up phase
    b. The execution phase
    c. Operation and maintenance phase
    d. Quality monitoring and research phase
2. Do you have regular stakeholder meetings? If yes, are there organizations that facilitate the interactions between the different actors involved in the project?

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[50] E.g. Municipalities, end users/residents, wastewater utility companies, technology developers/research institutes, waterboards, province, ministry (e.g. Rijkswaterstraat)

3. What were your expectations when starting the project and what is its future evolution?
4. What were the main technical and/or social issues you have encountered and how have you responded to them (i.e. lessons learned)? Have you carried out technical or social adjustments to the project since it started?

### Social acceptability

The literature highlights the prominent role of behavioural patterns in influencing innovation processes – novel technologies are often developed as a response to evolving social practices and cultural beliefs and their future success heavily depends on their ability to cater to these new needs.

5. Was the technological design of the installations matching the actual use pattern? What level of behavioural change does the system require?
6. Are there relevant psychological barriers that have hampered the functioning of the project?
7. Does the system create interdependencies (e.g. between households or operators and users) and to what extent are they responsible for the overall success? How are these interdependencies perceived by actors, do they trigger cooperation mechanisms?

## Part 2: Regime analysis

### Services provided by the system

Sustainable sanitation systems are based on the recovery of precious resources from waste streams and thus they provide a wider range of services compared to conventional sanitation, including wastewater purification, energy production, and nutrients recovery.

8. Which resources (i.e. water, energy, nutrients) does your system recover, and are they attractive for either the energy or the agricultural sector (e.g. are they suitable for food production?)
9. What are the main limits to reuse that you have encountered (e.g. legal or psychological barriers; chemical fertilizers availability/affordability)?

### Economic aspects

10. Does the system leads to extra costs compared to conventional sanitation systems?
    a. How are these additional costs distributed?
    b. In your opinion, is this repartition of costs logical/fair? If not, which repartition would you suggest?
11. Does the project have any governmental support?
12. How was the system financed? Is it economically viable in the long-term? If not, what are the main barriers encountered to economic viability and the strategies to overcome them?

13. Does the system benefit from a different (water and sewer) tax regime compared to the rest of the municipality?
    c. If not, do you think reconsidering tax schemes for decentralized sanitation benefits could incentivize further implementation of these systems?

## Water utility companies

1. What is the role of water utility companies that operate large infrastructure in the development of small-scale resource recovery sanitation systems?
2. Do you think it is part of your duties to enable innovations that promote a more efficient use of scarce resources and decrease pressure on non-renewable resources such as mined Phosphorus?
3. In your opinion, what are the main advantages and drawbacks for energy and nutrients recovery at a centralized level?
4. In your opinion, what are the main advantages and drawbacks for energy and nutrients recovery at a decentralized level?
5. The literature suggests that when new technologies are compatible with existing infrastructure – as for the electric car and the road infrastructure – this enhances their likelihood of success on the market because it reduces the costs that producers and users have to bear in order to adopt the new technology.
    a. Do you think that designing resource recovery sanitation systems that can be integrated with existing wastewater infrastructure – some sort of hybrid systems – would foster their wider implementation?

## Part 3: Landscape analysis

## German public policy

6. With increasing electricity prices[51], also considering the *Energiewende*, can biogas produced from sewage locally represent a cheaper alternative to grid-supplied electricity and thus act as incentive for citizens to switch to RRSS?
7. Under the *Energiewende* umbrella, is it possible to envisage economic incentives (e.g. public subsidies) for human waste-to-energy producers on the model of the feed-in tariffs for solar and wind power? In your opinion, would that stimulate the emergence/further expansion of RRSS projects and do you see drawbacks in setting up such incentive schemes?

## Part 4: Brainstorming session

8. In your view, what type of resource recovery sanitation systems hold the greatest potential to accelerate the transition towards sustainability of the sanitation sector and decrease its ecological footprint: newly built small-scale and decentralized systems or already existing, improved, centralized wastewater infrastructures?

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[51] With domestic energy prices +48% compared to EU average.

9. The implementation of decentralized resource recovery sanitation systems might alter well-established relationships between residents, municipalities, water bodies, technology developers, national governments etc., substantially modifying hierarchies, roles and responsibilities. In your view, how should the new relationships look like in terms of investments, tax regime, responsibility, and operation costs[52]?
    a. In particular, considering urban areas for which residents and municipalities have already contributed to the construction and operation of wastewater infrastructure, how can we imagine transitioning towards an alternative sanitation system that produces different/extra costs? How should be these additional costs distributed? What activity would cover this extra expense (e.g. research budget)?

## 7.3.2 Section 2: Experts questionnaire

### Part 1: Niche analysis

### Socio-cultural aspects

The literature highlights the prominent role of behavioural patterns in influencing innovation processes – novel technologies are often developed as a response to evolving social practices and cultural beliefs and their future success heavily depends on their ability to cater to these new needs.

1. In your experience, what management structures facilitate the success of resource recovery sanitation pilots (E.g. top-down or broad participation)?
    a. Does this apply also to Western urban contexts where minimal involvement in the wastewater cycle is currently required and desired?
    b. What are the risks of switching from a centralized and highly planned sanitation system to one that relies on active participation of different actors?
2. What is the role of habits, routines and cultural meanings in preventing/slowing down transitions? Did you experience in your project(s) situations where behavioural inertia or psychological barriers have hampered the development of sustainable sanitation projects and contributed to lock-in situations (lock-in certain technological designs)?

### Part 2: Regime analysis

### Resource reuse

Sustainable sanitation systems are based on the recovery of precious resources from human waste streams and thus they provide a wider range of services compared to conventional sanitation, including wastewater purification, energy production, and nutrients recovery.

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[52] This question is supported by a sketch in which I illustrate the relationships between stakeholders in the current sanitation system with the aim of producing a new “scenario” sketched together with the interviewee of how these relationships would look like if we were to alter the system.

However, the reuse of these value-added recovered products and their interface with the food and nutrient cycle is often problematic due to several socio-technical reasons.

3. Do the recovery of resources and the possibility of triggering innovative sanitation value chains through the products generated by the system represent a driver for implementing alternative sanitation solutions?
    a. If yes, what are the main barriers to reuse of these products?
    b. And if not, what else drives parties to implement alternative sanitation systems?
4. In your opinion, what are the main incentives for technology developers, housing residents to install and operate a resource recovery sanitation system?
5. What is the role of other sectors' actors such as farmers, energy providers or fertilizers companies for the success of resource recovery pilots?
    a. Are there relevant barriers to their involvement, such as concerns over the safety of products for market and consumers?
    b. Are there business models (e.g. B2B agreements, partnerships at early stages of the project) that create mutual benefits and therefore stimulate their cooperation?

### Economic aspects

6. Can economic incentives, tax credits or subsidies influence the development of resource recovery sanitation pilots[53]?
    a. If yes, in your experience, what mechanisms have proven successful to stimulate the set up of pilot projects?
    b. If not, what is the reason and what are the main drawbacks connected to such economic measures?
7. What is the current state of the market for products recovered from human waste streams such as struvite, compost and soil enhancer, black soldier fly larvae etc.?
    a. How can it be stimulated in contexts where there is great availability of energy, water and chemical fertilizers (e.g. Netherlands and Germany)?

## Part 3: Landscape analysis

### Public policy

8. In your experience, which policies are an obstacle for the reuse of recovered resources from sanitation systems and what policies instead are/could be an incentive to their implementation?
    b. I am referring for instance to environmental regulations that establish stricter limits for effluents discharge or lower the application allowance for N-based fertilizers.
9. In your opinion, does the government have to support the construction of legally and economically protected spaces where experiments with wastewater management

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[53] E.g. by increasing market competition, reducing switching costs and/or encourage users.

innovations can take place? This can be achieved for instance by granting the status of "living lab" to some projects and negotiating special legal conditions.

### Macro trends

10. What macro-trends put pressure on conventional sanitation systems and may create a window of opportunity for alternative sanitation systems to diffuse? E.g. Phosphorus peak, increasing fertilizers need in Asia and Africa; increasing energy prices for manufacturing chemical fertilizers; MDGs and Water-related international forums and panels; increased environmental awareness and policies to promote conscious use of limited natural resources?
11. Most of the alternative sanitation projects in Western countries are currently implemented as pilots in new neighbourhoods, how can we expand these pilots from new neighbourhoods to other urban areas? Do you see these pilots as stepping-stones for wider diffusion and eventually transition of the wastewater sectors towards sustainability?

### Part 4: Brainstorming session

12. In your view, what type of resource recovery sanitation systems hold the greatest potential to accelerate the transition towards sustainability of the sanitation sector and decrease its ecological footprint: newly built small-scale and decentralized systems or already existing, improved, centralized wastewater infrastructures?
13. The implementation of decentralized resource recovery sanitation systems may alter well-established relationships between residents, municipalities, water bodies, technology developers, national governments etc., substantially modifying hierarchies, roles and responsibilities. In your view, how should the new relationships look like in terms of investments, tax regime, responsibility, and operation costs[54]?
    d. In particular, considering urban areas for which residents and municipalities have already contributed to the construction and operation of wastewater infrastructure, how can we imagine transitioning towards an alternative sanitation system that produces different/extra costs? How should be these additional costs distributed? What activity would cover this extra expense (e.g. research budget)?

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[54] This question is supported by a sketch in which I illustrate the relationships between stakeholders in the current sanitation system with the aim of producing a new "scenario" sketch together with the interviewee of how these relationships would look like if we were to alter the system.