Transition of Water Infrastructure Systems

K. Maier and J. Londong

Bauhaus-Universität Weimar, Bauhaus-Institute for Infrastructure Solutions, Chair of Urban Water Management and Sanitation, Coudraystr. 7, 99423 Weimar, Germany (E-mail: *k.maier@uni-weimar.de*)

Abstract

Water infrastructure is a costly and long-lasting asset. At the same time changing boundary conditions e.g. climate change and demography, raise a demand for flexibility of water infrastructure. This conflict area can be mitigated by resource-oriented systems. Such systems provide a greater flexibility. Thus they are a valuable approach to face volatile environmental conditions. However, they can only be introduced into already existing settlements in a disruptive manner. Instead, establishing resource-integrated systems into convention end-of-pipe systems requires methods of smart transition and at least a temporary co-existence of both approaches. Such a concept of a transition path ensures the functionality of the water infrastructure over the complete period of the transition. In this article we present three case studies of transition processes and derive common rules for a formal model to frame these processes. In the first case study we have a look at a system change in the related discipline of solid waste management. Thereafter we describe the case of establishing a resource-oriented system within a comprehensive planning process. The third case study presents a detailed step-wise transition path in a rural area. In general, we conclude that a purposeful approach of transition contributes to flexible and there appropriate water infrastructure systems.

Keywords

New Alternative Sanitation Systems, NASS, transition, water infrastructure

INTRODUCTION

Water infrastructure systems (WIS) are more and more frequently facing new challenges. Instable boundary conditions like demographic and climate change make the determination of relevant design parameters such as population count or quantity of rain difficult. Nowadays sewer-bound, centralized systems are the preferred solution when new WIS are built or already existing WIS are modernised. These systems are inflexible due to long depreciation periods and therefore also prevent new resilient solutions to substitute the well-established systems. Additionally the raising awareness of decreasing resource availability claims a paradigm change – from a discharge to a resource-oriented system. New Alternative Sanitation Systems (NASS) present a possible approach to establish a more flexible, resource-oriented system.

Since such fundamental changes on rigid systems will be a long process several intermediate steps and conditions which allow a combination of both systems are necessary. We call this a transition process. The transition to a recycling based solid waste economy in Germany in the 1990s is an example for such a process in another area of technical infrastructure. In this paper we examine which aspects of this process can be applied for WIS. Therefore the approaches in solid waste economy are introduced before we present our own results describing a general method for WIS. Two case studies in Germany illustrate how a transition towards a resource-oriented WIS can be designed.

THE TRANSITION TO A RECYCLING BASED SOLID WASTE ECONOMY IN GERMANY

Over the last decades of the 20th century the problem of growing "mountains of waste", the standard practice of dumping untreated waste in inadequately lined landfills, leading to contamination of soil, surface water and groundwater and to the emission of landfill gas–a contribution to global warming–became more and more obvious. A paradigm shift towards a recycling-based economy that conserves resources and reduces adverse impacts on the environment appeared to be a worthwhile objective.

Legal Measures
Waste management legislation is based on European law, German federal law, regional laws of the federal states and the statutes of the local authority waste management services. The federal system, the subsidiary principle and the variety of involved laws made this shift more difficult. Nevertheless Germany was among the first European countries to introduce policies to limit landfilling in the 1990s. The *Technical Guidelines for the Disposal of Municipal Solid Waste* (TASi) of 1993 should change the waste management situation decisively latest by the year 2005. The guideline stipulated that only waste with less than 5 % of organic content may be disposed in landfills as to prevent biological conversion processes. This requirement presupposes that the residual waste from households and industry is pre-treated, although there are no technical instructions which prescribe the treatment methods to be used. (BMU, 2006 and UN, 2010)

Process and Achievements
The duration of a transition period for a technology shift should be determined in order to ensure acceptable economic conditions. As technical facilities have deprecation periods of about 10 years, 12 years seemed to be adequate. During this time the responsible authorities were permitted to grant exceptions allowing landfilling of untreated waste to continue (BMU 2006). Simultaneously a separate collection of municipal solid waste (MSW) and pre-treatment facilities had to be established. Incineration technologies for waste (including sewage sludge) reducing the misplacement of waste in the ash had to be adapted to the new 5 % rule for the organic content in ashes. Additionally mechanical-biological treatment (MBT) can be used to dispose MSW in an environmentally sound manner. Thus material-stream specific treatment like incineration or mechanical-biological stabilization are two possible options.
A further milestone on the way towards a recycling based economy was the German Closed Substance Cycle and Waste Management Act (*Kreislaufwirtschafts- und Abfallgesetz*, KrW-/AbfG) which became effective in 1996. It prioritized approaches to handle waste in the order Reduce, Reuse, Recycle.
As a result of the new waste-recycling paradigm by 2001 Germany already recycled about 48 % of municipal waste, thereof approximately 25 % was landfilled and 22 % was incinerated. Moreover the separate collection of domestic waste fractions have increased significantly the MSW recovery and recycling rate. Yet, the total level of municipal solid waste has changed little since 1990. Nevertheless after the whole 12-year transition phase the public sector waste management authorities had largely met their commitments and had succeeded in establishing the facilities needed to treat the wastes consigned to them. However, 200 landfills, which failed to comply with the new standards, were closed. In addition, some bottlenecks appeared in the management of high calorific value wastes from MBT facilities. As a result high waste prices and an increase in (partly illegal) waste exports affected in particular commercial wastes. (BMU, 2006)
To sum up a step-by-step ban on landfilling un-pretreated MSW, producer responsibility and a focus on separate collection have proven to be important policy initiatives. In 2010, the level of recycling had increased from 48 to 62 %, landfilling was almost inexistent and incineration had increased to 37 % (EEA, 2013).

ESTABLISHING A RECYCLING BASED WASTEWATER ECONOMY

Wastewater management is as well as waste management characterized by a federal law system and therefore affected by a similar problem. The legislation is based on European, national, regional and local acts or statues. Yet a fundamental paradigm change, like resource-oriented economy, became a promising approach due to changing conditions.

The Concept of New Alternative Sanitation Systems

Wastewater is characterized by a very uneven distribution of material fractions from different wastewater sources. Figure 1 illustrates this fact. For instance most of the nutrients like phosphorus or nitrogen occur in urine or faeces, whereas greywater comprises most of the flow.

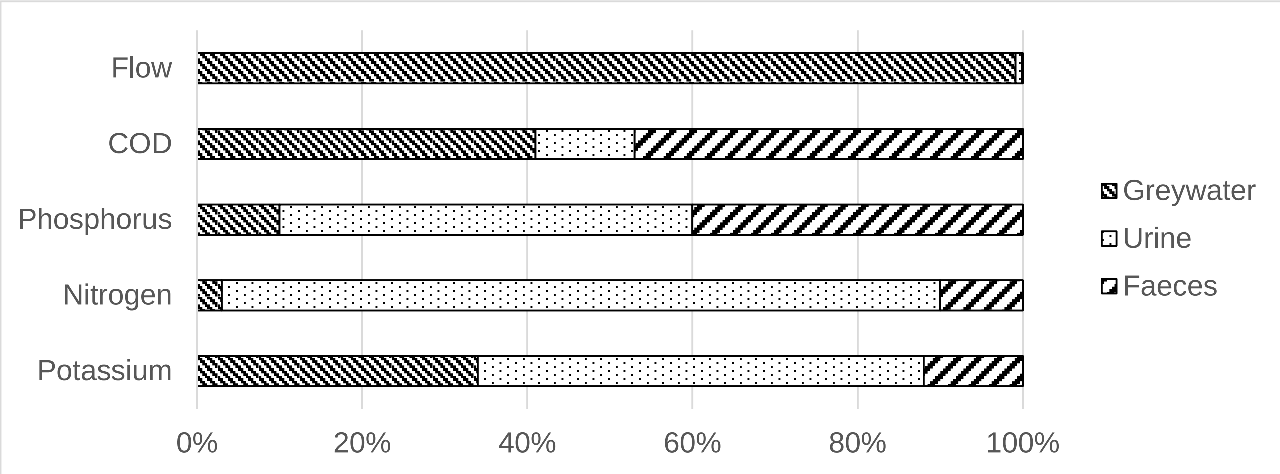

Figure 1. Mass percentage of wastewater components separated by its origin (data source Niederste-Hollenberg & Otterpohl, 2000)

Following the solid waste strategy of prioritising reuse options and collecting source separated, New Alternative Sanitation Systems (NASS) are based on not mixing faeces, urine and greywater. The aim is to use resources and to bring out products originated from wastewater. Figure 2 demonstrates how the components of the different wastewater flows can be recycled.

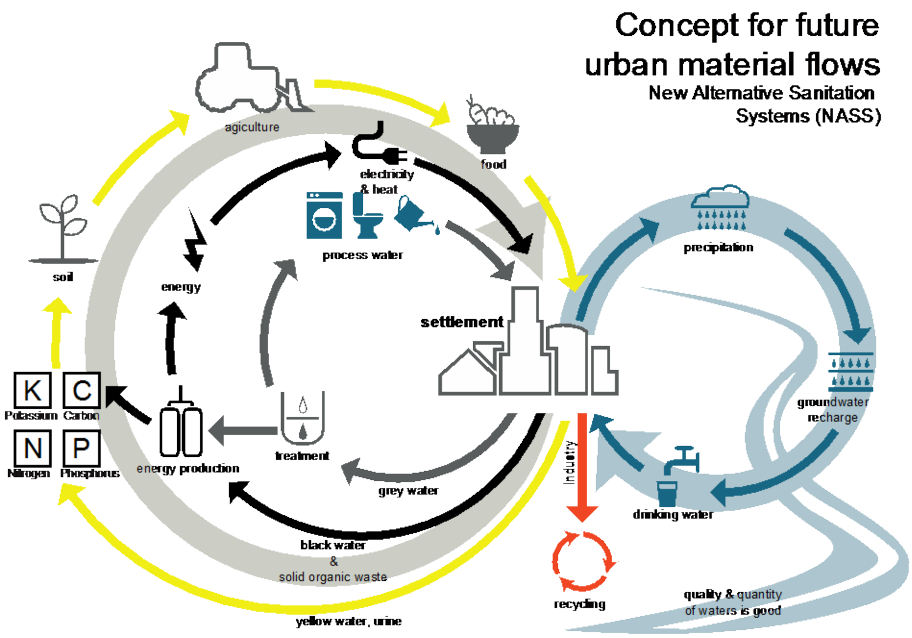

Figure 2. Concept for future urban material flows (Rost et al., 2015)

First demonstration measures are in operation and under construction. Additionally and a guideline for the design of NASS has been approved in Germany (DWA, 2014). Within the next years NASS can become a widespread alternative to the conventional, end-of-pipe-oriented sanitation system.

Experiences in Germany show that it was difficult to convince practitioners to think about source separation and recourse use or even invest in pilot plants. Obstacles for implementation are manifold:

- Products for collecting, transporting and treating the different wastewater flows are not established on the market and therefore not available in high quantity and at reasonable prices.
- Stakeholders need to question their own end-of-pipe developments.
- New partnerships (e.g. with agriculture using products as fertilizer, with energy company for making use of methane or off-heat) need to be established.
- New operational options and needs have to be evaluated due to changed system boundaries (public and private properties).
- Institutional barriers ...

Principles of a Transition Process

Compared to the solid waste approach, a transition from the emission and discharge oriented wastewater paradigm to a new wastewater recycling based concept is more challenging. As depreciation periods for wastewater infrastructure are longer – up to fifty years – the possibility of a stepwise transition is a much more important issue. These periods vary regarding to the area of application:

Collection (bathroom, toilet)	20 - 10 a
Transport (sewerage, truck)	50 - 10 a
Treatment (technical facility)	25 - 10 a

So called *Windows of Opportunity* are open, if changes are necessary anyway. The current condition of the sewer system in Germany could be a starting point for the change of the sanitation system – from a system based on dilution to a system of (re)use based on separation of different wastewater streams (Londong et al. 2013). In an intermediate term 20% of private sewer systems and 40% of public sewer systems are classified as in need of rehabilitation (Bieker & Frommer, 2010).

THE RESEARCH PROJECT "KREIS" IN HAMBURG

HAMBURG WASSER, a company providing both water and wastewater services for the Free and Hanseatic City of Hamburg, developed the so called Hamburg Water Cycle® (HWC), which is a NASS based on the separation of black- and greywater. Within in the transdisciplinary research project KREIS (meaning "cycle" in German) the implementation of the HWC in the quarter Jenfelder Au in Hamburg for 2500 residents was prepared. (www.kreis-jenfeld.de)

Technical Concept

The sewer network transporting blackwater is based on vacuum technology. In a digestion plant besides blackwater also other bio-resources like fats, food residuals, grass clippings or fractions of these substances, which can be collected in the immediate surroundings of the quarter, are treated. They supply additional heat and electricity as well as increased process stability. The electricity then is fed into the public grid. The heat is partly used to temper the digestion plant. The excess heat will be applicable for the heat supply of the quarter (see Figure 3). This implementation of the HWC is the largest example of a resource-oriented sanitation concept working with vacuum technology for the collection of concentrated blackwater in Europe (Londong et al., 2016).

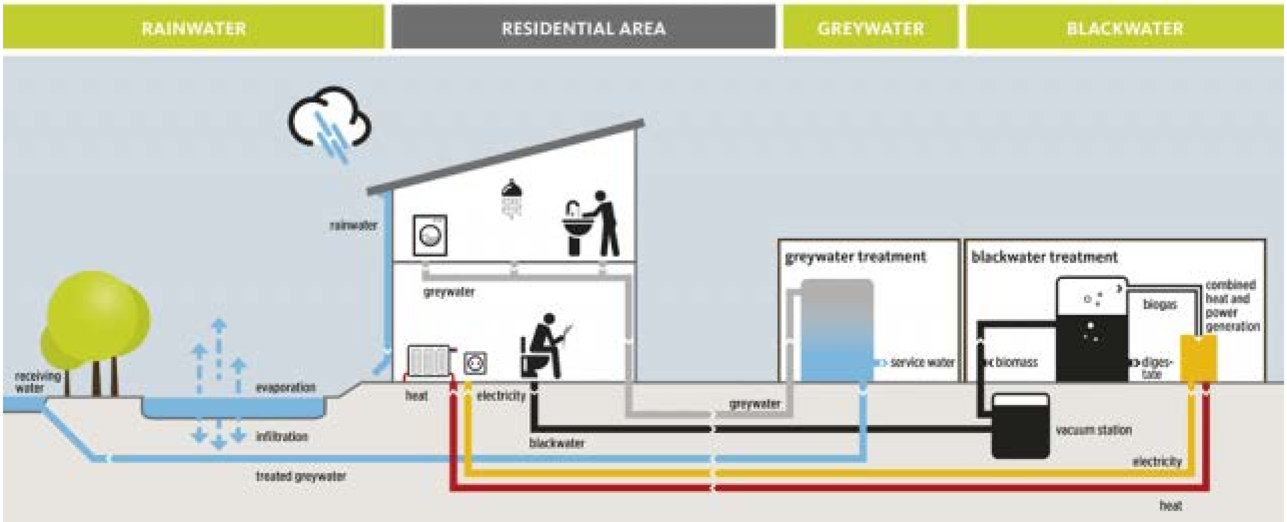

Figure 3. Concept of HWC implemented in the quarter Jenfelder Au (Hamburg Wasser, 2016)

Process of Planning and Modifcation

Many stakeholders with different interests, obstacles regarding the legal framework for NASS and organizational boundaries impeded the implementation. The planning of the project already started 2006 with an urban and landscape competition on the re-use of the former barracks area in Jenfeld. Within in the last ten years several incidents caused delays so that only by 2017 the first inhabitants will move in.

The official development plan procedure began after adjusting the HWC to local parameters. The first obstacle occurred when the regional *Wastewater Act of Hamburg* (HmbAbwG) needed to be reviewed as vacuum technology was never build in Hamburg before. This required lobbying within the authorities to allow other transport options besides gravity sewers.

A major adaptation of the concept was required 2012 after the tendering process upon the energy concept was completed. The applied criteria were profitability and carbon footprint. The winning concept is based upon virtual CO_2-trade and therefore eliminated geothermal and photovoltaic approaches, which were planned in an earlier stage.

Since the area has been used by the armed forces before, a clearance of all explosive and military material was required. The clearance has been delayed due to unpredictable substances. This resulted in a further delay of starting the construction works for several months.

The most recent amendment for the wastewater system occurred when an additional compaction of housing development was decided. At this time the building of the sewer systems was already in progress. Especially the vacuum system could not be modified anymore as the vacuum pump was on order. Therefore not all residential houses will be connected to the HWC.

Results

The Implementation of a resource-oriented wastewater systems requires changing fundamental parts of a system. All incidents illustrate that a transition process even for newly developed building project with less significance of technical innovations is crucial. A sound project management needs to be established to guide a still non-standard implementation process and to react to unforeseen impediments. Therefore the cooperation management of involved stakeholders is necessary. To evaluate the acceptence of the system and of its compounds further research is required.

SUSTAINABLE SANITATION SYSTEM FOR A RURAL AREA IN GERMANY

Unlike the KREIS project, the research project TWIST++ emphasizes conceptual and planning approaches in already built residential areas. TWIST++ focusses on the integration of transition and management strategies which makes the system more flexible and able to adapt to future changes. A further task of the project is the development and adaption of specific technologies, which are of special use for transition paths. All results were developed on the demands of three different model regions: a shrinking city close to the Ruhr area, a brownfield in the centre of an urban area and both a shrinking and a growing small village in a rural area. In this article we describe the possible implementations of intelligent transition approaches for water infrastructure systems in one of these villages. (www.twistplusplus.de)

Background

The village Rohrbach is situated in the middle of Germany in Thuringia. Demographic change has a strong influence on the declining population, which averaged 210 inhabitants in 2015. Concerning wastewater infrastructure, the village is separated in two parts. A newly constructed part, where 30 inhabitants live, is connected to a wastewater treatment plant. In contrast, in the old village center each house holds its own settling tank. The pre-treated wastewater is either discharged into an old sewer system, which also collects the rainwater, or directly into a small receiving water.

The immediate area is mainly characterized by rural settlements and large-scale farms. The village under investigation is part of a compound association of 24 villages, which takes care of all wastewater management components. Regarding the local boundary conditions almost 50 % of the 9.000 inhabitants in 24 villages are not connected to biological wastewater treatment. Most of these villages are supplied only with a sewer system: the pre-treated wastewater is directly discharged into the water bodies. Although such a system is not in compliance with legal requirements, a first survey in two villages reveals that around 70 % of the population are satisfied with this situation. Furthermore 94 % reject higher fees, which could be used to modernize the water infrastructure system. (Maier & Londong, 2015)

Step-By-Step Transition Process

One approach of the research project TWIST++ is the identification of a planning approach which support a transition process towards a resource-oriented sanitation concept. These four steps are: define a target corridor, describe a system, identify windows of opportunity and determine transition steps.

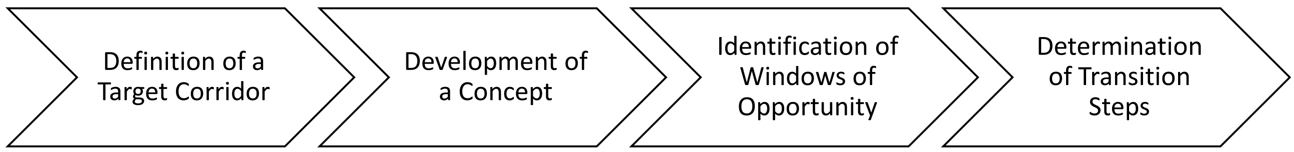

Figure 4. Planning approach for establishing a transition process

It has to be emphasized, that the planned system and the implementation steps can be adjusted over the transition period in a kind of moving-target-approach. The above named village is used to demonstrate the applicability of the proposed transition process.

Defining a Target Corridor. The aim of the first step is to come to an agreement with all stakeholders about the general objective. In our case study the purpose is to establish a wastewater system which:

- meets the current legislative condition,
- is affordable for an economic weakened wastewater compound association and
- takes the reuse of resources in a regional context into account.

Describing a system. Based on these targets the technical system was developed. Figure 5 shows the general idea. The core is to separate black- and greywater. The greywater will be treated according the state of the art and can then be either domestically reused or discharged into natural surface water. The blackwater will be used together with regional organic residues to generate energy in a biogas plant. The post processed digestate can be used as a fertilizer.

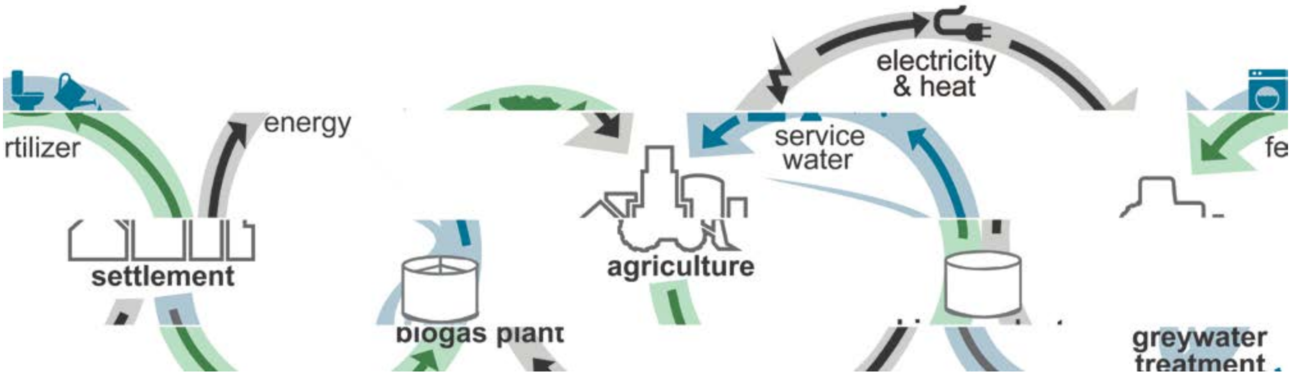

Figure 5. Resource-oriented concept for the case study village

Identifying Windows of Opportunity. Implementing a new system is more accepted when changes are necessary anyway. Thus comprehensive analysis of the appropriate conditions regarding the technical systems, legal framework or other circumstances are crucial. In our model village the old sewer system is in need of rehabilitation. The responsible wastewater association has planned to build a wastewater treatment plant in 2017 and a new sewer system in 2018. Furthermore the *International Building Exhibition in Thuringia* (IBA Thüringen) is an event which can be considered as an external trigger for possible changes. The above described system is a nominated so-called IBA candidate within a two stage process. The IBA will document its interim progress in 2019 and concludes with a presentation year in 2023. In consequence, the project should demonstrate intermediate results by 2019 and be finished in 2023.

Determining Transition Steps. Based on all the above mentioned knowledge a transition process was developed for our project. Since changes on wastewater infrastructure are fundamental for habitability, intermediate steps, which allow a combination of a discharge and resource-oriented system, are necessary. The determined steps in our case study are:

1. Building of a constructed wetland for all wastewater (excluding rain discharge)
2. Building of a vacuum sewer system for all wastewater (excluding rain discharge)
3. Establishing a cooperation with agricultural company to build and operate a biogas plant
4. Separation of black- and greywater
5. Building of a biogas plant
6. Restoration of the old sewer system for rain discharge

After the building of the constructed wetland and the vacuum sewer system two milestones are formulated: “A cooperation with an agricultural company could be established” and “An adequate technology to separate black- and greywater in already existing houses was devolved”. If one of these milestones will not be achieved, the transition process comes to an end. Though two of three criteria of the target corridor, building an affordable wastewater system which meets the state of the art, are succeeded already with step two.

Results

The presented method of a four-step-planning-approach for transition processes is an appropriate measure in rural areas as the example shows. It can meet the objective of adjusting a system less immediately and of staying flexible according to (possibly) changing circumstances–development of new technical solutions, modification of legal framework and change in volume and composition of wastewater are only a few to name. In our example we focus on the monitoring and developing new technologies to separate black- and greywater in already existing buildings. Another research project proved the possibility to equip down-pipe installations with a separate blackwater pipe by introducing two differently sized liners. If this technology can also be used in horizontal pipes, the new method of lining two pipes into one old pipe would allow to implement a vacuum blackwater and a gravity flow greywater system in existing houses. (Veser & Berndt, 2014) Another option would be to employ not a sharp distinction but to implement a sensor-based separation of highly and low loaded wastewater according to their organic load. By the milestone "An adequate technology to separate black- and greywater in already existing houses was developed" a convenient criteria was established.

DISCUSSION

The example of the recycling-based waste economy proved that establishing limiting values in a legislative acts can be one step towards a resource-oriented system. Nevertheless an appropriate interim period and additive measurements concerning the separate collection are necessary. Especially deprecation periods of technical components should be taken into account when establishing a paradigm shift. Wastewater infrastructure is less flexible due to the sewer-bondage then waste infrastructure. For this reason, it demands longer transition periods and a combination of discharge and resource-oriented system as an initial step.

Another significant difference between our case studies is founded within the strategy of decision making. In the waste sector the process was a top-down strategy, initiated by national authorities, who introduced recycling-based economy into legislation. Whereas the important drivers for implementing NASS were local stakeholders who were open for innovations. Thus, when changes within a sector become more fundamental a bottom-up strategy is more promising due to the prevalence of "safety-oriented" stakeholders in executive positions.

CONCLUSSION

The introduction of resource-oriented wastewater systems is a time consuming process. This article argues that a stepwise transition is an adequate measure to introduce paradigm changes into rigid infrastructure systems. The broad spectrum of all examples confirms the applicability of a transition process. However, the configuration depends on many specifications like depreciation periods of technical components, decision-making-strategy or whether it is a retrofit solution or not.

The presented four-step-planning-approach is capable to encourage the planning of a resource-oriented sanitation concept even when changing boundary conditions are observed throughout the whole process. Especially within a bottom-up process a dedicated project management is crucial to pursue defined targets.

Further research is needed to evaluate, whether a key policy priority should be to establish a top-down strategy for the long-term care of implementing paradigm shifts in water infrastructure systems and whether the organisational framework needs to be adapted.

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