Smart renovation of Dutch residential housing and residential infrastructure for closed-loop, future proof water & nutrient management

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MSc Thesis submitted to the sub-department of Environmental Technology (ETE)
Wageningen, November 2016

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Master thesis ETE-81839

Submitted in partial fulfilment of the requirements for the MSc Urban Systems Engineering (MUE) at Wageningen University and Research Centre

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Cover design: MORIN. 2016. Modern solution for dry toilet [Online]. Available: http://www.ecodomeo.com/english/ [Accessed 27 September 2016].

Abstract
The main objective of this thesis research is to make two conceptual future proof designs for renovation of residential buildings community-on-site (unless a centralized solution is clearly more future proof based on the criteria). One for a rural setting and one for an urban setting, using promising technologies that have been proven at least on lab scale and choosing technologies that fit best with the criteria for a future proof design. This is done by making a useable definition of future proof in the context of closing water and nutrient loops for existing households and receiving feedback from stakeholders on the conceptual design. The analysis of the business as usual (BAU) centralized wastewater treatment concept versus four new sanitation solutions shows that the BAU system is not future proof in both the studied rural and urban cases. The list of 24 criteria, which was developed based on sustainability frameworks The Natural Step and cradle to cradle, shows the extent to which the selected alternative new sanitation concepts are future proof, fully excluding economic aspects. In the context of a long-term future vision for wastewater infrastructure for both the rural case of Exel and the urban case of Centrumeiland IJburg, it was possible to determine the best-fitting new sanitation concept. These new sanitation concepts, which only partially realize the visions, are flexible platforms or stepping stone technologies from which, in theory, in the future the full realization of the vision is possible. In the rural case the vision for a *Dry sanitation system as maximum eco-efficient water metabolism* led to the selection of the stepping stone technology of *Composting dry toilets with urine storage*. In the urban case the vision for *Separated water and nutrient reuse infrastructures with lifestyle change* let to the selection of stepping stone technology *Vacuum system for black water*. The research concludes that the application of the developed criteria for selection of future proof sanitation concepts will help stakeholders in the selection and fine-tuning of sustainable stepping stone technologies in cases where renovation of sewers, residential buildings or both are imminent. Moreover, when coupled with a true stakeholder participation process, the vision selection, practical application analysis and criteria scoring as suggested in this research will help select the most future proof sanitation concept and conveniently simultaneously creates a solid basis for finding creative ways of financing the transition.

Key words
Future proof, sustainable, systems thinking, new sanitation, renovation, rural household wastewater, urban household wastewater, compost toilet, vacuum sewer, urine diversion, The Natural Step, cradle to cradle, circular economy.

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Chapter 1: Introduction

Definitions

Below is a list of definitions that are relevant to the thesis research.

Black water	According to DWA (2010, p5) black water refers to: **"Excreta and flush water (and toilet paper)"**. In other words brown and yellow water combined.
Brown water	According to DWA (2010, p5) brown water refers to: **"Faeces and flush water (and toilet paper)".**
Circular Economy	The Ellen McArthur Foundation (EMF, 2016) defines Circular Economy as: "**A circular economy is one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.**"
Closed loop recovery	"**The reverse channel supplies high quality (recovered) products, components and materials to the forward channel thereby reducing the need for virgin sourcing and production**" (Krikke, 2011).
Community-on-site	According to the dictionary (Oxford University Press, 2005): Community = "A group of people living together in one place" and Site = "A place where something is located or happens." An average Dutch wastewater treatment plant serves 67,200 inhabitant equivalents (UvW, 2013), with an average Dutch household size of 2.19 (CBS, 2016b), this equates to 30,685 households. In this thesis community-on-site will refer to: **The physical location where a certain group of people live together. This can range from several households to a small village or neighbourhood of a larger city, but is significantly smaller than the service area of one average Dutch wastewater treatment plant (30,685 households).**
Future proof (design)	According to the dictionary (Oxford University Press, 2005): Future = "time that is still to come" and Proof (adj) = "able to resist". The official definition of future proof then is "able to resist the time that is still to come". This definition will be elaborated by combining it with the first widely publicised (Johnston et al., 2007) definition of sustainable development of the Brundtland Commission (1987, p16), which reads: "Ensure that [humanity] meets the needs of the present without compromising the ability of future generations to meet their own needs." In this thesis future proof will refer to: • **A design that is able to resist the time to come while meeting**

both the needs of current and future generations.

Greywater	According to DWA (2010, p5) greywater refers to: **“Wastewater without excreta (water from kitchens, showers, sinks, washing machines, etc.)”**.
High-tech design	According to the dictionary (Oxford University Press, 2005): High technology = “Using [advanced] technology.” In this thesis high-tech design will refer to: **A design using advanced technology.**
Low-tech design	**A design using less advanced or relatively basic technology.**
Mid-tech design	**A design using technology in between high-tech and low-tech.**
New sanitation	Different stakeholders in The Netherlands use different definitions, such as: • Collecting separate wastewater streams and decentralized treatment (STOWA, 2015); • “Treating wastewater differently than the status quo” (Tauw, 2015); • “To fully recover valuable resources from separated waste streams and close the nutrient and water cycle, while producing energy” (LeAF, 2015). In this thesis new sanitation will refer to: • **To fully recover valuable resources from waste (water) streams and close the nutrient and water cycles (including collection, transport, treatment/recovery, and reuse) locally while at least reaching energy neutral conditions and preferably producing surplus energy.**
Nutrient	According to the dictionary (Oxford University Press, 2005): Nutrient = “A substance that is essential for life and for growth.” In this thesis the definition will be broader, nutrients will refer to: • **All possible resources or materials that are ‘nutrients’ to an industrial system.** This broader definition is based on the cradle to cradle design methodology which distinguishes between biological and technical nutrients (McDonough and Braungart, 2002, Braungart et al., 2007).
Organic fertilizer	According to the dictionary (Oxford University Press, 2005): Organic = “Produced without artificial chemicals such as fertilizers.” In this thesis the definition will be broader, nutrients will refer to: • **A fertilizer that is derived from animal or vegetable matter.**
Renovation of houses	According to the dictionary (Oxford University Press, 2005): Renovation = “restore something old to a good state of repair” and House = “building

	for people to live in". In this thesis renovation of residential buildings will refer to: • **Restoring the structure, wiring, piping, and installations of residential buildings, including the surrounding private garden if applicable.**
Renovation of residential infrastructure	According to the dictionary (Oxford University Press, 2005): Infrastructure = "the basic structures (e.g. buildings, roads, power supplies) needed for a society or organization to function." In this thesis renovation of residential infrastructure will refer to: • **Removal, redesign or renovation of drinking water and sewage infrastructure from the household connection to the drinking water facility and the wastewater treatment plant.**
Sustainability	In this thesis sustainability will refer to the first widely publicised (Johnston et al., 2007) definition of sustainable development of the Brundtland Commission (1987, p16) reads: "**Ensure that [humanity] meets the needs of the present without compromising the ability of future generations to meet their own needs.**" This thus focuses more on people and planet than on prosperity (economy).
Sustainable and solidarity economy	The Dutch Platform sustainable and solidarity economy (Platform DSE, 2016) defines a sustainable and solidarity economy as: "**A just and service oriented economy that is in balance with the natural capacity of the Earth.**"
Synthetic fertilizer	According to the dictionary (Oxford University Press, 2005): Synthetic = "Made by chemical synthesis, especially to imitate a natural product." In this thesis the definition will be broader, nutrients will refer to: • **A fertilizer that is derived from chemical synthesis.**
Yellow water	According to DWA (2010, p5) yellow water refers to: **"Urine and flush water".**

Environmental problems in water and nutrient loops in Dutch households

According to De Graaf and Van Hell (2014) of the Dutch foundation for applied water research STOWA, the centralized treatment of wastewater in The Netherlands is getting more and more efficient and treatment quality has improved. In terms of reducing energy use, footprint, and costs, eco efficiency in Dutch water treatment is very good. Also resource recovery is becoming more important and is considered a realistic future ambition. These developments are taking place in the existing paradigm of collection, transportation, and treatment of wastewater. In this concept relatively large amounts of wastewater are often still mixed with rain water and are gravity transported to treatment facilities. In these predominantly large scale treatment plants, in order to achieve economies of scale, the mix of wastewater with rain water is treated mostly aerobically.

In most Dutch households, water and nutrient flows through the building are linear. Regarding water, drinking water enters the building and after several types of use (Foekema et al., 2008) it leaves as one combined stream through the sewer in over 99.4% of households. The sewer may be combining sewage with rain water, which is the case in 68.2% of sewers, or it only transports sewage because rain water is decoupled locally, which is the case in over 31.2% of sewers. All centralized sewage systems are connected to wastewater treatment plants that comply with European directives (Oosterom and Hermans, 2013). Rain water itself generally does not enter the building; however it can be used to substitute drinking water when it is used for garden plant irrigation, for example. When water is used for irrigation, it generally does not enter the sewer system, but is evapotranspirated or infiltrated in the soil. Theoretically, rain water can be used for drinking water or greywater purposes; however, this is generally applied in regions with relatively high water scarcity and not often in The Netherlands (Naddeo et al., 2013).

Nutrients enter Dutch households generally as externally grown or processed foods, personal care products and detergents, nutrients in drinking water, and as indoor plant fertilizers. A substantial portion of this nutrient input enters the digestive system and is excreted as urine or faeces. Urine contains 85% of nitrate and 48% of phosphate whilst constituting of only 1% of the total household wastewater stream (Kooistra, 2012). This human waste leaves the building through the wastewater. The other portion leaves through the organic waste collection system (Smit et al., 2010). A small portion leaves through the residual municipal waste. In some households, a compost heap consumes some nutrients which are applied to the local garden. In this latter case the system is somewhat circular.

Both water and nutrient linear systems, which are intertwined in current modern sewage systems, require large amounts of energy for transport and processing, and valuable resources which can be turned into energy or fertilizers are generally lost with current (waste)water treatment methods (Rittmann, 2013). Especially the loss of phosphorous is of concern, as it faces scarcity in five dimensions. It can technically be recovered in biological wastewater treatment plants as struvite or from the ash from incinerated sewage sludge, but this is difficult and not widely applied yet (Cordell, 2013, EFGF, 2016e, Kalmykova and Fedje, 2013). Based on the preferred scenario's for long-term phosphorous supply and current phosphate rock fertilizer use by Cordell et al. (2009), almost a quarter of demand can be satisfied by kitchen waste and human excreta nutrient recovery. Several projects and pilots are now being implemented to recover some wastewater products, such as phosphorous, cellulose, and energy, from centralized wastewater facilities in The Netherlands (EFGF, 2016e).

Degrading soils are also linked to linear water and nutrient systems. Soil fertility worldwide is of growing concern; experts say the world may be running out of useable topsoil within 60 years. This is due to soil degrading farming techniques, deforestation, overgrazing, and climate change (Crawford, 2012, Arsenault, 2014). Soils urgently need carbon to feed microorganisms but it is removed at a higher rate than it is replenished. Degraded soils have lower productivity and hold less water, which means more irrigation or precipitation is needed. Also, the important function of soil as a carbon sink is lost because it does not sequester atmospheric CO_2 (Tervahauta, 2014). Besides better farming practices and adding manure to the soil, the return of human faeces, urine, and kitchen waste is part of the solution (Crawford, 2012). This will help replenish the soil battery and close cycles (McDonough and Braungart, 2013). Moreover, reliance on compost instead of carbon sequestering peat from nature works just fine for soil conditioning, especially on a household scale (Van de Veen, 2015, RVO, 2016, Tervahauta, 2014). Lastly, the behavioural component is not to be underestimated, as personal choices of local (urban) residents regarding food have a large impact on global agriculture. Yet changes in water use in households have a much smaller effect (Beck et al., 2010).

There are several benefits expected from a change from linear to circular water and nutrient systems. Lloyd (2007) writes that the direct benefits of closing the nutrient loop are a reduction in carbon and nitrous oxide which both are potent greenhouse gasses. Another is the improvement of water quality which will benefit biodiversity. Lastly, he asserts there is an economic value for both farmers and water customers, as fertilizers and drinking water treatment can become cheaper when nutrients are reused. Regarding the wastewater management in general, Gujer (2013) states that a new approach to wastewater management is desperately needed in today's world and in his professional opinion the new approach will include source separation as well as decentralization. According to Larsen and Gujer (2013) coupling of these concepts, as they are in new sanitation, is needed to best capture advantages of both. Clearly, there are not just problems with the current system but also great merits in a closed loop approach with source separation and decentralization elements present for the future.

To close water and nutrient loops several decentralized, new sanitation pilot and implementation projects have been carried out in The Netherlands. The development of these projects was driven by a dissatisfaction of certain stakeholders, such as politicians (Harder, 2012), in wastewater treatment with the current centralized paradigm. These groups were critical of the high energy use, high drinking water needs of conventional toilets, broad application of chemicals for treatment, the inflexible system and loss of valuable resources. The results of the new developments show new sanitation is an attractive option to turn wastewater into a valuable resource (Swart and Palsma, 2013). Other incentives for new sanitation are the need for modernization and optimization of urban areas or wastewater treatment systems (Harder, 2012)

New residential building developments are however not going to be able to make the overall residential building stock future proof with respect to water and nutrient loops. First, very few new housing projects currently implement closed loop systems (Swart and Palsma, 2013). Second, there is a parallel with the bottleneck with energy saving campaigns for households, which have to aim at mostly existing buildings to generate substantial savings in absolute numbers. This is because about 1% of residential buildings are built new each year (Ministerie BZK, 2013) and the existing houses will not be replaced for several decades or centuries. To be precise: the building envelope has a functional lifetime of 40 to 100 years whereas installations[1] have a functional lifetime of 1 to 15 years (Paesschen, 2011) and plastic piping has a functional lifetime of at least 50 years (BureauLeiding, 2013). Moreover, sewers have an average technical lifetime of 60 years, with a range of 30 to 100 years depending on the condition of the soil and aboveground developments (Oosterom and Hermans, 2013). So to make a big step in closing water and nutrient loops for households, the future proof designs need to be made suitable for renovation of existing buildings and/or existing infrastructure. Especially the transport and collection of separated streams need to be researched (Harder, 2012).

With regard to the sewer system, the majority of Dutch buildings are connected. Only in the case of large urban renewal projects where buildings themselves are renovated at the same time the sewer is technically revised or replaced, or when new developments are planned, De Graaf and Van Hell (2014) say a good basis exists for contemplating an alternative collection and treatment system. These are both situations that are effectively of the clean slate type. De Graaf and Van Hell (2014) reason that substantial extra costs will be incurred for replacing home piping and sanitary fittings for existing residential buildings to connect to decentralized solutions with vacuum sewers, making connections to existing buildings not economically feasible at this time.

Next to new sanitation, (Vreeburg, 2015b) suggests that a sewer system that completely separates rain water from wastewater and uses small diameter pipes, as well as a branched layout instead of a looped one, designed to meet the hydraulic performance indicators rather than traditional rules of thumb for both infrastructures is a sustainable alternative to the current sewer system. Vreeburg (2015a) suggests that not rain water is decoupled, but suggests decoupled household wastewater. The wastewater system then needs to be closed, so no cross contamination with rain water is possible or at least is identified easier to enable accurate counter measures. This will increase the concentration of resources in wastewater and decrease energy use for transportation as well as the costs for sewage systems. On community scale additional organic waste could be added to increase concentration of organic matter even more. On the other hand, water efficiency should also be achieved to decrease dilution. This infrastructure change to smaller diameters and fewer loops has proven itself successful in drinking water distribution. This new approach to sewage design can be applied in both centralized and community-on-site decentralized sewage systems, because those systems have the same collection infrastructure. However, it has not been applied yet in pilot or full scale to date.

How future proof are decentralized solutions

Advantages found in the implementation and development of the decentralized vacuum sewer solution applied in the Dutch district of Noorderhoek, Sneek were a relief to the existing wastewater treatment facility or a lowering of the peak load for the treatment facility. From the results it was derived that attractive niches for similar systems in The Netherlands exist in situations with relative long transport systems such as remote villages, districts with a high population density, short pipes with high heat content such as apartment complexes and hospitals or new developments or renovation projects as described above. Additionally, opportunities are recognized at recreational sites especially when an application for the heat surplus can be found (De Graaf and Van Hell, 2014).

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[1] Installations consist of peripheral equipment and generating devises (Paesschen, 2011).

More and more research shows that centralized solutions are generally not preferable to tackle sustainability issues. An extensive study by Ford (2015, p195) on why human caused climate change, one of the biggest sustainability challenges, has not been acted upon adequately by society, discovered that the dominant paradigm of the “One World Market” is not compatible with sustainability solutions. She argues that global, centralized policy instruments and technologies favoured by the dominant paradigm are causing a wedge between our history, locale, and where we are now. In order to shift to a sustainable society, humans need to relearn from history to return to a regional or local economic orientation with locally-sourced resources (Hopkins, 2008, Berry, 2001). Local sources Ford (2015) mentions include local, seasonally sourced food, local sources of energy and low speed transportation of products and people. Moreover, the marginalization of local, decentralized initiatives by the dominant paradigm should stop.

Decentralized new sanitation solutions can provide solutions to current environmental problems in several ways. In addition to the Noorderhoek, Sneek pilot, literature points out other advantages. Rittmann (2013) and Harder (2012) point out that decentralized sanitation can help lower energy use of current wastewater collection, transportation, and treatment schemes. Furthermore, if decentralization leads to more concentrated streams, nutrient recovery, and subsequent energy production from wastewater, it a serious option. However, decentralized systems do require equal investments as large systems do and high-efficiency is needed to overcome diseconomies of scale. Cordell (2013) argues that decentralized sanitation plays a significant role in reaching phosphorous supply security in the future, as well as in phosphorous pollution prevention. Furthermore, decentralized technologies are critical in efficient phosphorous recovery, they provide a local, renewable alternative to fossil phosphorous, and they reduce dependence on global financial market fluctuations and geopolitical unstable suppliers. Erisman and Larsen (2013) point out that 80% of nitrogen in domestic wastewater originates from urine. They see a huge potential for capturing this nitrogen and reusing it as fertilizer, instead of it becoming reactive nitrogen in untreated wastewater, which unsettles the natural nitrogen balance. This mostly applies to the global South. Worldwide, only roughly 6% of nitrogen metabolized by humans is removed in water treatment plants (Larsen et al., 2007). In water scarce regions, which is in the foreseeable future not the case in The Netherlands, Falkenmark and Xia (2013) see a dual role for new sanitation in urban areas. Nutrients can be recovered as fertilizer while radical water-saving and local wastewater reuse are promoted. In order to mitigate risks from micropollutants in urban wastewater, Kümmerer (2013) states that two strategies need to be combined. First chemicals needs to be designed to be benign when released in wastewater. Second, source separation and local recycling of wastewater will increase customer interest in biodegradable products, thereby lowering the micropollutant load in wastewater. Harder (2012) also states that new sanitation offers new opportunities to remove micropollutants from wastewater, as this is accomplished easier from concentrated streams than from the diluted streams treated in centralized wastewater plants.

An attempt at a financial cost-benefit analysis of wastewater infrastructure shows some key benefits of decentralized sanitation over centralized solutions. These are flexibility and possible lower costs per unit (Maurer, 2013). Tchobanoglous and Leverenz (2013) write that decentralized and source-separated wastewater strategies will become a significant part of the future technology mix for sustainable wastewater management. Advantages compared to centralized systems include that decentralized systems can have shallow, corrosion proof, and easier to repair infrastructure, these systems have the ability to exclude rain water inflow and it is easier to recover resources from source separation in decentralized solutions. Challenges that remain to be addressed in decentralized sanitation are flow equalization, potentially higher energy use per flow unit treated and often a larger physical footprint.

Concluding, the current approach of most stakeholders involved in drinking water and wastewater as well as nutrient use and reuse, within the four walls of residential buildings, is not future proof. It therefore needs to be changed, but it is undecided what the optimal future proof solutions are. It is therefore of great interest to determine if these decentralized solutions are more future proof than centralized sanitation. This is difficult to determine looking at isolated problems or at the end of pipe problems of current water and nutrient management systems, due to complex impacts on the environment and social wellbeing. Theoretically, choosing a system's level perspective and using a comprehensive set of principles for sustainability for selection of technology will help to determine if a water and nutrient management concept is future proof.

Focus of this research

Focus nutrients/resources from wastewater

A review has been made of nutrients and resources that can currently technically be produced from wastewater in the Dutch situation. These are phosphate, nitrate/ammonia, potassium, cellulose, direct heat, carbon sources (organic fertilizer/industrial fertilizer, bio plastics, alginate, methane biogas/energy and methanol, humic acid, lactic acid), fresh water, hydrogen, $CO_{2,}$ metals (various), aliphatic hydrocarbons, sulphur, and synthetic petroleum. For these nutrients and resources, an estimate has been made of the applications and markets, value estimate in Dutch context, recovery technology and phase and impacted sustainability principles of TNS.

Based on this analysis the focus of this research will lie on phosphorous, nitrogen, potassium, cellulose, direct heat, and organic matter (for a variety of applications) recovery. These nutrients and resources were chosen because of their relative large ecological impact in The Netherlands, technology readiness for at least pilot application and value for reuse. Care will be taken that technologies to be selected for the recovery and reuse of these nutrients do not block future application of currently emerging technologies for the remaining nutrients. Also, in principle only technologies that have already been implemented on pilot scale in a comparable situation to the cases will be considered, although very promising technologies that have been extensively researched on lab scale may be considered by exception.

Geographical and functional focus and scale

This research will focus on solutions for closing water and nutrient loops in The Netherlands. One case will be focusing on a rural cluster of buildings and one case on a dense urban area. Only wastewater from residential buildings is being considered. Only existing buildings that are to be renovated are part of this study, due to their large impact on the total wastewater stream. The scale for the future proof designs to be proposed in this study is community-on-site, unless the future proof criteria clearly show a centralized solution is more sustainable.

As has been mentioned, rain water generally does not enter the building and is therefore excluded from this study. It will be assumed that rain water follows a circular approach nonetheless, but does not mix with the in-house water and nutrient streams. So at the minimum, rain water will be infiltrated on-site and will enter the groundwater reserves, as for example in the German Lübeck Flintenbreite technical concept for decentralized wastewater management (Londong, 2013).

Excluding the economic aspects

To make a future proof design feasible under current market conditions the business case has to be considered, as well as new financing models. A new way of looking at financing of closed loop systems is circular economy financing. Customers pay per use or for a service and do not purchase a product. A classic example is the washing machine, a customer can buy one and the ownership transfers to the customer and they pay the purchase price to the producer. But in a circular economy the customer can lease the washing machine and will pay per use, so only gradually paying the 'purchase price' to the producer. In the long run the producer will generate more cash flow, but in the short them there is a funding gap. The value for the customer is that he has the guarantee of a superior service, which will be maintained by the service company and does not have built in obsolescence[2] (EMF, 2013).

In the water and nutrient cycle a similar approach can be taken. Possibly, instead of a flat fee per drink water and sewage connection, the customer can choose where and how to purchase these infrastructure services and can pay for the amount of wastewater produced and get reimbursed for the amount of valuable nutrients sold back to the system.

Sooner or later it is feasible that a system of sustainable and solidarity economy (see definition list) will be implemented by human society, which would involve a revision of the taxing system to less tax on labour and more tax on resources (ECSC-EEC-EAEC, 1993, European Union, 2014, ILO, 2012). The result of such a transition would be that services, requiring manpower, would become cheaper. This in turn will increase the labour force, will boost craftsmanship and will enhance creativity. Moreover, such a change would greatly accelerate a circular economy and long lasting prosperity (The Ex'tax Project, 2016). It is conceivable that this taxing system would make implementation of future proof closed water and nutrient loop designs economically favourable over the linear centralized approach which is favoured by the current form of capitalist economic system in The Netherlands.

Considering the trends of circular economy and sustainable and solidarity economy that aim to reshape the economy, it seems feasible to assume that the current economic model will not be a constraint for future proof, sustainable technology and approaches in the long run. Hence the economic constraints are not taken into account in this research, the focus lies on sustainability in terms of people and planet.

Research aim

The aim of this thesis research is to translate the four sustainability principles of The Natural Step framework in combination with the cradle to cradle design concept to the specific case of closing water and nutrient loops in existing households in The Netherlands. It will be determined if a decentralized community-on-site solution for wastewater treatment and closing water and nutrient loops is more sustainable than a centralized wastewater treatment solution as is currently common

[2] Parts that were designed to break after a few years so the customer is encouraged to buy a new product.

in The Netherlands. A case in a rural setting and a case in an urban setting will be considered. Both renovation of buildings including or excluding sewers (as the chance both sewer and building are renovated at the same time is very small) and solely renovation of the sewer system with minor changes to existing buildings are of interest, as long as they lead to a future proof overall design. As implementation of a fully future proof design may currently not be (technically, behaviourally, economically) feasible, stepping stones will be researched that enable future implementation of the fully sustainable design and enable present capturing of sustainability goals.

Objectives and research questions

Objective 1: To make a useable definition of future proof in the context of closing water and nutrient loops for existing households.

RQ1: What criteria can be defined based on the TNS and C2C frameworks for selecting technologies for a future proof design for closing water and nutrient loops (collection, transportation, treatment, and reuse) in households to be renovated in The Netherlands?

Objective 2: To make two conceptual future proof designs for renovation of residential buildings community-on-site (unless a centralized solution is clearly more future proof based on the criteria), one for a rural setting and one for an urban setting, using promising technologies that have been proven at least on lab scale and choosing technologies that fit best with the criteria for a future proof design;

RQ2: According to the defined criteria, what is the best future proof (conceptual) design for closing water and nutrient loops in a) renovation of the sewer system and possibly some in-house piping of a small cluster of existing Dutch residential buildings in a rural setting and b) total renovation of a Dutch residential apartment building in an urban setting?

RQ3: What stepping stones, or flexible platforms, can be selected today to ensure current developments in wastewater collection, transport, treatment and reuse enable future innovations that aim towards a (more) fully sustainable future can be implemented?

Objective 3: To receive feedback from stakeholders on the conceptual designs.

RQ4: What is the feedback of stakeholders on the sustainability criteria and design of the rural and urban case? Can stakeholders provide practical improvement suggestions?

Methodology

This section will describe the methods and analysis that will be used to answer the research questions.

Methods

To answer each of the research questions, the following methods are proposed. These are arranged per research question.

RQ1: What criteria can be defined based on the TNS and C2C frameworks for selecting technologies for a future proof design for closing water and nutrient loops (collection, transportation, treatment, and reuse) in households to be renovated in The Netherlands?

As is proposed in step 3 of the approach above, **criteria for a future proof design for closing water and nutrient loops (collection, transportation, treatment, and reuse) in households to be renovated in The Netherlands** are developed to prioritize one technology or approach over another. These are based on the three guiding principles of a circular system, combined with key guiding principles of TNS. Literature will be used to make sound and controllable criteria.

The approach to come to future proof criteria by combining the TNS framework with the cradle to cradle design concept is described below.

1. The basis of the future proof definition are the four system conditions which lead to the four principles of sustainability and accompanying four sustainability objectives of TNS. These principles and objectives are combined with the positive concept of eco-effectiveness. It then follows that compliance with these objectives means a design is future proof in theory.
2. Based on the future proof definition an intention or vision for the future design is formulated.
3. To select stepping stone technologies for the future proof design, criteria are developed to prioritize one technology or approach over another. These are based on the three guiding principles of a circular system, combined with key guiding principles from TNS.
    a. Waste equals food
        i. Toxicity[3]
        ii. Purity (and hence economic value) of the product[4]
    b. Use current solar income
        i. Energy neutrality or energy production of process
        ii. Trade off between energy production and value of nutrients[5]
    c. Diversity
        i. Local reuse of products
        ii. Cascading water qualities
        iii. CSR, stakeholder involvement
    d. Flexible platforms
        i. Does investment in one technology lead to a foreseeable dead end for using technologies that in the future will comply with all four sustainability principles?
4. Analyze what is business as usual, what are trends and what is technically possible (at least at pilot scale with promising results).
5. Reinvent the current design with a new future proof design that follows directly from the intention. The goal is to redefine the process of water and nutrient management as a service that fulfils the same need or fulfils it even better than the old design.

RQ2: According to the defined criteria, what is the best future proof (conceptual) design for closing water and nutrient loops in a) renovation of the sewer system and possibly some in-house

[3] Use the C2C five step strategy for eco-effective design

[4] The main point is that if a 'product' made from wastewater is not 100% pure, but for example still contains heavy metals, it may have a low value or may not be allowed to be used by government regulation for the intended purpose, such as fertilization of crops.

[5] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible to recover? This would be conflicting with sustainability principle 1.

piping of a small cluster of existing Dutch residential buildings in a rural setting and b) total renovation of a Dutch residential apartment building in an urban setting?

First a material flow analysis (MFA) and case description of relevant data will be made for the water and nutrients in the current state of both cases. These will be based on literature giving Dutch averages for these situations. Second, a list of all Dutch and some relevant European examples of implementation of new sanitation will be made to analyze applied technology for collection, transport, treatment, and recovery as well as community support. Third, a list of all recoverable resources from wastewater will be made, including all possible technologies for recovery, their suitability for on-site, decentralized application, and phase of development (lab, pilot, commercial). Fourth, based on the future proof criteria and possible technologies, a visionary future proof design for both cases will be proposed. Fifth, based on the future proof design, literature on the technologies and fair assumptions on unknown factors, an MFA for water and nutrients based on the future situation will be made for both cases. So in total 8 MFA's will be made.

RQ3: What stepping stones, or flexible platforms, can be selected today to ensure current developments in wastewater collection, transport, treatment and reuse enable future innovations that aim towards a (more) fully sustainable future can be implemented?

In answering this research question it is important to keep in mind that reuse options that may be implemented in the future determine the quality of technology for collection, transport, treatment, and perhaps even recovery today.

RQ4: What is the feedback of stakeholders on the sustainability criteria and design of the rural and urban case? Can stakeholders provide practical improvement suggestions?

Possible stakeholders can be (a final list is to be determined): water boards, municipalities, users, architects/interior architects/landscape architects, law makers, installers, building consultancies (like DGMR), contractors/constructors, social housing companies, producers of technology, associations of owners (VVE) of apartment buildings, farmers. Representatives from these stakeholders will be invited to one or two stakeholder meetings discussing one or both future proof designs and stepping stones. Feedback will be asked on several aspects of the design, alternative solutions, (conflicts of) interests, feasibility, and practical improvement suggestions.

Lastly, if time permits two separate interviews will be conducted with a Dutch expert on circular economy and a Dutch expert on sustainable and solidarity economics[6] to give some insight on how these envisioned economic models will help make the envisioned future proof designs financially feasible. Outcomes of these interviews will be discussed in the discussion section of the thesis report.

Analysis

The main analysis that will be undertaken will be a qualitative analysis of the literature on the topic as well as of interviews with experts and feedback received on the stakeholder meetings. Additionally, for both case studies an MFA of the current situation for water and nutrients, and an

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[6] Possible interviewees are: for example Frido Kraanen, director cooperative & CSR of pension fund PGGM on circular economy financing and Klaas van Egmond, member of the Sociaal-Economische Raad and Sustainable Finance Lab on sustainable and solidarity economics.

estimation of the new design will be made. This is the qualitative aspect of the research. There will be no lab or pilot experiments.

Chapter 2: Future proof sustainability criteria and visions

Background

This chapter focuses on a way to set conclusive sustainability objectives and get meaningful guidance for design of future proof systems from a design concept, which will lead to a comprehensive set of criteria to prioritize technologies in the future proof design.

The Natural Step framework

In order to arrive at a set of conclusive sustainability objectives and herewith a definition for a future proof design The Natural Step (TNS) framework is used. For two reasons it is deemed most fitting to use TNS for the systems' level perspective of designing future proof closed water and nutrient loops for residential buildings to be renovated. First, the TNS framework has been developed to define at the systems level, the basic principles of a sustainable future, as it is not possible to describe a sustainable future in detail (Robèrt, 2000). These principles are derived from scientific, constitutional principles for the functioning of the ecosphere, as will be explained below, and are the basis for complementary, and non-overlapping system conditions that describe a sustainable future (Holmberg and Robèrt, 2000, Robèrt, 2000, Robèrt et al., 2002, Johnston et al., 2007).

Second, several scholars (García-Serna et al., 2007, Zimmerman and Kibert, 2007) and numerous governments, academic institutions, companies, and other organizations use the TNS framework (TNS INTERNATIONAL, 2016c). For example, a broad review of trends for understanding and applying sustainability in chemical engineering by García-Serna et al. (2007) deems TNS, biomimicry, cradle to cradle, getting to zero waste and resilience engineering most fitting for the purpose of making future designs. Specifically, they judge the sustainability principles of TNS adequate for framing, designing, implementing and operating, and end-of-use stages of implementing a project.

<u>Funnel metaphor</u>

To visualize the overall problem of the declining ability of the ecosphere (explained below) to support present-day human societies the funnel metaphor is used in TNS (see figure 1). Human activities such as overharvesting are leading to a decline of vital resources for human survival. The walls of the funnel represent the operating space for human survival, which are leaning in due to non-sustainable behaviour. Furthermore, demand for resources is increasing which leads to more narrowing. In order to achieve health and prosperity, activities need to be directed to the opening of the funnel or to the widening of the walls. If human action is directed at the walls of the funnel these actions will be confronted with increasing "costs for waste management, taxes, insurance, resources, loans, loss of credibility in the market, and market shares lost to those who are planning ahead by skilfully taking [sustainability] aspects into account" (Robèrt, 2000, p245).

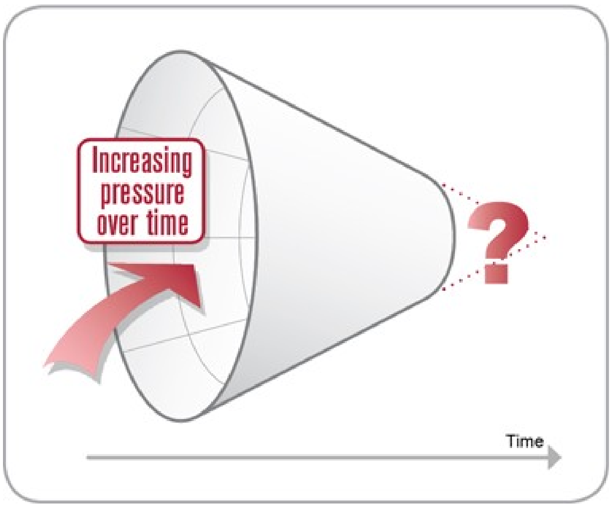

Figure 1: The funnel metaphor that shows the problem of non-sustainability in the TNS framework, copied from *Understanding the Problem* by TNS International (2016e).

The TNS framework is based on systems thinking so that the system as a whole needs to be considered in order to focus on the relevant issues (Holmberg and Robèrt, 2000). In order to deal with complex systems a five level model has been developed. Each level hierarchically depends on the others (see figure 2). These levels are explained below.

Figure 2: Hierarchical five-level model of the TNS framework to deal with complex systems, copied from *The 5 level framework* by TNS International (2016a).

<u>Systems level: Ecosphere</u>

The ecosphere refers to the entire space from the earth's crust to the ozone layer, in other words the biosphere and the entire atmosphere (Robèrt, 2000, Robèrt et al., 2002). The overall system that comprises of human societies and the ecosystems exist in the ecosphere. This is the starting point of the definition of principles for a sustainable future (Robèrt et al., 2002). The constitutional principles for the functioning of the ecosphere are used to determine by which mechanisms the ecosphere can be destroyed, in order to determine what (human) activities need to be avoided to create a sustainable future (Holmberg and Robèrt, 2000). These principles are: "(a) the principle of matter conservation, (b) the laws of thermodynamics, (c) the principles of the sun driven biogeochemical cycles, (d) the fact that the biosphere cannot sustain systematic shifts of its physical parameters (lower and lower pH, higher and higher concentrations of NO_x, smaller and smaller areas for renewable resources, [CO_2 equivalents], etc.), and (e) society's dependence on sustainable resource flows and services from the ecosphere" (Robèrt, 2000, p248). In figure 3 these principles are summarized visually.

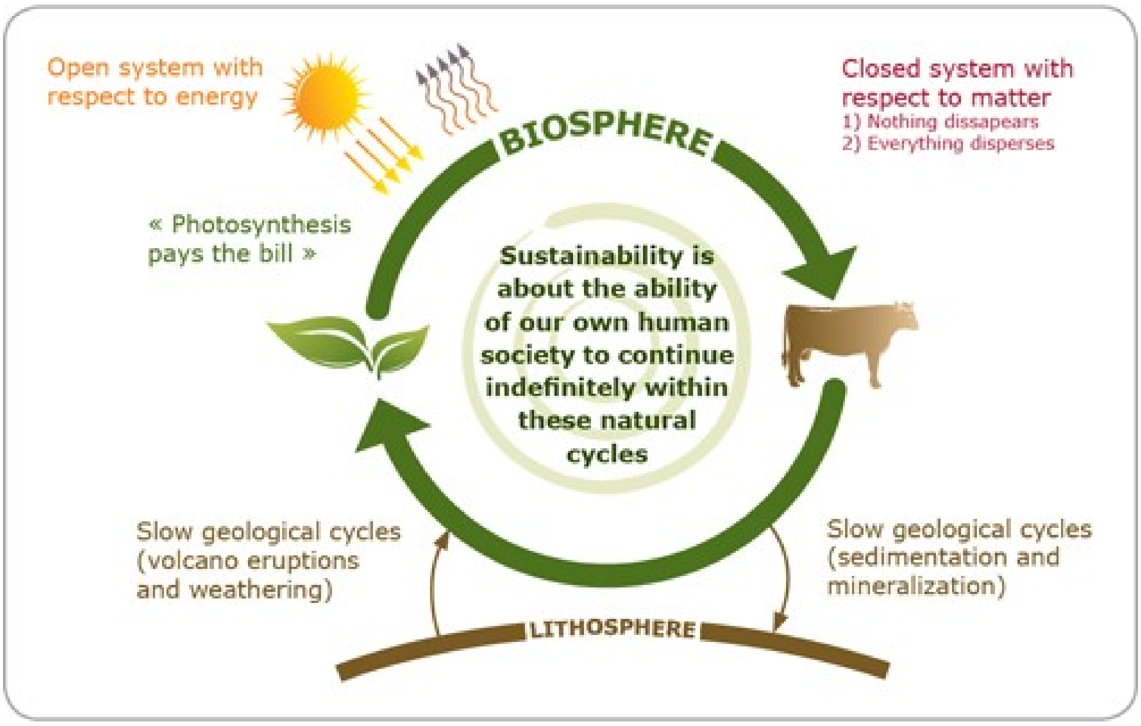

FIGURE 3: BASIC SCIENTIFIC LAWS OF THE ECOSPHERE TNS IS BASED ON, COPIED FROM *THE SCIENCE BEHIND OUR APPROACH* BY TNS INTERNATIONAL (2016D).

<u>Success level: Principles for sustainability</u>

To determine success, the goal of a sustainable future needs to be defined in specific terms. The TNS framework provides a structure of four complementary, non-overlapping system conditions for ecological and social sustainability. The three ecological system conditions are derived from the principles by which the ecosphere can be destroyed, followed by the word 'not' to aim for the opposite of these mechanisms (Robèrt et al., 2002). This is logical as sustainability only became a relevant expression when human activity created non-sustainability (Holmberg and Robèrt, 2000). The social system condition is simply aimed at meeting human needs, whilst taking into account the three ecological principles.

The four system conditions for sustainability are then defined as follows (see figure 4 for a schematic representation and annex 1 for further explanation). "In the sustainable society, nature is not subject to systematically increasing...

1. Concentrations of substances extracted from the Earth's crust.
2. Concentrations of substances produced by society.
3. Degradation by physical means.
4. And, in that society human needs are met worldwide" (Robèrt et al., 2002, p198-199).

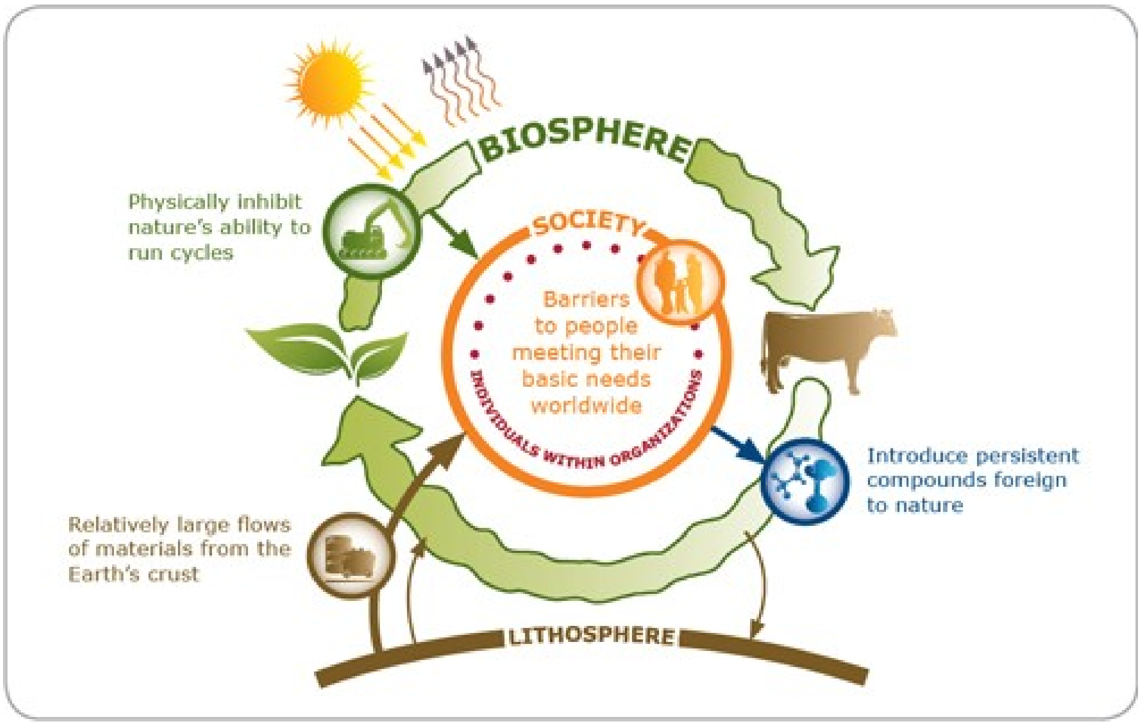

Figure 4: Schematic representation of the four system conditions defined by the TNS framework, copied from copied from *The Science Behind our Approach* by TNS International (2016d).

Using the four system conditions it is possible to formulate four principles of sustainability that describe the objectives for planning for the future. This leads to four definitive sustainability objectives (Robèrt et al., 2002):

1. Eliminate human contributions to the steady increase of concentrations[7] of substances in the ecosphere that originate in the lithosphere (Earth's crust). The objective is then to:
    a. Substitute lithospheric minerals that are naturally scarce in the ecosphere with ones that are naturally more abundant, as to keep the ecosphere balanced;
    b. Make efficient use of all mined substances;
    c. Steadily reduce human dependence on fossil fuels.
2. Eliminate human contributions to the steady increase of concentrations of substances fabricated by civilization in the ecosphere or lithosphere that are unnatural and persistent. The objective is then to:
    a. Substitute unnatural and persistent substances with ones that are naturally more abundant;

[7] According to the dictionary Concentration refers to "the amount of a particular substance within a solution or mixture" (Oxford University Press, 2005). In the case of TNS this means substances are transferred from the lithosphere to the ecosphere, thereby increasing their concentration in the ecosphere and decreasing their concentration in the lithosphere.

   b. Substitute unnatural and persistent substances with ones that biodegrade in biological cycles;
   c. Make efficient use of unnatural and persistent substances to ensure they are not released in natural environments.
3. Eliminate human contributions to the steady physical degradation of the environment by, for example overharvesting fish and trees, destroying habitats and other forms of modifications of natural ecosystems. The objective is then to:
   a. Only using resources from well-managed ecosystems;
   b. Make efficient use of resources and land;
   c. Apply the precautionary principle (explained below) for modifications of the natural environment.
4. Maximise human contributions to the steady increase of capacity of humans worldwide, now and in the future, for meeting their own basic needs. The objective is then to:
   a. Make efficient, fair, and responsible use of resources.

Strategic level: Process to achieve objectives

Investments for the future are planned at the strategic level. The TNS framework proposes four guiding principles to select investments that systematically move society in the direction of sustainability (Robèrt et al., 2002). This can be complemented by the ABCD planning method, which incorporates these guiding principles, graphically represented in figure 5 (Robèrt, 2000).

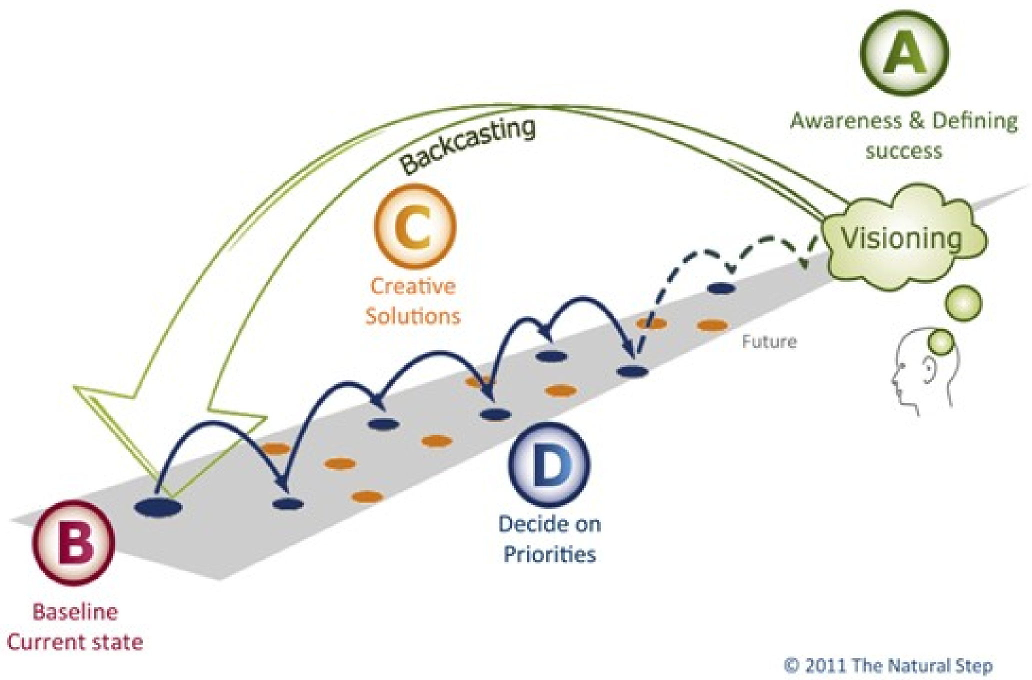

FIGURE 5: SCHEMATIC REPRESENTATION OF THE PROCESS TO ACHIEVE OBJECTIVES IN THE TNS FRAMEWORK, COPIED FROM *APPLYING THE ABCD PLANNING METHOD* BY TNS INTERNATIONAL (2016B).

Backcasting

The first guiding principle for the process level is backcasting. This is a planning methodology that uses an envisioned successful future outcome of the planning as the starting point. In the case of complex systems, where current trends, actions, and planning are part of the problem, using backcasting is essential to break with the current paradigm. This methodology ensures that the trends of today, such as customer preferences or company culture, only influence the pace and initial scale of the transition and not its direction (Robèrt et al., 2002).

Flexible platforms

In order to align current investments to future investments that aim to comply with the four sustainability principles, it is important that dead ends are avoided in the future. This means that the steps taken today need to provide technically feasible stepping-stones for future investments. This makes each investment a flexible platform to enable further and more far-reaching compliance with the four sustainability principles (Robèrt et al., 2002).

Within the realm of water and wastewater engineering flexibility, adaptability, and robustness are becoming increasingly important in face of the dynamics of new ambitions for sustainable urban water management and changing water demands due to economic development, urban sprawl, changing water use habits, technological advances, and climate change (Spiller et al., 2015).

Good return on investment

To select amongst several flexible platforms the guiding principle of good return on investment should be used to prioritize amongst them. According to Robèrt et al., good return on investment can for example be translated as relatively inexpensive, meeting a growing market demand, and/or foreseeing coming regulatory changes (2002). Moreover, selecting flexible platforms with a good return on investment ensures enough seed money is available to bring the technology to full fruition.

Precautionary principle

To avoid costly ecological or economic consequences, caution is advised when there are uncertainties on the ecological consequences of an activity (Robèrt et al., 2002). Moreover, when there is doubt if an investment that requires large amounts of resources complies with the four sustainability principles it is important to apply the precautionary principle (Robèrt, 2000). Lastly, it has been found that short-term economic arguments are frequently used to cover up an unwillingness to change well established routines. However, doing nothing is also a decision. The burden of proof to justify action should not be higher than the burden of proof for inaction according to rational reasoning. So inaction also requires caution (Robèrt et al., 2002).

ABCD planning method

To apply the four sustainability principles and guiding principles to the process a four step planning method is proposed by Robèrt (2000). Step A is a shared mental model, step B is looking at today´s situation, step C is thinking about tomorrow, and step D is the design of a strategic program. More information is provided in annex 1.

<u>Actions level</u>

At the actions level it is important to act in coherence with the constitutional principles for the functioning of the ecosphere, which are translated into the four principles of sustainability and have been incorporated in the strategy planning. In other words, activities should be selected according to a complete sustainability perspective. In order to facilitate this, tools and concepts that comply with the four principles of sustainability should be selected to help select and monitor appropriate actions and facilitate sustainable design (Robèrt et al., 2002).

Tools and concepts level

To manage actions successfully, the TNS framework proposes to use a selection of tools, concepts, and metrics which are based on a total systems perspective. On the one hand they help audit progress towards sustainability by focusing on evaluating how the actions comply with the strategic plan and four principles of sustainability. On the other hand they help to monitor the actual impacts in the ecosphere (Robèrt et al., 2002). The TNS framework lists on their website what they consider excellent sustainability tools. These include Environmental Management Systems, ISO 14001, Life Cycle Assessment, Biomimicry approaches, cradle to cradle design, Factor 10, Natural Capitalism, Ecological Footprinting, and Zero Emission (TNS INTERNATIONAL, 2016a). As the focus of this thesis research lies on technical future proof design, the cradle to cradle methodology is used to provide further guidance on design.

Cradle to cradle

Using the TNS framework in combination with the cradle to cradle as a design concept will lead to a future proof design by definition. When a design complies with the four sustainability principles of TNS it will be aimed at the opening of the funnel where a prosperous and healthy society awaits (Robèrt, 2000). On the tools and concept level of the TNS practical sustainability tools are used to guide sustainable actions and design. For several reasons the cradle to cradle design concept fits the purpose of this research best as a guiding concept for sustainable design of closed water and nutrient loops in households. First, all Dutch Water Boards are active with the cradle to cradle concept in the Energy and resource factory (Waterschap Brabantse Delta, 2012, EFGF, 2016e). Moreover, both the Dutch foundation for applied water research STOWA and the Dutch KWR Watercycle Research Institute use the cradle to cradle concept to guide sustainability issues in their research and design, especially when focusing on new technology development (Boekel and Van Weeren, 2010, Hofs and Jong, 2012).

Second, several scholars see cradle to cradle as a valuable guiding principle for future design of the urban water chain and strategic thinking (Verstraete and Vlaeminck, 2011, Kopnina, 2015). Cradle to cradle thinking has also been firmly embedded as one of the founding principles in the Circular Economy framework which is a framework for an economy that is restorative and regenerative by design (EMF, 2013). The Circular Economy has been embraced by the European Commission (2015) with an ambitious mandate and action plan, as well as by numerous corporations, governments and cities, academic institutions, emerging innovators, small and medium sized enterprises (SMEs), and affiliates (EMF, 2015).

Cradle-to-grave

Cradle to cradle design is a concept that was developed by architect McDonough and chemist Braungart, which incorporates several earlier sustainability concepts such as biomimicry (García-

Serna et al., 2007) to come to a comprehensive methodology to guide sustainable future proof design. According to McDonough and Braungart (2002, p26)): “Neither the health of natural systems, nor an awareness of their delicacy, complexity, and interconnectedness, have been part of the industrial design agenda.” In the early days of the industrial revolution innovators believed that natural capital was in endless supply. There was no concern for the degradation of the natural environment and ecosystems because there was a widespread view of nature as a mother earth that was everlastingly regenerative and was able to absorb anything while continuing to grow. Moreover, Western societies still saw nature as a dangerous, hostile force that had to be civilized and controlled by man (McDonough and Braungart, 2002). This view may have been a key to human survival in earlier centuries, however coupled with industrialization it became a threat to ecosystem services that humans depend on for survival, health, and prosperity. The result is, according to McDonough and Braungart (2002) that currently products are designed on a linear, one-way cradle-to-grave model of which modern day sewage systems are a classic example (McDonough and Braungart, 2002).

Intention for eco-effectiveness

In order to go from cradle-to-grave to a cradle-to-cradle design of products and society, McDonough and Braungart (2002) offer the cradle to cradle design concept which helps answer the question of intention. They start with a vision for a future world that the designer wants and the follow up question of how to make designs that align with this vision. The answer to this question is, analogous to the backcasting from a vision in the TNS framework, the start of a cradle to cradle design for a product or service. Eco-efficiency in the cradle-to-grave linear model is described as being less bad and thus aiming to get more from less, like less waste, resource use, or toxicity. Cradle to cradle conversely design aims instead for eco-effectiveness, which “designates all outputs from human activity as positive – healthy waste is good – and makes people native to the planet once more by re-establishing a positive link between human activity and natural systems” (Braungart et al., 2007, p1342). Eco-effectiveness envisions an industrial system which is “100% good” and aims to regenerate ecological systems and creates long-term economic prosperity (Braungart et al., 2007, p1342). Figure 6 shows the difference between eco-efficiency and eco-effectiveness.

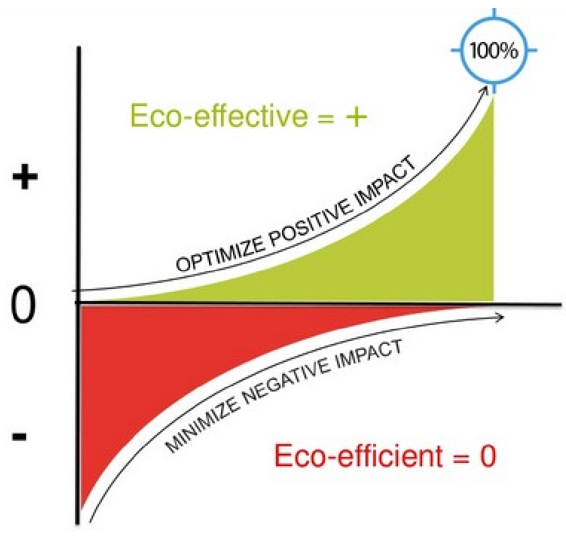

FIGURE 6: GRAPHIC REPRESENTATION OF ECO-EFFICIENT VERSUS ECO-EFFECTIVE, TIME ON THE X AXIS AND IMPACT [%] ON THE Y AXIS, COPIED FROM *STRIVING FOR ZERO?* BY MBDC (2016B), MCDONOUGH BRAUNGART DESIGN CHEMISTRY, LLC.

Circular, closed loop, biological, and technical metabolisms

In order to go from a linear to a cradle-to-cradle, circular closed loop system, McDonough and Braungart (2002) identified two separate metabolisms, the biological and technical cycle. It is possible to close these loops when three principles are adhered to. These principles are:

1. *Waste equals food.* Products and materials need to be designed for life cycles that are safe for human and environmental health. Moreover, products and materials need to be able to be reused endlessly in either the biological or technical closed loop in order to recover their value after use.
2. *Use current solar income.* Renewable energy needs to be used for all power needs to the maximum.
3. *Celebrate diversity.* Both human and natural systems need to be respected. This translates to managing water use and cascading different qualities of water. It also means promoting healthy ecosystems and respecting impacts at the local level. Lastly, it can refer to employing corporate social responsibility for internal and external stakeholders (MBDC, 2016a, McDonough and Braungart, 2002).

Materials become nutrients in either the biological or technical metabolism. Biological nutrients are biodegradable and do not pose a threat to ecosystems or human health in the short or long term. They can be safely returned to nature as food for biological processes. Products made from biological nutrients are called products of consumption. Conversely, technical nutrients need to stay safely in a closed-loop system of manufacture, recovery, and reuse, and not enter biological systems. Perhaps they are toxic materials for which the consumer does not want liability, or the materials are too valuable to lose to landfills, like rare metals. Technical nutrients are used to make products of service, which stay in ownership of the manufacturer, but are used by the customer for a certain use period in return for a fee (McDonough and Braungart, 2002, Braungart et al., 2007). Figure 7 shows an elaborated scheme with options for upcycling materials or products of the biological and technical cycle. This scheme describes the basics of the Circular Economy concept that was built on cradle to cradle.

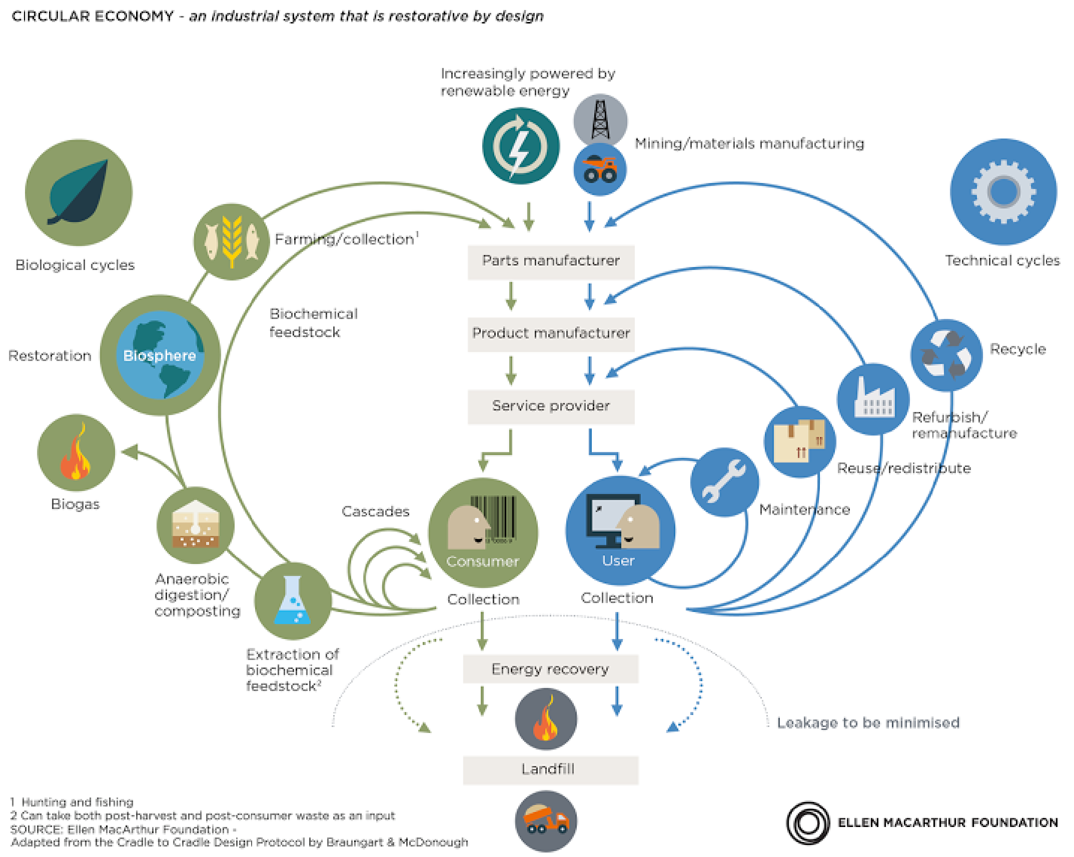

Figure 7: An elaborated scheme of the biological and technical cycles in a Circular Economy, leakage to the linear process of energy recovery and landfill has to be minimized and completely avoided in the future, copied from *A new version of our 'butterfly diagram'* by Webster (2016).

Five step strategy for eco-effective design

Braungart et al. (2007) argue that starting with an existing more or less eco-efficient product it is possible to transition to an eco-effective alternative in five steps. The basic purpose is to continue to fulfil the ultimate need for which the original product or process was intended, but in a completely reinvented way, without toxicological and ecotoxicological substances.

Step 1: Removal of X-substances

The most dangerous substances to humans and the natural environment are called X-substances. These should be removed or replaced. However, TNS's principle of precaution also applies here. It should be certain that the substance that is to replace the X-substance is less harmful (Braungart et al., 2007).

Step 2: Educated choices

It is often impossible or totally unrealistic to have detailed knowledge of all the impacts of each substance contained in a product or process on the health of humans and the natural environment. Making choices then comes down to educated guesses based on the best available sources of information at that time (Braungart et al., 2007).

Step 3: Classification of suitability of a substance for the biological metabolism

A systematic assessment of all the ingredients present in a product or process should be undertaken. The substances then need to be classified according to their toxicological and ecotoxicological characteristics. This shows how suitable substances are for safe cycling in the biological metabolism (Braungart et al., 2007).

Step 4: Choosing substances to fit biological or technical metabolisms

At this point in product or process design only substances that can be positively defined as an ingredient for either the biological or technical metabolism can be used. This will lead to a fully redesigned product that fits a closed-loop circular system (Braungart et al., 2007).

Step 5: Reinvention

Looking at the intention of the product or process instead of the current design, it may be possible to fully redefine the product as a service that fulfils the same need or fulfils it even better than the old design (Braungart et al., 2007). This has been further elaborated in the Circular Economy concept, which does not only look at product design but at a total redesign of the industrial system in order to make it regenerative. Judging by the number of important advocates of the Circular Economy and the positive economic benefits expected from its implementation, this concept may become an important driver for more and more cradle to cradle designs of processes and products (EMF, 2013). This development will help take full advantage of the 'design-filter' in designers heads, which according to McDonough and Braungart (2002) is much more effective than a filter at the end of the pipe.

Vision

A long-term vision is the basis of a sustainable, future proof design, according to the TNS framework and cradle to cradle. Beck (2011) agrees. He states that it is in the nature of water engineers who want to minimize the risk of failure, to only see *one* set of indicators as *the* way to become sustainable. However, in order for water engineers to become more sustainable and adopt a more pluralistic view, adoption of a long-term vision is needed.

As in the scope of this research it is not possible to arrive at case specific visions together with stakeholders, literature about several existing visions for (waste) water infrastructure has been searched. These visions from literature have been adapted in order to provide a basis for the vision for the rural and urban case. Beck (2011, p5) proposes an overarching vision with the intent to:

"re-engineer[... the] urban water infrastructure so as to make the city a force for good in its watershed" (Beck et al., 2010).

He states that this definition is quite vague on purpose, just like the Brundtland definition of sustainability. This will similarly help to inspire, motivate, and innovate the daily practice of engineering in the water sector. Moreover, change and flexibility to deal with change are pivotal to sustainability and its assessment. So even though the wastewater sector is dominated by engineers who prefer to work on objective goals, reaching sustainability through long-term vision requires a certain degree of subjectivity, especially in the assessment of performance (Beck, 2011). Examples of innovative wastewater projects studied by Hegger (2007, p198) also show that "there is no 'objectively provable' best direction for change. Experts may find out that, confronted with others' points of view, the value of their expertise comes to stand in a different light." In the cradle to cradle design concept this subjective element of making a design is referred to as the need for making educated choices.

Based on the overarching vision Beck (2011) proposes four different future visions for waste (water) infrastructures or city metabolisms. It is not possible to quantify the advantages and disadvantages of these future visions because these visions are far off in the future. As the TNS framework and the cradle to cradle design concept explain (see above), the purpose of these visions is to invoke innovation and break with the current paradigm. Quantifying the visions means making too many assumptions about future parameters to render a realistic result. Instead educated choices of experts and input from stakeholders are used to choose and adapt a vision for a specific case. The four visions of Beck are described below and represent the choices that can be made for the future vision of specific cases of waste (water) infrastructures.

Vision 1: Water-based wastewater infrastructure Global North, based on Beck (2011)

The first future vision is the current technocratic water-based wastewater infrastructure of cities in the Global North (see figure 8A). This infrastructure has been engineered by combining the disciplines of civil engineering, chemical, and environmental engineering. The main goals are that the unpredictability of the weather, principally precipitation, does not affect the daily routine of receiving water, maintaining hygiene, and public health security. This vision also continues to support the flush-and-forget mentality of the users (Harder, 2012). The lock-in to this technological solution has had three consequences:

1. There is no symbiosis of urban-rural nutrient flows anymore (Tervahauta, 2014);
2. Nutrients and other unnatural and persistent substances from excreta are fully diverted to the aquatic environment when no wastewater treatment is present. In the Global North these substances are mostly removed from wastewater and become partly wastewater treatment plant sludge which is incinerated and then placed in a landfill or reused (Tervahauta, 2014). Previously this is not where they would have ended up;
3. Increased hygiene and fewer disease epidemics allowed for large population shifts towards urban environments (Beck, 2011) although currently slums without sewers, let alone wastewater treatment, attract large populations in the Global South. Present day drivers are rapid population growth and reduced economic opportunities in rural areas (AfDB, 2012).

Under this scenario current personal choices for diets are assumed to stay unchanged in the future. Diets have a great impact on global water distribution. Input of water into households is not only from tap water, but also “virtual water”, which was needed for food and fibre production (Allan, 2003, SIWI-IWMI, 2004). Likewise, virtual nutrients are linked to food and fibre consumption (Grote et al., 2005). However, diets and consumption patterns are not part of this thesis as water footprints and nutrient footprints are outside the scope.

This centralized state of business as usual is not a long-term sustainable option in terms of the overarching vision of Beck (2011). This has also been discussed in chapter one of this thesis report.

Vision 2: Water-based wastewater infrastructure Global North with resource recovery, based on Beck (2011)

In this second vision the technocratic water-based wastewater infrastructure stays in place, but end-of-pipe changes are made to recover, for example, water, nutrient, and energy resources (Guest et al., 2009) (see figure 8B). The disciplines of green chemistry and information technology are combined with civil, chemical and environmental engineering to arrive at new technologies. Application of this vision to technology will fix the occurrence of harmful effects in distant downstream environments, such as marine algal blooms (Billen et al., 2007). The recovery of some nutrient and energy sources does make it more eco-efficient (as opposed to eco effective which is the aim of the cradle to cradle design philosophy) than the vision of 8A. Public health is also secured because there is constant availability of clean water for hygienic purposes, regardless of precipitation. The comfort of flush-and-forget is also maintained.

The distant connections with virtual water and nutrient intakes into households from all over the globe are not translated into a change of behaviour of people's diets or consumption patterns. However, as said earlier water and nutrient footprints are outside the scope of this thesis.

This second vision also does not constitute a long-term sustainable option but should be classified as a parasitic ecosystem (Beck, 2011, Odum, 1989). With other words, the system created by humans is at the expense of nature, risking collapse of ecosystem services. Instead Beck (2011) argues we should take on the challenge of Otterpohl et al. (1999) who state that once the issue of urban public health is resolved, the urban wastewater infrastructure needs to prioritize on keeping soils fertile. As carbon rich soils provide a number of ecosystem services needed for human survival as explained in chapter one.

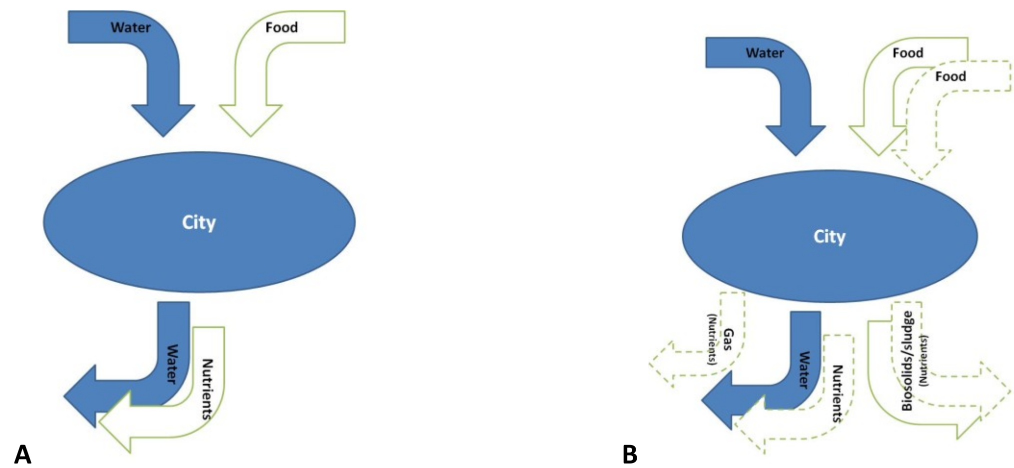

FIGURE 8: 8A: "CURRENT WATER-BASED WASTEWATER INFRASTRUCTURE OF CITIES IN THE GLOBAL NORTH" ADAPTED FROM BECK (2013, P466) AND 8B: "THE CURRENT PARADIGM OF THE GLOBAL NORTH BENT TO SOME OTHER PURPOSE, FOR EXAMPLE, THE RECOVERY OF RESOURCES FROM THE SOLIDS (SLUDGE) STREAM, WITH YET RESOURCE LOSSES TO THE WATER AND ATMOSPHERIC MEDIA" ADAPTED FROM *WHY QUESTION THE PREVAILING PARADIGM OF WASTEWATER MANAGEMENT?* BY BECK (2013, P466), IWA PUBLISHING.

Vision 3: Separated water and nutrient reuse infrastructures with lifestyle change, based on Beck (2011)

The third vision overhauls the water-based wastewater infrastructure in order to fully separate the nutrients from the water (see figure 9C). This is not done end-of-pipe but right at the source where currently nutrients and water are combined. It is apparent that this option will require a lifestyle change by users in facilitation of a new type of sanitation (Beck, 2011). In this thesis the diet and fibre consumption is left out of scope, although they could have a large impact on the water and nutrient footprint and thus their displacement globally.

A logical conclusion is that this system will be able to rectify to a great extent the distortions of global metabolisms by resource recovery including water (Beck, 2013). Ecosystem services can be restored or even improved, both in the direct downstream watershed as in the distant ecosystems connected by imported food and fibre (Beck et al., 2010), the latter being out of scope of this thesis. This is in line with the challenge of Otterpohl et al. (1999) to focus on fertile soils after public health is secured. However, seen from today's trends, both economically and socially this vision represents a disruptive transition, which makes implementation difficult (Beck, 2013, De Graaf and Van Hell, 2014).

Vision 4: Dry sanitation system as maximum eco-efficient water metabolism, based on Beck (2011)

Focal point of the fourth and last vision is some version of an earth closet or composting toilet (see figure 9D). Such a toilet does not require water and generally separates urine from faeces. When urine and faeces are not separated, urine is ventilated up to 80%-100% by an (electric) fan. When leachate occurs, it can be separated and tapped occasionally. In larger applications urine separation is advised with a no-mix toilet to ensure optimum composting (Berger Biotechnik GmbH, 2006).

Composting toilets can be applied to ground bound residential houses or apartment buildings (Berger, 2003). The goal is to fully separate the nutrients from the water, but also to minimize the water usage to a minimum. Collecting faeces and urine in this way means there is no direct introduction of human waste in the water cycle. Contact with human waste would be indirect. On the one hand this would be when transporting the waste from the toilet to the treatment location. On the other hand when the treated waste is reused on (agricultural) land through groundwater systems or the atmosphere, if it is dry enough to be picked up by the wind (Beck, 2011).

Water and nutrient reuse will be optimal, because water is not contaminated by faeces and urine and relatively easy to clean for different qualities of reuse (Hernandez Leal et al., 2010). So discharge into the surrounding surface water is minimal. Nutrients can be recovered more energy efficiently because of the high concentrations when there is no water diluting the substances (Beck, 2011). This implies a high degree of recycling to (urban) agriculture directly with compost or indirectly with fertilizer products (Beck, 2013).

Logically, this vision is the most sustainable, although it does present a challenge of sufficiently dealing with risk of pathogens and public health as well as achieving adequate comfort in order to become a viable option for cities (or rather citizens) in the North who are now enjoying centralized waster-based infrastructure and flush-and-forget sanitation as depicted in figure 8A (Beck, 2011, Beck, 2013).

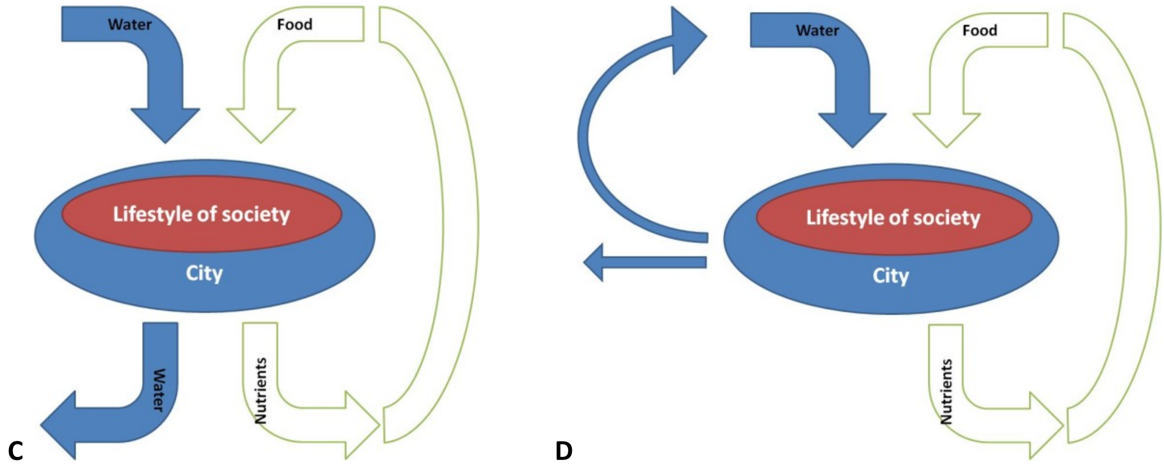

FIGURE 9: 9C: "FUTURE VISION OF [SEPARATED] WATER AND NUTRIENT [REUSE] INFRASTRUCTURES, INCLUDING A CHANGE OF LIFESTYLE" (BECK, 2013, P466) AND 9D: "THE LOGICAL LIMIT OF A MAXIMALLY ECO-EFFICIENT CITY WATER METABOLISM, THAT IS, WITH A DRY SANITATION SYSTEM" " ADAPTED FROM *WHY QUESTION THE PREVAILING PARADIGM OF WASTEWATER MANAGEMENT?* BY BECK (2013, P466), IWA PUBLISHING.

Criteria for selecting stepping stone technologies/processes

Compliance with the four system conditions which lead to the four principles of sustainability and accompanying four sustainability objectives of TNS means a design is future proof in theory. Of the four visions for the future waste (water) infrastructure the four objectives are met least by vision 1 and most by vision 4. According to Beck (2011) the most sustainable are for vision 3: "Separated water and nutrient reuse infrastructures with lifestyle change" and vision 4: "Dry sanitation system as maximum eco-efficient water metabolism". Each specific location may have a different future vision for 60 years from now, based on location specific opportunities or constraints. The author expects the difference to be largest (within the boundaries of The Netherlands) between a rural and an urban case, which is why these were selected to study. Main reasons for this are differences in population densities, types of buildings, and proximity to agricultural land. In chapter 3 the future visions for each of the cases studied are elaborated.

In order to use the future vision as the starting point for backcasting, specific indicators are needed to select stepping stones, or flexible platforms, today. These indicators help prioritize between currently available technologies and may also help direct investments in research for upcoming technologies. This ensures that current developments in wastewater collection, transport, treatment, and reuse enable the implementation of future innovations that aim towards a (more) fully sustainable future. Furthermore, there are some basic requirements that the waste (water) infrastructure in The Netherlands needs to comply with, which partly overlap with the sustainability principles. Water reuse has been omitted from this table because in the Dutch situation there is no structural water shortage foreseen in the foreseeable future (Rijkswaterstaat, 2016). These are summarized in table 1.

TABLE 1: BASIC REQUIREMENTS OF WASTE (WATER) INFRASTRUCTURE FOR THE DUTCH SITUATION, BASED ON HARDER ET AL. (2013) AND BECK (2011)

Requirement (geographic scale)	**Description**	**Suggested sub requirements**
Public health (local & community)	Prevention of diseases related to (in)direct contact with pathogens and	Public health Safety (from dangers other than

	harmful substances, such as micropollutants or metals, in faeces and urine	public health)
Convenience (local & community)	The system should comply to the demands for user-friendliness and convenience of the users, keeping in mind that these are cultural norms which are in constant flux and different for cultural subgroups	Acceptance by users Service quality Maintainability Controllability
Recovery of nutrients and resources (city)	Uncouple water and nutrient cycle as much as possible. Apply source separation. Avoid or remove micropollutants in black water, greywater or dry faeces and urine streams	High quality products
Water quality (watershed)	Robust systems that prevent discharge of untreated effluent of water based sanitation or faeces and urine from dry sanitation in the surface or ground water	Robustness for malfunction Sensitivity for failure Vulnerability Resilience (recovery malfunction)
Sustainability (global)	Enhance ecological resilience	Ecologically resilience (enhanced with high quality effluents or deposits)

A set of measurable criteria for collection, transportation, treatment, and reuse of water and nutrients in the Dutch wastewater sector was made by taking into account the four sustainability principles of TNS, TNS's guiding principles, the cradle to cradle design process principles, and the basic requirements for waste (water) infrastructure. Part of these criteria are scored on a five point Likert scale, ranging from ++ to --. This scoring method was chosen because judgement on the score is not completely quantifiable and hence an educated choice needs to be made by the scoring party. Other indicators are quantifiable and here a percentage from 0% to 100% (rounded to whole numbers) was chosen to represent the scores. The number may still be based on assumptions, but a percentage can be calculated with reasonable certainty. A score of ++ or 100% implies the stepping stone technology/process is future proof in respect to this indicator. No weights were given to the different indicators, as this would require an expert panel to assign weights according to the importance of each criterion. So the scores cannot be accumulated into one single score.

Please note, these indicators are meant to assess the sustainability of the chosen stepping stone technologies/processes, but they do not assess the entire feasibility of the technologies for the specific situation, such as in terms of footprint (m^2) and costs. Also, these are criteria applicable in the Dutch situation today. This means they do not take into account a possible shift in habits like diets or hygiene, which may spark the need for additional, altered, or removal of indicators. This does not mean that stepping stone technologies/processes that ask users to change their lifestyle are discouraged. It only means they are not scored on this aspect.

Vision

1. A **vision for** the long-term of **60 years**[8] **in the future** is selected that fits the specific opportunities and challenges of waste (water) infrastructure of the case at hand.

   Scored ++, +, +-, - or --.

Waste equals food

2. Total **phosphorous** (P) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) since phosphorous is a fossil resource (Cordell, 2013).

   Scored as percentage (of kg P input).

3. Total **nitrogen** (N) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) since reactive nitrogen, which is a small by-product from wastewater treatment, unbalances the natural nitrogen cycle (Erisman and Larsen, 2013).

   Scored as percentage kJ saved by RECOVERY (of kJ N baseline embedded energy input).

4. Total **potassium** (K) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) since potassium is a fossil resource (UNEP, 2001, Schönning, 2001).

   Scored as percentage (of kg K input).

5. If cellulose is recovered as a separate stream[9] : Total **cellulose** entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as useful product which can be cellulose, biogas – when combined with other organic matter - or another resource) since cellulose in wastewater mostly originates from toilet paper which is mostly made from virgin wood (Wüstenberg, 2015).

   Scored as percentage (of kg Cellulose input).

6. Total **organic matter** entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse, as biogas, fertilizer, or bio-building block for bio plastics e.d. (EFGF, 2016e, Zeeman, 2016b).

   Scored as percentage (of kg organic matter input)

[8] 60 years in the future, as this is how long average Dutch sewers last, which is the longest asset in the wastewater chain OOSTEROM, E. & HERMANS, R. 2013. Riolering in beeld - Benchmark rioleringszorg 2013. Ede: RioNED.

[9] If cellulose is not recovered as a separate stream it is added to total organic matter, indicator #6.

7. **Nutrient/resource input**[10] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with TNS's four sustainability principles.

   Scored ++, +, +-, - or --.

8. **Quality of effluent or residual waste** from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem by applicable governmental standards[11].

   Scored ++, +, +-, - or -- [12].

9. Recovered nutrient is free of unnatural and persistent substances such as **micropollutants** (from pharmaceuticals, hormones, and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of **metals** (Tervahauta, 2014) or other unwanted by-products from treatment[13].

   Scored ++, +, +-, - or --.

Use current solar income

10. Total **direct heat** energy content from natural gas entering the residential building and exiting the combined sanitation & kitchen waste (water) stream recovered for reuse since direct heat recovery lowers the household demand for natural gas which is currently the main source of heating for water in The Netherlands (Milieu Centraal, 2016b).

    Scored as percentage direct heat recovery (of GJ direct heat input from natural gas in households).

11. **Energy** generated (or lost) by collection, transport, treatment, and recovery of the combined sanitation & kitchen waste (water) stream[14].

    Scored ++, +, +-, - or -- [15].

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[10] Materials and chemicals (not energy).
[11] Please note, as micropollutants currently are not regulated in The Netherlands, their presence in effluent or residual waste does not influence this indicator. However, removal of nutrients is important.
[12] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.
[13] This is excluding recovery of micropollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scales.
High purity and low toxicity can be reached by avoiding the entrance of micropollutants and metals into the waste (water) stream by cultural and lifestyle changes and avoiding combination of wastewater streams (TERVAHAUTA, T. 2014. *Phosphate and organic fertilizer recovery from black water.* PhD, Wageningen University.) An example of a lifestyle change is the use of more ecological pharmaceuticals or cosmetics (source STOCKHOLM COUNTY COUNCIL 2012. Environmentally classified pharmaceuticals.)
[14] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.

12. The **trade-off** between **energy** production and production of **recovered nutrients** has been given consideration with regard to optimizing positive environmental impact[16].

    Scored ++, +, +-, - or --.

Diversity

13. **Technical knowhow** to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

    Scored ++, +, +-, - or --.

14. **Benefits** from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources, or an attractive treatment facility that mimics nature[17] for recreation or landscape purposes, are allocated and accessible to the **communities** where the waste (water) originates from.

    Scored ++, +, +-, - or --.

15. **Users accept the system**, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

    Scored ++, +, +-, - or --.

16. The stepping stone technology/process has **high convenience** in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

    Scored ++, +, +-, - or --.

17. The chosen system/process is **robust**: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

    Scored ++, +, +-, - or --.

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[15] When there is more energy used for collection, transport, treatment, and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.

[16] For example, does energy recovery from incinerating sludge mean that fossil, mined phosphorous becomes difficult, impossible, or very energy intensive to recover? This would be conflicting with TNS's sustainability principle 1.

[17] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

18. (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence **public health is optimized**.

    Scored ++, +, +-, - or --.

19. If locally there is poor, infertile soil, the waste (water) effluent is used to **increase local soil fertility**.

    Scored ++, +, +-, - or --.

20. Relevant **stakeholders** are actively involved in the design process.

    Scored ++, +, +-, - or --.

Flexible platforms

21. Investment in technology today does not block the future proof technical design implementation, so only investment in **flexible platforms**.

    Scored ++, +, +-, - or --.

Good return on investment

22. Investment in flexible platform technology today has a **good return on investment**[18].

    Scored ++, +, +-, - or --.

Precautionary principle

23. Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles, so taking **precaution**.

    Scored ++, +, +-, - or --.

24. Inaction or business as usual is not undertaken without **conscious consideration** of the consequences **of inaction**.

    Scored ++, +, +-, - or --.

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[18] Refers to all types of value, including financial and investment in future technology development, but also prosperity in the broader sense than just financial profit.

Chapter 3: Rural and urban renovation case descriptions

Case descriptions

In this research two, partially fictive, Dutch cases are studied to apply and fine-tune the indicators and to determine what would be the most future proof stepping stone technologies/processes that can be applied for each. Furthermore, the focus lies on either only renovation of buildings; renovation of buildings and internal and external infrastructure; or only renovation of external infrastructure with minor changes to the internal infrastructure of buildings. One case focuses on a rural cluster of buildings and one case on a densely populated urban area. The rural case is the village centre of Exel in the municipality of Lochem. The urban case is the Centrumeiland IJburg in the municipality of Amsterdam.

Description of the rural case: Exel

The village centre of Exel, in the municipality of Lochem, The Netherlands, (see figure 10) is surrounded by forest area in the south and agricultural area in the north. The buildings consist of 61 residential homes with a garden of which 32 are connected to a combined rain water and wastewater gravity sewer. The remaining 23 are connected to a separate gravity sewer with only wastewater which will be expanded by 6 houses in the near future. It is however assumed that all rain water from all houses is disconnected from the sewer. Furthermore an old school building which is currently inhabited, a restaurant “De Exelse Molen”, and an agricultural contractor are located within the village boundaries. The wastewater of all these buildings is transported to a pumping station to the south of the village where the wastewater is transported through a pressure sewer to the main gravity sewer to the wastewater treatment plant of Zutphen (see figure 11 and figure 12), which has conventional biological treatment of wastewater (Stichting Nederlandse Watersector, 2016). It is assumed that the pressure sewer is at the end of its economic lifetime, although it is still functioning properly. An average house in Lochem has a floor surface of 149 m^2 (Bunschoten, 2012).

FIGURE 10: AERIAL PHOTOGRAPH OF EXEL, COPIED FROM *HAALBAARHEID AFKOPPELEN BUITENGEBIED EXEL* BY VAN DEN BULK AND TELKAMP (2015), TAUW BV.

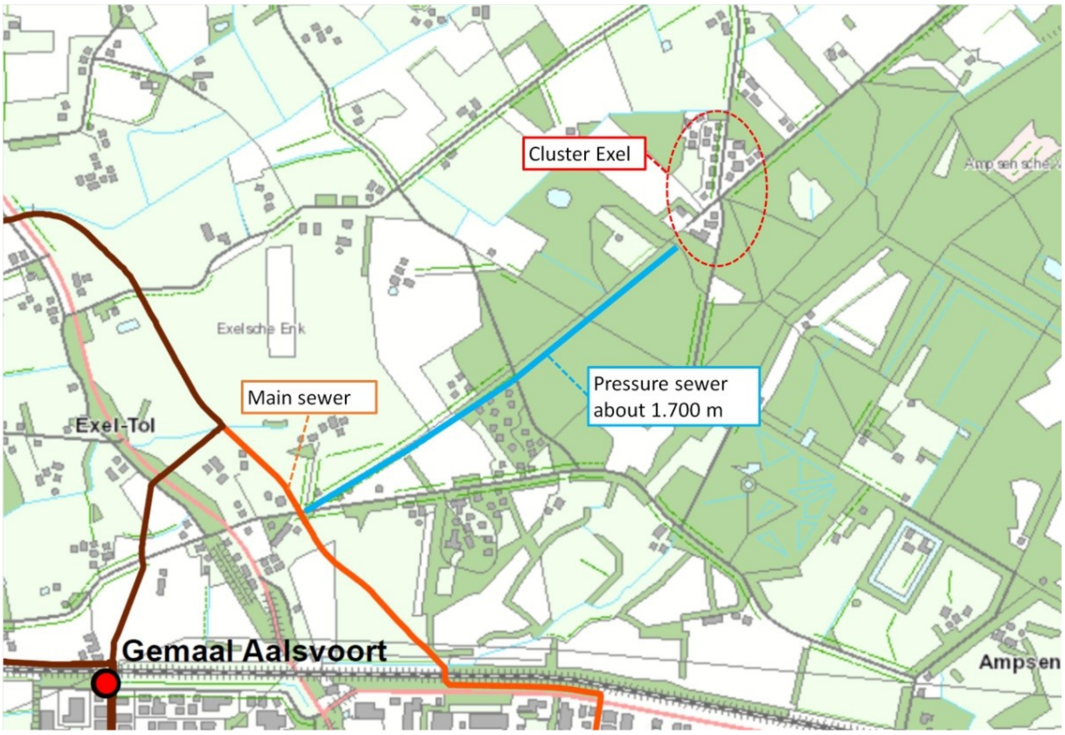


FIGURE 11: PRESSURE SEWER CONNECTING EXEL TO THE MAIN SEWER COPIED FROM *HAALBAARHEID AFKOPPELEN BUITENGEBIED EXEL* BY VAN DEN BULK AND TELKAMP (2015), TAUW BV.

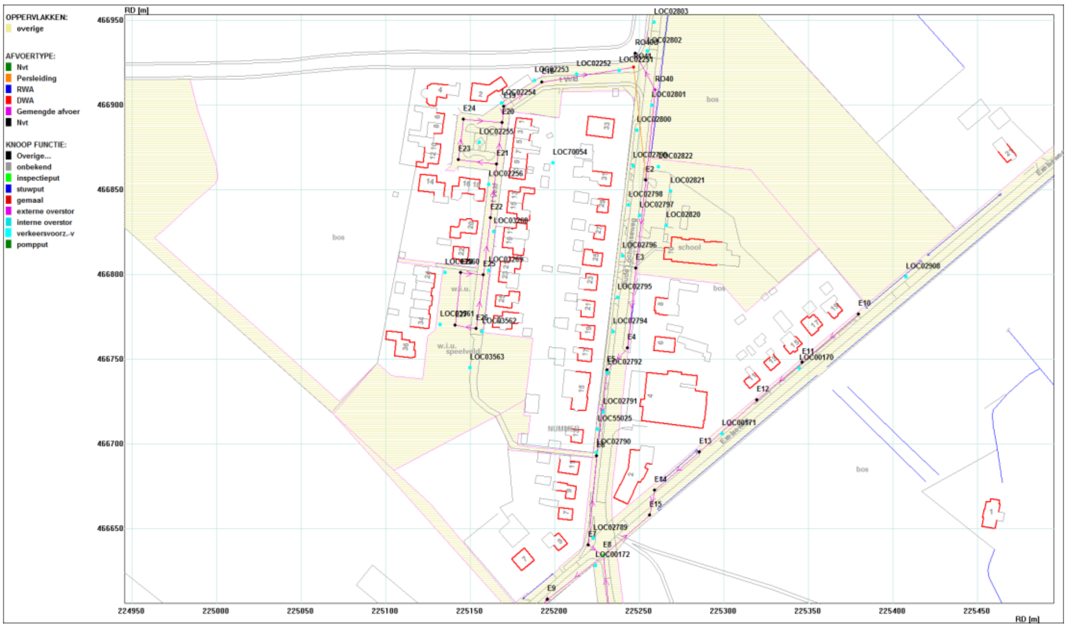


FIGURE 12: HOUSEHOLD SEWER CONNECTIONS IN EXEL, COPIED FROM *HAALBAARHEID AFKOPPELEN BUITENGEBIED EXEL* BY VAN DEN BULK AND TELKAMP (2015), TAUW BV.

The houses are all in individual ownership and will not simultaneously be renovated. When changes need to be made to existing houses, this will be done mostly at a natural replacement interval, at the end of the technical or economic lifetime of toilets or bathrooms or when homes change ownership. It is assumed that the typical layout of a ground bound home is applicable to the houses in Exel (see a schematic drawing in figure 13). This means that brown and yellow water are combined in the toilet as black water and this is mixed with greywater in the building before it exits the building in one pipe that is connected to the sewer. It is assumed that there are on average 3 inhabitants per household. The age demographics are shown in table 2 and other demographic characteristics in table 3. Compared to the urban case, Exel has a low population density and relatively few inhabitants in their twenties and thirties and many inhabitants in their fifties.

The six planned new houses could be simultaneously built and implement the same waste (water) infrastructure, either centralized or decentralized. It is however unclear when these homes are going to be realized. So it is assumed that for the entire housing stock of Exel only minor changes to the indoor piping and installations can be realized and that the main change could be made in the sewer infrastructure which is currently at the end of its economic lifespan. The soil build-up in Exel is shown in figure 14 and the surface area use in the municipality of Lochem in table 4. From this it can be concluded that the soil is suitable for wastewater treatment effluent infiltration (Van den Bulk and Telkamp, 2015).

The restaurant and the contractor will be excluded from analysis for several reasons. First, this makes comparison with the urban case better as this will also only comprise of households. Another reason is that there are no numbers available for water and nutrient flows for these companies, so inclusion would be based solely on assumptions and not real data. Third, to make this case reproducible for other urban clusters the exclusion of specific business activity is logical. It is then better applicable to other situations.

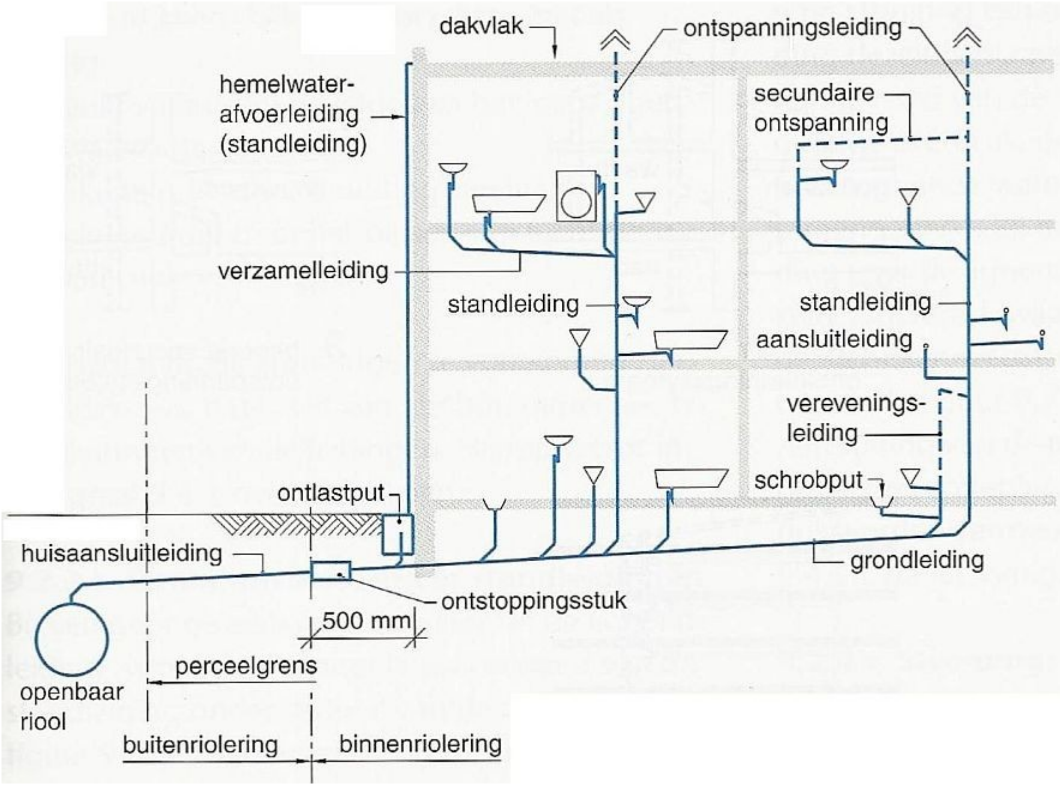


FIGURE **13: S**CHEMATIC DRAWING OF A TYPICAL WASTEWATER COLLECTION SYSTEM INSIDE GROUND BOUND BUILDINGS, COPIED FROM ***H**OGERE BOUWKUNDE* ***J**ELLEMA* ***6A E**LEKTROTECHNISCHE EN SANITAIRE INSTALLATIE*S BY **H**ARTELOH **(2000), T**HIEME**M**EULENHOFF **BV.**

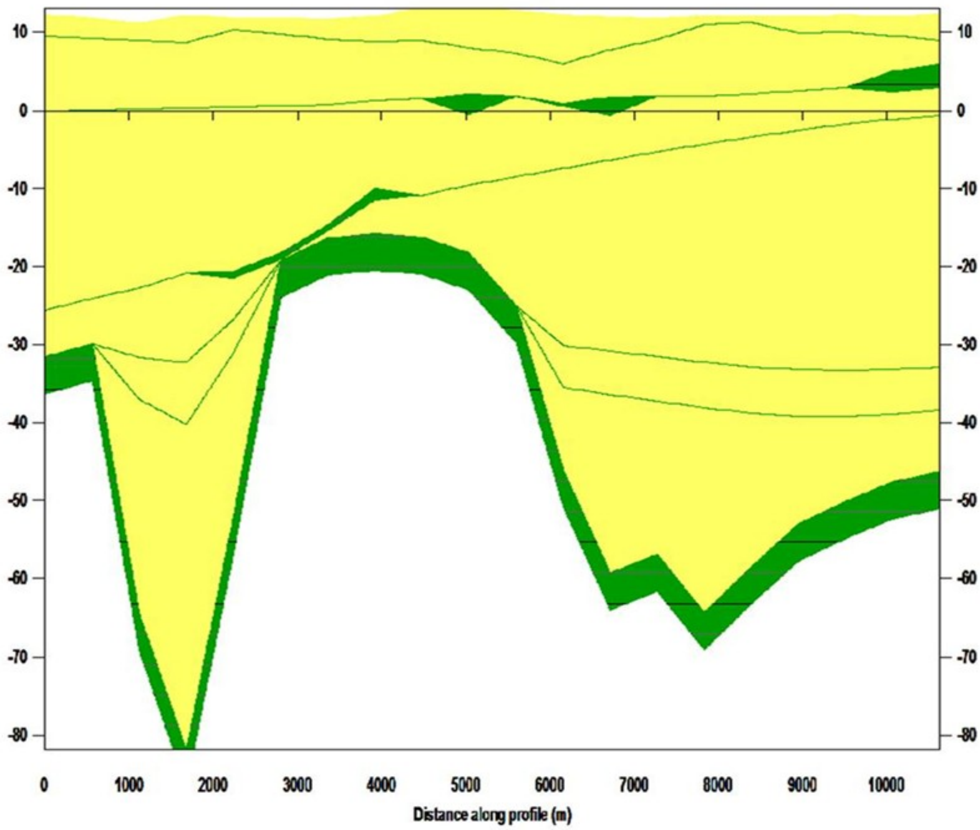


Figure 14: Cross-cut soil showing the build-up of soil in Exel, yellow is sand, green is clay, units in meters, copied from *Haalbaarheid afkoppelen buitengebied Exel* by Van den Bulk and Telkamp (2015), Tauw BV.

Stakeholders in the village of Exel are the inhabitants, the municipality Lochem, the Water Board Rijn IJssel, owners of the bordering country estates Verwolde (in the north) and Ampsen (in the south, also owner of the forests of Ampsen) and farmers owning surrounding farmland.

Table 2: Age demographics of municipality Lochem to which Exel belongs to (CBS, 2015)

Municpality (unit)	**Total**	**0–19 year**	**20–29 year**	**30–39 year**	**40–49 year**	**50–64 year**	**65–79 year**	**80 year or older**
Lochem (# of people)	33,244	7,084	2,460	2,632	4,780	7,789	6,262	2,237
Lochem (% of total)		21,3%	7,4%	7,9%	14,4%	23,4%	18,8%	6,7%

Table 3: General demographics of municipality Lochem to which Exel belongs to (CBS, 2015)

Municipality	**Surface in km**			**Population density per km² land**	**Housing stock 2)**	**Housing density per km² land 2)**	**Urbanity 3)**
	Total 1)	**Land**	**Inland water**				
Lochem	215.94	213.14	2.80	156	14,519	68	4

1) Including the surface of municipally classified open water.
2) Provisional numbers.
3) A categorical classification of municipalities that is based on the neighbouring address density of a municipality. For the classification of urbanity the numerical values of the neighbouring address density for the separate municipalities are categorized in the following groups:
1. Very strongly urbanized municipalities: neighbouring address density of 2,500 addresses or more per km²;
2. Strongly urbanized municipalities: neighbouring address density of 1,500 to 2,500 addresses per km²;
3. Moderately urbanized municipalities: neighbouring address density of 1,000 to 1,500 addresses per km²;
4. Slightly urbanized municipalities: neighbouring address density of 500 to 1,000 addresses per km²;
5. Not urbanized municipalities: neighbouring address density of less than 500 addresses per km².

Table 4: Surface use of municipality Lochem to which Exel belongs to (CBS, 2016a)

Munici-pality	**Total surface area** (ha)	**Total traffic area** (ha)	**Total built up area** (ha)	**Total semi built up area** (ha)	**Recreation area**					**Agricultural area**		**Total forest and open natural area** (ha)
					Park en public garden (ha)	**Sports area** (ha)	**Allot-ment garden** (ha)	**Day re-creation area** (ha)	**Resort re-creation area** (ha)	**Area for horti-culture** (ha)	**Other agri-cultural area** (ha)	
	ha	*Ha*	*Ha*	*Ha*	*ha*	*ha*	*ha*	*ha*	*ha*	*ha*	*ha*	*ha*
Lochem	21,594	555	901	113	24	156	2	2	187	2	15,896	3,475

Description of the urban case: Centrumeiland IJburg

As nowhere in The Netherlands there are actual plans for renovation of residential housing or an apartment building in an urban setting, the choice was made to fictionally place an existing apartment building that was rigorously renovated in a new development site where the waste (water) infrastructure had to be designed from scratch. The selected apartment buildings are the Elementum flats in Vlaardingen Holy Zuid-Oost, which were built at the beginning of the 1960s (see figure 15, figure 16, and figure 17 for an impression of the buildings). The apartment buildings are fictionally 'placed' on the Centrumeiland IJburg, part of the municipality of Amsterdam, The Netherlands, which is currently being developed. The buildings are to be renovated down to the frame, the apartments are enlarged and a new building layer and facade was added. The old buildings were completely stripped and all layouts, installations and facades were removed. This leads to a total of 300 apartments in 6 separate apartment buildings (Koopman, 2014). As both building and sewer are going to be renewed at the same time, the new sanitation concept can be implemented at once. An average house in Amsterdam has a floor space of 75 m^2 (Bunschoten, 2012).

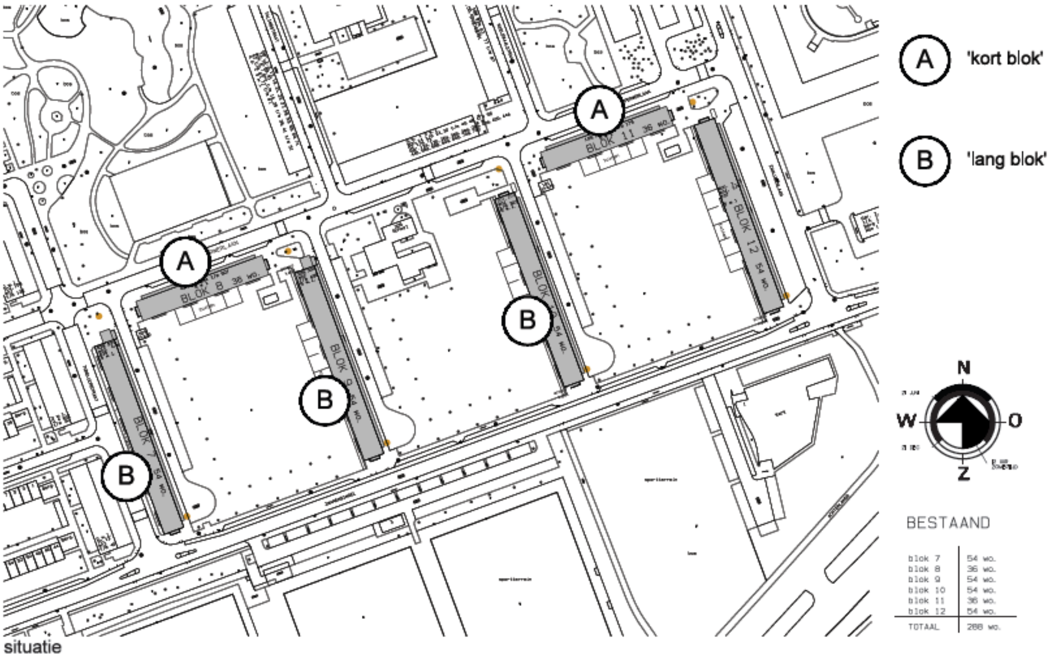


FIGURE 15: LAYOUT OF THE ELEMENTUM FLATS TO BE RENOVATED, COPIED FROM *SITUATIESCHETS | DIFFERENTIATIESCHEMAS | DOORSNEDE | WONINGPLATTEGROND NIEUWE TOESTAND CASCO/RENOVATIE DE TOEKOMST HOLY ZUID-OOST* BY A3 ARCHITECTEN (2016).

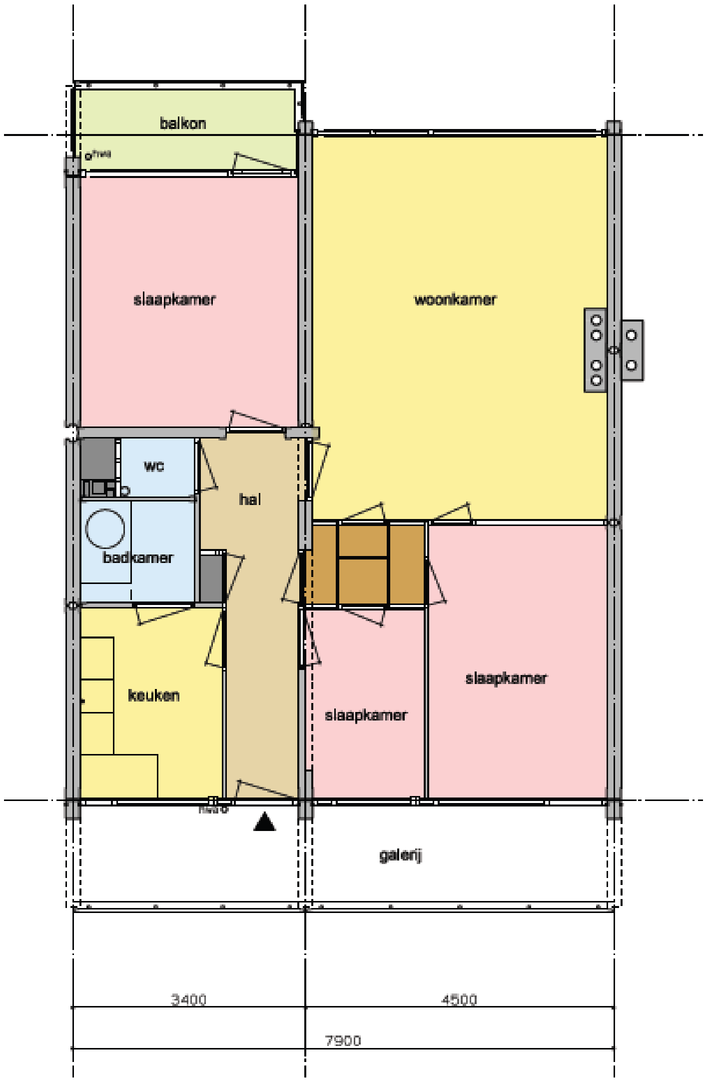
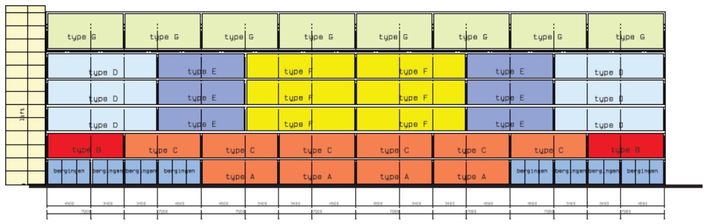
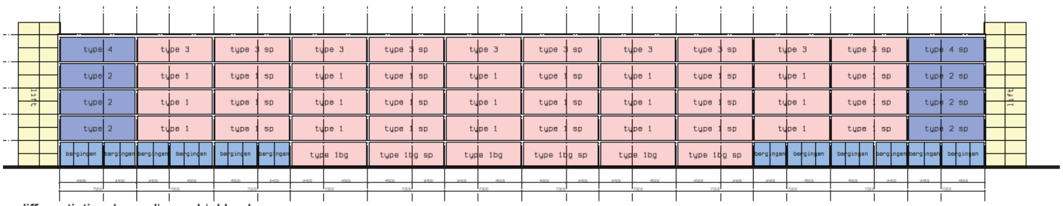


Figure 16: Layout standard apartment in old situation copied from *Situatieschets | Differentiatieschemas | Doorsnede | Woningplattegrond Nieuwe toestand Casco/Renovatie De Toekomst Holy Zuid-Oost* by A3 Architecten (2016).



differentiatieschema 'korte blokken'



differentiatieschema 'lange blokken'

FIGURE 17: LAYOUT OF DIFFERENT REDESIGNED APARTMENTS IN ELEMENTUM FLATS COPIED FROM *SITUATIESCHETS | DIFFERENTIATIESCHEMAS | DOORSNEDE | WONINGPLATTEGROND NIEUWE TOESTAND CASCO/RENOVATIE DE TOEKOMST HOLY ZUID-OOST* BY A3 ARCHITECTEN (2016).

The average number of inhabitants per household in Amsterdam is 1.81 (CBS, 2015). The age demographics are shown in table 6 and other demographic characteristics in table 7. Compared to the rural case, Centrumeiland IJburg has a high population density and relatively many inhabitants in their twenties and thirties and few inhabitants in their fifties. The apartments are assumed to be in the top left quadrant of the Centrumeiland IJburg (see figure 18 where the pink star indicates the 'height accent'). The apartment complex will be surrounded by built up area and communal green zones. table 7 shows the surface use of the municipality. The Centrumeiland IJburg will be built like a mound with a height difference of about 3.5 meters between the lowest and highest point. The banks will be 2.1 meters above groundwater and the island is made of sand, which allows for excellent infiltration of rain water. The island is surrounded by water, on the north and south by the open surface water of the IJ-lake and on the East and West side by canals. The development on the West has not started, so there is no land there right now. The sustainability ambition of the municipality of Amsterdam for Centrumeiland IJburg is rainproof and energy neutral (Ontwerpteam Centrumeiland, 2015). Moreover, Waternet is studying decentralized sanitation for the entire island of roughly 1,200 households (Telkamp, 2015a).

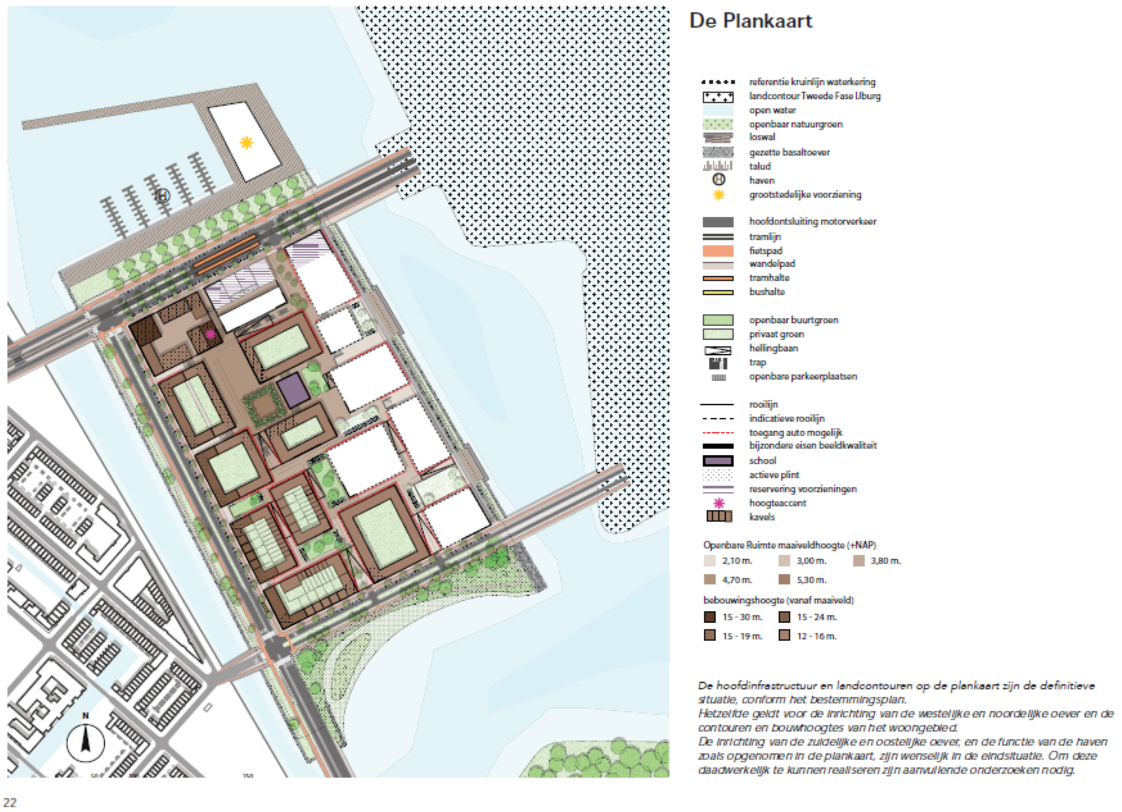


FIGURE 18: THE PLANNING MAP CENTRUMEILAND IJBURG, COPIED FROM *STEDENBOUWKUNDIG PLAN CENTRUMEILAND CONCEPT NOVEMBER 2015 BY* ONTWERPTEAM CENTRUMEILAND (2015), GEMEENTE AMSTERDAM.

Stakeholders in the renovation of the apartment building in Centrumeiland IJburg are first of all the housing corporation that owns the buildings. This could also be the association of owners that maintains the communal assets of apartment owners, however, a renovation to the frame with individual ownership is highly unlikely, just like in the case of Exel, so a housing corporation that rents out the apartments is assumed. The other stakeholders are the municipality of Amsterdam, the Water Board Waternet, and owners of the bordering residential and commercial buildings.

TABLE 5: AGE DEMOGRAPHICS OF THE AMSTERDAM MUNICIPALITY TO WHICH CENTRUMEILAND IJBURG BELONGS TO (CBS, 2015)

Municpality (unit)	**Total**	**0–19 year**	**20–29 year**	**30–39 year**	**40–49 year**	**50–64 year**	**65–79 year**	**80 year or older**
Amsterdam (# of people)	821,752	165,475	153,492	142,350	118,582	144,337	74,570	22,946
Amsterdam (% of total)		20,1%	18,7%	17,3%	14,4%	17,6%	9,1%	2,8%

TABLE 6: GENERAL DEMOGRAPHICS OF MUNICIPALITY AMSTERDAM TO WHICH CENTRUMEILAND IJBURG BELONGS TO (CBS, 2015)

Municipality	**Surface in km**			**Population density per km^2 land**	**Housing stock [2)]**	**Housing density per km^2 land [2)]**	**Urbanity [3)]**
	Total [1)]	**Land**	**Inland water**				
Amsterdam	219.49	165.89	53.60	4,954	416,966	2,514	1

1) Including the surface of municipally classified open water. 2) Provisional numbers. 3) A categorical classification of municipalities that is based on the neighbouring address density of a municipality. For the classification of urbanity the numerical values of the neighbouring address density for the separate municipalities are categorized in the following groups: 1. Very strongly urbanized municipalities: neighbouring address density of 2,500 addresses or more per km²; 2. Strongly urbanized municipalities: neighbouring address density of 1,500 to 2,500 addresses per km²; 3. Moderately urbanized municipalities: neighbouring address density of 1,000 to 1,500 addresses per km²; 4. Slightly urbanized municipalities: neighbouring address density of 500 to 1,000 addresses per km²; 5. Not urbanized municipalities: neighbouring address density of less than 500 addresses per km².

TABLE 7: SURFACE USE OF THE AMSTERDAM MUNICIPALITY TO WHICH CENTRUMEILAND IJBURG BELONGS TO (CBS, 2016A)

Munici-pality	**Total surface area** (ha)	**Total traffic area** (ha)	**Total built up area** (ha)	**Total semi built up area** (ha)	**Recreation area**					**Agricultural area**		**Total forest and open natural area** (ha)
					Park en public garden (ha)	**Sports area** (ha)	**Allot-ment garden** (ha)	**Day re-creation area** (ha)	**Resort re-creation area** (ha)	**Area for horti-culture** (ha)	**Other agri-cultural area** (ha)	
	ha	*Ha*	*Ha*	*Ha*	*ha*	*ha*	*ha*	*ha*	*ha*	*ha*	*ha*	*ha*
Amster-dam	21,932	1,347	8,057	1,338	1,484	709	320	125	19	30	2,655	448

Material Flow Analysis baseline situation

For the baseline situation a Material Flow Analysis (MFA) is made for both water and nutrients. As these parameters are not measured, they are based on assumptions and peer-reviewed studies and official reports on average water and nutrient flows in households. The purpose of the water MFA is to show how the current water based sanitation is laid out as well as to put in perspective the water requirements for this type of sanitation. Rain water is out of scope as it is assumed to be decoupled from the wastewater sewer. Infiltration of water into the sewer and leakage out of the sewer have not been specified as these parameters do not influence the comparison of different visions and stepping stone technologies. So even though there is no criterion for water use, this MFA is relevant as water is the carrier of human waste. A lower or different water flow affects the concentrations and therefore the nutrients and resources that can be produced from the streams. In figure 19 the MFA baseline for water in the rural Exel cluster is given. In figure 20 the MFA baseline for water in the urban apartment building in the Centrumeiland IJburg in Amsterdam is given.

The purpose of the nutrient MFA is both to show the amount and sources of nutrients and resources that enter the waste (water) systems of both cases. This shows where opportunities for nutrient recovery lie. It also allows for calculations of nutrient recovery for several criteria related to resource recovery. In figure 21 the MFA baseline for nutrients in the rural Exel cluster is given. In figure 22 the MFA baseline for nutrients in the urban apartment building in the Centrumeiland IJburg in Amsterdam is given. The underlying calculations and assumptions for the MFAs are shown in annex 2, 3, 4 and 5.

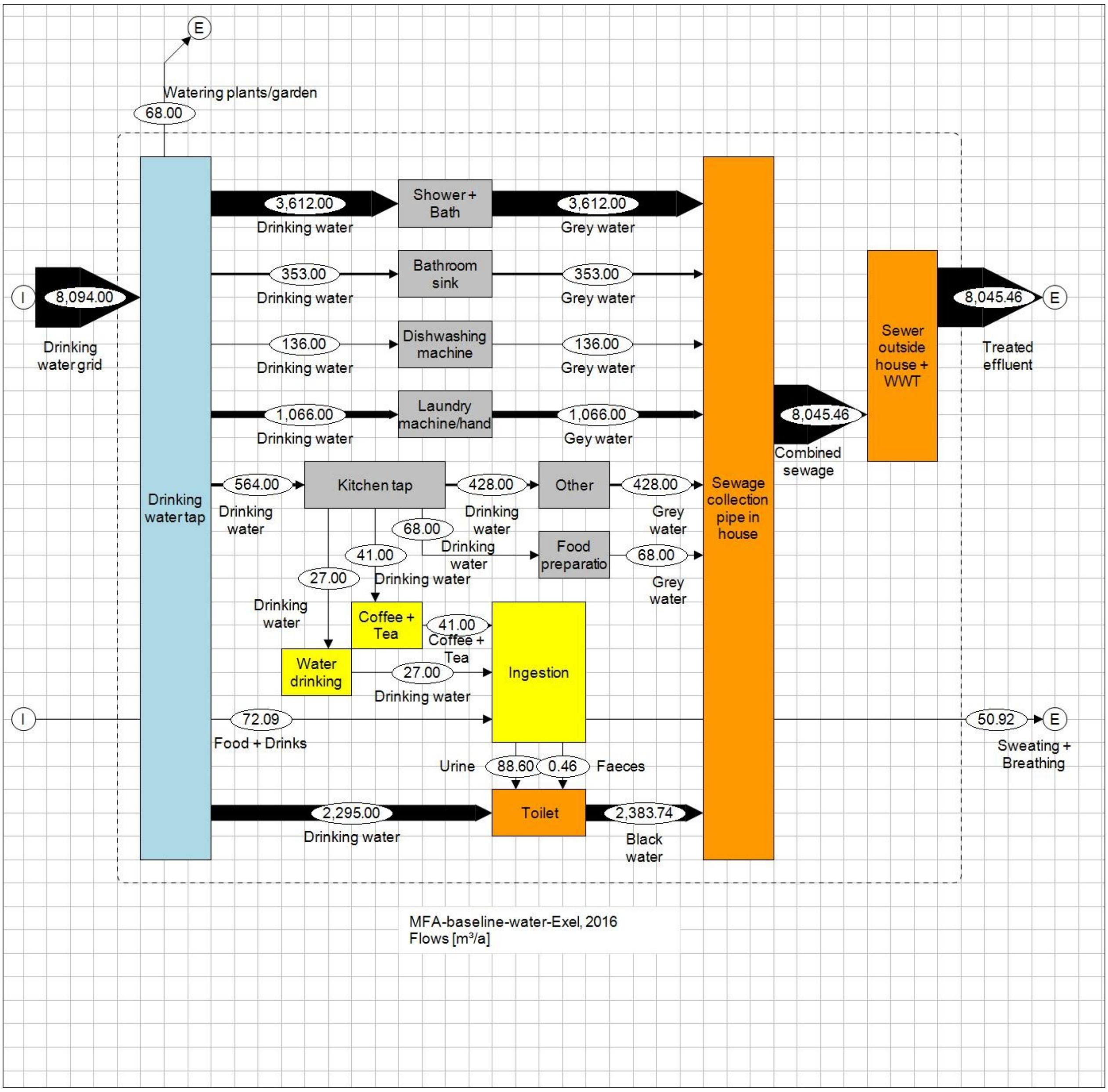


FIGURE 19: MFA BASELINE WATER FOR EXEL, 186 INHABITANTS [M^3 Y^{-1}] (SEE ANNEX 2 FOR CALCULATIONS AND ASSUMPTIONS)

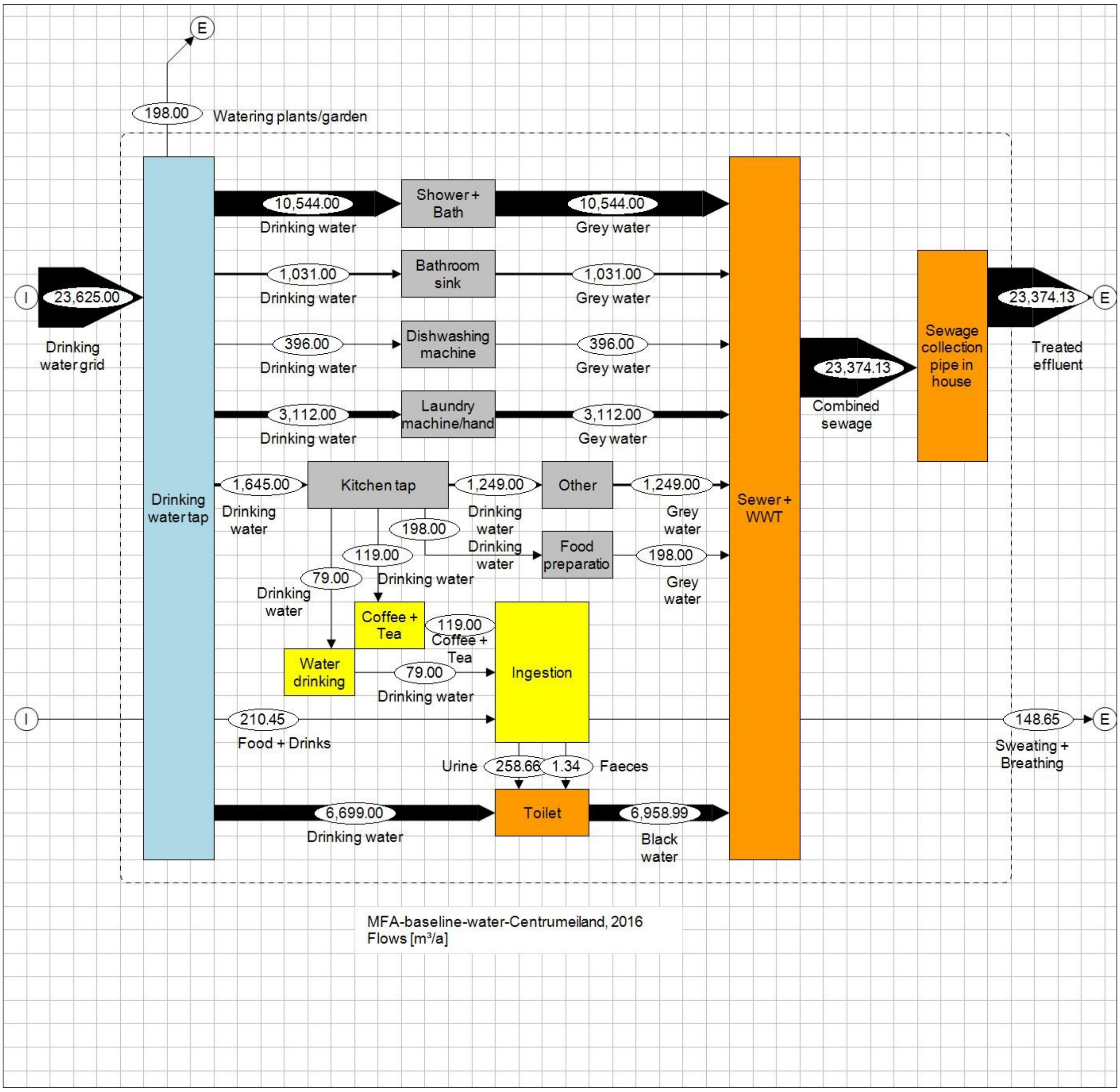


FIGURE 20: MFA BASELINE WATER FOR APARTMENT COMPLEX CENTRUMEILAND IJBURG AMSTERDAM, 543 INHABITANTS [M^3 Y^{-1}] (SEE ANNEX 3 FOR CALCULATIONS AND ASSUMPTIONS)

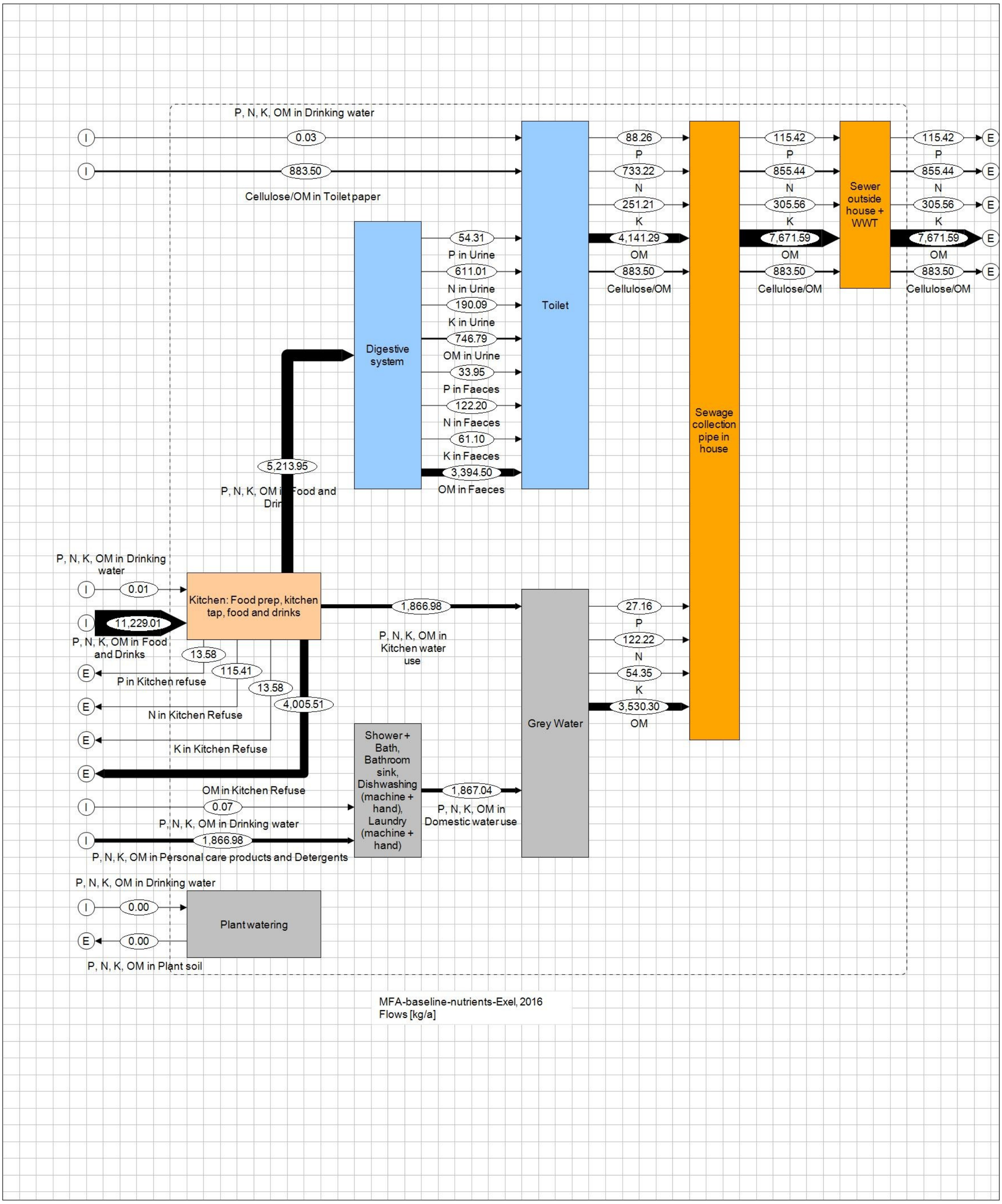


FIGURE 21: MFA BASELINE NUTRIENTS FOR EXEL, 186 INHABITANTS [KG Y^{-1}]. IN SOME CASES THE P, N, K AND OM FLOWS ARE SUMMED FOR READABILITY. IN ANNEX 4 THE SEPARATE STREAMS ARE SPECIFIED (SEE ANNEX 4 FOR CALCULATIONS AND ASSUMPTIONS).

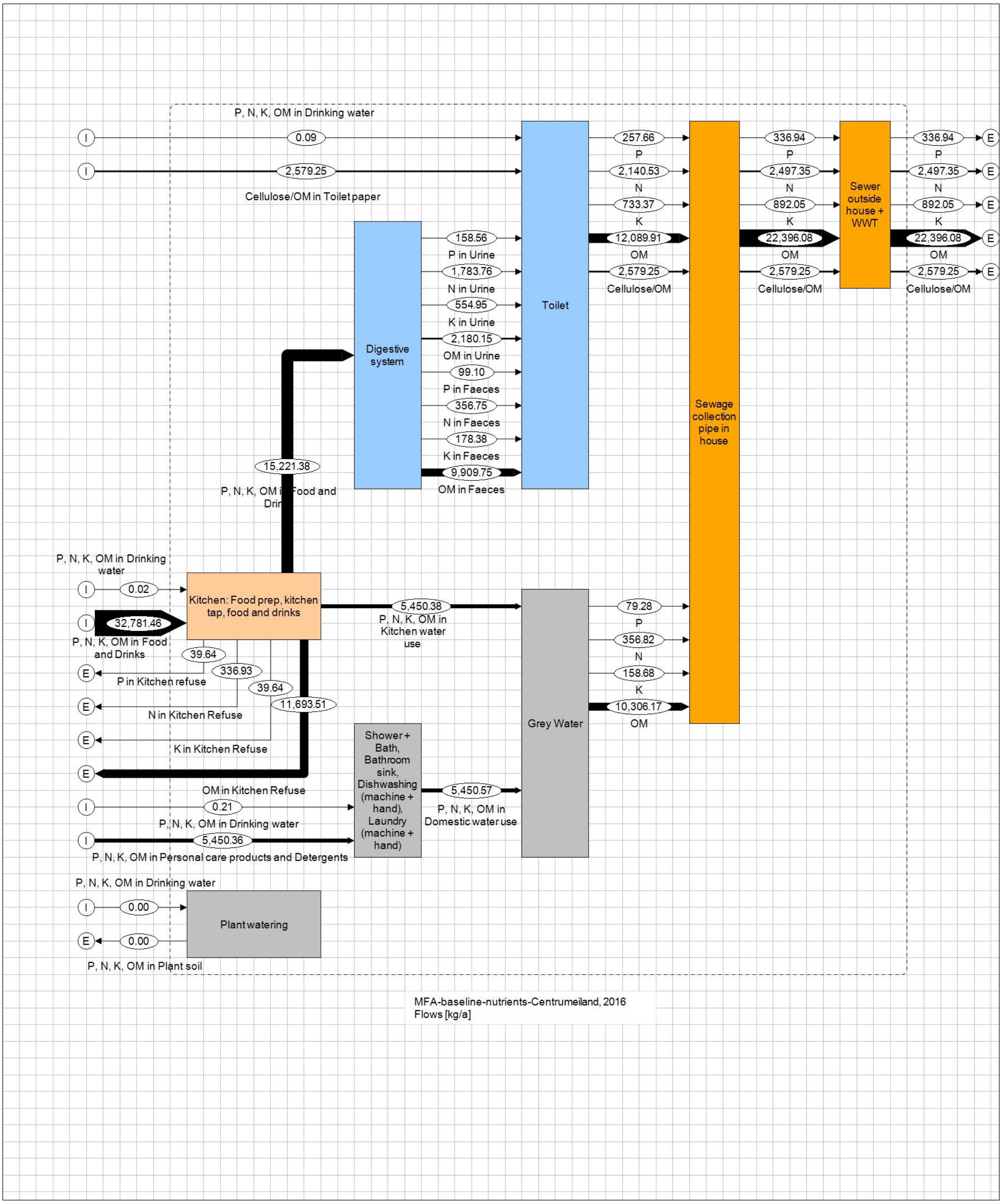


Figure 22: MFA baseline nutrients for apartment complex Centrumeiland IJburg Amsterdam, 543 inhabitants [kg y^{-1}]. In some cases the P, N, K and OM flows are summed for readability. In annex 5 the separate streams are specified (see annex 5 for calculations and assumptions).

Heat balance baseline

Because the reuse of heat in the waste (water) streams is a feasible and demonstrated technology, the resource direct heat is also of interest (Cipolla and Maglionico, 2014). This cannot be modelled by a MFA because heat is not a material or volume flow. To give insight in the options for direct heat recovery, the temperatures of the different streams for Exel and Centrumeiland IJburg are given in table 8 and table 9. For the underlying calculations and assumptions see annex 6 and 7. These temperatures will be compared to the applied technology for direct heat recovery, which could be a shower heat exchanger, a heat exchanger on one or more waste (water) streams or the use of heat in a local digester which needs a constant high operating temperature (such as an UASB).

To express if the heat balance for the chosen technologies is positive or negative, criterion #10 expresses the heat recovery in a percentage. This is calculated by taking the energy content of natural gas entering the residential building as an input. The amount of energy 'recovered' in terms of avoided use of the energy content is the amount of energy recovered.

TABLE 8: CALCULATED TEMPERATURES OF DIFFERENT WASTE (WATER) STREAMS IN EXEL, RIGHT AFTER PRODUCTION AND BEFORE TREATMENT, BASED ON: TERVAHAUTA (2014) AND (VITENS, 2015)

	Temperature *[degrees Celsius]*
Greywater	32.0
Black water, consisting of:	13.4
Faeces	37.0
Urine	37.0
Flush water	12.4
Food prep water	12.4
Kitchen refuse	20.0
Average temperature in combined sewage right outside the house	20.2

TABLE 9: CALCULATED TEMPERATURES OF DIFFERENT WASTE (WATER) STREAMS IN APARTMENT COMPLEX CENTRUMEILAND IJBURG, RIGHT AFTER PRODUCTION AND BEFORE TREATMENT, BASED ON: TERVAHAUTA (2014) AND (WATERNET, 2015)

	Temperature *[degrees Celsius]*
Greywater	32.0
Black water, consisting of:	18.2
Faeces	37.0
Urine	37.0
Flush water	17.5
Food prep water	13.1
Kitchen refuse	20.0
Average temperature in combined sewage right outside the house	21.3

Visionary design

To achieve sustainability in general in the Global North, reliance on raising efficiency of technology is unlikely to achieve sufficient results. A change in lifestyle is also needed (Notter et al., 2013). The same is true for waste (water) infrastructure. According to Beck (2011) the two most sustainable future visions for waste (water) infrastructures also require a lifestyle change. The two future visions, described in chapter 2, based on Becks work are "Vision 3: Separated water and nutrient reuse infrastructures with lifestyle change" and "Vision 4: Dry sanitation system as maximum eco-efficient water metabolism".

For the densely populated inner city of Amsterdam it seems that separated water and nutrient reuse infrastructure is the best fitting vision for 60 years from now. One reason is because a dry system would have larger space requirements than a separated water and nutrient reuse infrastructure. Inner cities are notorious for spatial challenges due to high ground prices. Another reason is that if fertilizers are to be reused in agriculture to close cycles with reuse, the agricultural land needs to be close by or transportation needs to be energy efficient. As agriculture is currently located mostly outside the city except for urban farming (Wielemaker, 2014), energy efficient fertilizer needs to be produced from the nutrients. This means the fertilizer needs to be as dry as possible to minimize energy for transport (Stauffer, 2016). A synthetic fertilizer such as struvite contains less water than an organic fertilizer like composted human waste. Thus separated water and nutrient reuse infrastructure fits better with an urban setting, whereas in a rural setting with short transportation distances to a suitable agricultural soil, could implement dry sanitation. An organic fertilizer that still contains some moisture will more easily attain a positive energy balance when applied on the close by agriculture land in the rural setting.

On the other hand, in the rural case of Exel it is feasible to envision a dry sanitation system which will achieve to the maximum possible eco-efficient water metabolism (Beck, 2011). This is due to the proximity of agricultural and forest land that can use compost, digester sludge or fertilizer products directly, without large transportation distances and without the need for maximum dewatering. Also, spatially the rural case is more favourable for a dry sanitation system, as the larger floor area of the residential buildings allows for the larger compost toilets required by some technical solutions. Moreover, the larger area around the free standing homes versus the apartments in Centrumeiland IJburg allows for more options for house-on-site waste treatment needed to create safe products for reuse.

Another practical benefit to choosing two different visions for both cases is that the urban setting can learn from the experience in the rural setting before aiming for the most sustainable vision. Dry sanitation is the furthest away from the current system, so it will require the largest change in technology and behaviour (Beck, 2011). However, if it is successful it will spark innovation for dry sanitation technologies in all parts of the system, from collection, transport, treatment to recovery and reuse. This will create seed money to bring the technology to full maturity and thus will create a good return on investment in the long run, as the TNS framework argues (Robèrt et al., 2002). It will then be possible in 60 years or less to implement these new to be developed technical and behavioural solutions in urban settings, thereby creating a fully sustainable waste infrastructure in the far future.

TABLE 10: POSSIBLE CONSIDERATIONS ABOUT THE TWO CHOSEN VISIONS IN TERMS OF TNS'S FOUR SUSTAINABILITY PRINCIPLES.

	TNS's principle 1: Concentrations of substances extracted from the Earth's crust	**TNS's principle 2: Concentrations of substances produced by society**	**TNS's principle 3: Degradation by physical means**	**TNS's principle 4: In that society human needs are met worldwide**

Vision 3 *Separated water and nutrient reuse infrastructures with lifestyle change*	This vision could still require substantial amounts of (renewable) energy to run and specialty materials from the earth's crust to make a high tech system such as Waterschoon even though the system as a whole could become energy neutral (De Graaf and Van Hell, 2014)	Lifestyle change could mean fewer micropollutants in the wastewater from pharmaceuticals and personal care products for example (Butkovskyi, 2015) and possibly lower metals from greywater (Tervahauta, 2014)	Ecosystems could be restored or enhanced, mostly with regard to nutrients (for example reducing algal blooms & increasing soil fertility) and somewhat with regard to water (less water use for toilet flushing)	Technologies that comply with this vision may only be available to the Global North due to high tech components
Vision 4 *Dry sanitation system as maximum eco-efficient water metabolism*	This vision could reduce the use of (renewable) energy and specialty materials from the earth's crust even further than the source separation vision, because it can be realized with low to medium tech systems (SuSanA, 2009b)		Ecosystems are likely to be restored or enhanced, with regard to both nutrients (for example reducing algal blooms & increasing soil fertility) and water (less water contamination & no water use for toilet flushing)	Technologies that comply with this vision can be applied worldwide – but may not be perceived as comfortable or culturally appropriate right now – so innovation of technology and perception change needed. In the Global North incapable (for example elderly) users pose a challenge (SuSanA, 2009b).

As the considerations in terms of the four principles of TNS in table 10 reveal, vision 4 could become more future proof than vision 3. This is in line with the assessment of Beck (2011) who describes vision 4 as maximum eco-efficient compared to the other visions.

Lifestyle change to enable future visions

Implementation of the ambitious visions for the rural and urban case will require a lifestyle change of users. The extent of adaptation depends partially on the chosen technology to make the vision a reality. Moreover, some lifestyle changes for users and cultural changes inside organisations of involved stakeholders are imminent regardless of technology.

Lifestyle and TNS's principle 2: Reduction of household micropollutants in wastewater

Users play an important role in reducing human contributions to the steady increase of concentrations of substances fabricated by civilization in the ecosphere or lithosphere that are unnatural and persistent (TNS's principle 2). A large portion of household micropollutants are pharmaceuticals, cosmetics and domestic chemicals. If users are able and willing to choose products that are benign by design and easy to biodegrade as much as possible in the wastewater treatment of the future, the concentrations of these substances that need to be removed can be lowered drastically. Also, users should not dispose of drugs through their toilets and sinks. European publicity campaigns have shown that citizens, patients, and healthcare employees are receptive to the idea to reduce the impact of medicine residues to the environment. The public wants to do 'what is right' and thinks that correct and accessible information on how to avoid environmental damage from pharmaceuticals will help them do this. Patients think the issue of medicines in (waste) water is foremost an issue for the pharmaceutical industry, secondly for themselves, and thirdly for the water board (Waterschap Groot Salland and Deventer Ziekenhuis, 2015).

Kümmerer (2013) suggests that the closer to home the waste (water) treatment takes place, the higher the willingness of consumers to use biodegradable products. This approach should be accompanied by green chemistry however, to ensure a large range of suitable products enter the market. The pharmaceutical, cosmetic, and domestic chemical industries will need to be involved in the innovation and marketing of these green products. Moreover, doctors have an active role to play in prescribing environmentally preferable pharmaceuticals, also called 'green pharmacy', when several effective options are available (Stockholm County Council, 2012, Van der Hoek et al., 2013). Pharmacists can ensure that clients are given correct dosages and are informed how to correctly dispose of excess medicine (Van der Hoek et al., 2013). Studies in changing lifestyles and organizational culture have shown positive results in willingness to participate (Waterschap Groot Salland and Deventer Ziekenhuis, 2015) and further research is expected to give useful insight in how to further influence lifestyle and culture to achieve cleaner influents.

Lifestyle and TNS's principle 4: Comfort and convenience for users in the Global North

With regard to the accepted and perceived level of comfort and convenience of a new technology, the question arises in how far this is considered a basic need now and in the future. Principle 4 of TNS reads that humans now need to contribute maximally to the steady increase of capacity of humans worldwide, now and in the future, for meeting their own basic needs. Research by Van den Bulk and Telkamp (2008) shows that the market acceptance in the Dutch context of vacuum toilets, which are somewhat more noisy than flush toilets, varies between projects. Likewise, the acceptance of users of vacuum sewers that are perceived by users to be more prone to blockages due to smaller diameters than larger diameter gravity sewers varies between projects. The difference between high and low market acceptance seems to be largely attributable to one or several factors. These factors are the robustness of the implemented solution, the age of the system, noise dampening applications, management of expectations of stakeholders and users from the start of the project, and the degree to which tangible agreement is realized upfront between stakeholders (on at least implementation and maintenance costs, construction and responsibility for maintenance). As several projects have been implemented to high satisfaction of the users (Van den Bulk and Telkamp, 2008), vacuum systems and the required lifestyle change are considered feasible and future proof.

No-mix toilets that separate urine from faeces could be applied as a collection technology to implement both vision 3 and vision 4. According to (Lienert and Larsen, 2009) acceptance of no-mix toilets is high, but the technology needs further development. When a well-designed toilet is combined with an integral strategy of project managers, communities and politicians, no-mix toilets are likely to succeed.

Composting toilets with or without urine separation and composting systems as a whole present a totally different toilet experience for people in the Global North, and thus also in the Dutch context. This refers both to the use of the toilet itself and the involvement of users in the treatment. Hence it seems logical that only residents in ecological settlements in Europe have taken the step to implement these in their homes and that this technology is not at all mainstream. This may have to do with perception, because Tilley et al. (2008, p65) write in the Compendium of Sanitation Systems and Technologies that "Depending on the design, Composting Chambers can be used indoors with the comfort and convenience of a flush toilet." Moreover, the resulting product, "compost, is a stable, inoffensive product that can be handled safely and used as a soil conditioner." A composting toilet does require manual labour for maintenance of 1 hour per month and users need to be careful not to throw in substances that will disturb the composting process (SuSanA, 2009b). So installing a composting toilet does end the flush-and-forget mentality that users find convenient in the current centralized system (Harder, 2012). The help of neighbours or a hired labourer is also needed if residents are unable to maintain the composting toilet due to physical limitations or old age (SuSanA, 2009b). However, when composting toilets are installed in single houses or apartment buildings in close cooperation with the sanitary technology provider, the design can be adjusted according to the requirements for comfort and other needs of users. This increases the likelihood of a positive experience and spurs innovation (Berger, 2003).

According to Harder (2012) the positive or negative perception of a new sanitation solution is also linked to the perceived value the solution adds to the house. If comfort is perceived as being lower, home owners will not want to implement it for fear of a lower market value of their property. However, this is an economic concern that should also be mitigated by either circular economy financing or green taxing (see chapter 1). Hence in this thesis it is not a concern in the assessment of how future proof a sanitation concept is.

Moreover, Vreeburg (2015a) questions if sanitation systems need to be designed for abuse, such as the deposition of materials other than excreta, toilet paper, and water. Or if a simple unblocking system needs to be incorporated, so that abuse creates only a short term inconvenience but no permanent damage. However, in any case a lifestyle change is needed to move from flush-and-forget (Harder, 2012) to a new system. Even if that new system constitutes only a change to 'uncoupled household wastewater' (more commonly referred to as uncoupled rain water) as proposed by Vreeburg (2015a), see chapter 1.

Lastly, Hegger (2007) concludes that users in the future will need to choose deliberately how to dispose of their wastewater. It will become part of a wide range of social practices that one shapes themselves, just like the choice who to get married to or where to go on vacation.

Chapter 4: Stepping Stone technology selection for rural and urban renovation case

New sanitation and reuse concepts in The Netherlands and Europe

Even though no implemented examples of new sanitation projects on community scale and household scale have been found for renovation, there are numerous examples of new developments using some form of new sanitation in The Netherlands and Europe. These pilot and implementation projects can be classified as:

- centralized collection, transport, treatment and reuse technologies;
- urine separation systems; composting dry toilets;
- vacuum system with UASB for black water;
- vacuum system for black water with algae nutrient recovery;
- constructed wetland systems;
- “natural” filter systems (willows, fungi);
- direct heat collection;
- local wastewater treatment for hospitals; and
- local greywater treatment for local low quality water reuse.

An inventory of all relevant examples is given in annex 8. In general it can be said that reuse and recovery have not been applied very often in decentralized solutions (Swart, 2015).

From the perspective of recovery and reuse, which is the focal point of the vision for both the rural and urban case, an inventory of available technologies has been made per nutrient/resource. This is summarized in annex 9. Infiltration of (rain) water is considered reuse of a resource in this context, because ground water is a source for drinking water production. Technologies are either still in their lab development phase, or pilot or commercial phase. The list is not exhaustive because in theory every trace material could be recovered. However, recovering every constituent is unlikely to become energetically or economically feasible, which is exemplified by the lack of commercial application or even lack of research on the recovery of many constituents to date, such as for recovery of pharmaceuticals. Hence, the inventory focuses on the main constituents of waste (water) that have been identified in relevant literature and reports.

The conclusion from the inventory of new sanitation concepts and recovery and reuse technologies is that the new sanitation concepts form a good starting point to select stepping stone technologies for fulfilling the future visions for the rural and urban case. They cover a broad range of applications and sufficient information is available on their technical application as well as ecological impact. To ensure optimal sustainability, these new sanitation concepts need to be complemented or augmented to fit the specific cases studied. Moreover, an outlook is provided on several technologies that are theoretical or lab scale today and might fit with the new sanitation concept in the future. This may influence the selection on the most suitable stepping stone as well as the way the technology is implemented.

Stepping stone technology concepts for consideration in rural and urban case

To determine which stepping stone technologies (SST) should be considered for the rural and urban case the inventory of new sanitation concepts was used. From this list (see annex 8) five concepts were selected based on the following criteria:

- Proven to work in a pilot or commercial scale implementation;
- Applicability to residential housing, as opposed to industrial application;
- Completeness (addressing more than one aspect of the wastewater chain of collection, transport, treatment and reuse);
- Range from low to high tech;
- Sufficient data availability.

The concepts were augmented to include best practices from other concepts and from the nutrient recovery inventory (see annex 9) in so far as this fits with the low to high tech character of the solution. Several future expansion options which cannot currently be implemented are listed for each concept.

The five stepping stone technology concepts are described below. They are subsequently analysed on three aspects:

1. Can the SST concepts be applied to the existing situation in the rural and urban case?
2. Do the SST concepts fit with the future vision for the rural and urban case? (Criterion 1 for selecting SST, see chapter 2)
3. How do the remaining SST concepts score on the selection criteria for stepping stones? (Criteria 2 through 24 for selecting SST, see chapter 2)

Stepping stone technology 1: Centralized treatment with energy and nutrient reuse

Grey and black water are collected through conventional gravity- or water-saving (pressure) toilets and water-saving showers, baths, sinks and other appliances. The wastewater is combined into one stream, which exits the house through one single sewer connection pipe. Currently in the Netherlands, rain water is decoupled (27.3% of cases) or is combined in the sewer (68.2% of cases). Transport of sewage is managed through conventional, large diameter sewage gravity pipes between houses and the centralized wastewater treatment plant. Almost all sewers are gravity sewers, only 3.9% are mechanical, generally in remote rural locations (Oosterom and Hermans, 2013). Kitchen waste and garden waste is collected separately from wastewater by trucks and is processed to digest or compost at separate centralized digesting/composting plants.

When wastewater reaches the centralized wastewater treatment facility, the goal is nutrient and carbon removal. Any pathogen and micropollutant removal that takes place is coincidental. Nitrogen removal is accomplished by sequential biological nitrification and de-nitrification with sludge flocks, releasing N2-gas. Phosphorous is fixed in the sludge flocks by precipitation with iron or by applying the Enhanced Biological P Removal (EBPR) process (ValueFromUrine, 2016). More and more the Nereda® aerobic granular biomass process is used instead of the more energy and space consuming sequential biological nitrification and de-nitrification and phosphorous removal (Van den Heuvel, 2012). In conventional and Nereda® wastewater treatment processes, micropollutants and metals that are removed end up in the sludge mostly through adsorption and also through degradation (micropollutants), biosorption (metals) and precipitation (metals) (Pagnanelli et al., 2009, Falås et al., 2016). The effluent complies with current Dutch standards for contamination of these substances; however, future standards for removal of micropollutants may provide a challenge.

In the Dutch situation, the larger traditional wastewater treatment plants are slowly being expanded to include end-of-pipe resource and nutrient recovery. The focus lies on biogas recovery through bioflocculation and subsequent anaerobic digestion of sludge (Khiewwijit et al., 2015), phosphorous recovery as synthetic slow-release fertilizer through struvite reactors or phosphate recovery from incinerated sludge, cellulose recovery through sieving and alginate recovery from granular biomass in Nerada® plants (EFGF, 2016e, STOWA, 2016d). To this end, in some places urine is collected through waterless urinals and transported by truck to a struvite reactor at the wastewater treatment facility or Saniphos factory. The end products comply with Dutch regulation for concentration of micropollutants and metals present.

An important consideration is that when cellulose is recovered through a fine sieve before treatment, the biogas production from sludge is considerably lower (STOWA, 2013). However, a new approach called CADOS is in the pilot phase and uses the sieved cellulose as a dewatering aid for wastewater treatment sludge. Sieving out cellulose before the activated sludge step means less energy for aeration is needed in the treatment of the wastewater. Moreover, when it is added to the waste sludge, dewatering becomes more efficient than current technology, which increases the amount of dry matter. This saves energy in transport of dewatered sludge to the sludge treatment facility. The dewatered sludge can be digested to produce biogas (De Fooij, 2015, Ekkelboom, 2014). In this case there is no trade-off between cellulose recovery and biogas production.

In summary, there is hardly any source separation except for some urine collected mostly from waterless urinals. Recovery focuses on a balance between energy and resource recovery. Furthermore, the approach is highly centralized, high-tech and there is hardly any active support or awareness by the general public. Transport is arranged mostly via conventional large diameter sewage pipes, some mechanical sewage pipes and trucks for kitchen and garden waste, and occasional source-separated urine transport.

Future options SST1

In the future, transport of wastewater can be arranged through small diameter gravity sewage pipes, designed to meet hydraulic performance indicators, that “uncouple household wastewater” (more commonly referred to as uncoupling of rain water) (Vreeburg, 2015a). The system should be closed to avoid cross contamination with rain water and to keep the concentration of resources high. This makes transport and treatment more energy efficient.

Theoretically, a wet sealing toilet could also be applied to centralized wastewater collection and treatment. However, this is not compatible with small diameter sewers, as the technology calls for a special sealing toilet that sends “packets” of urine or faeces down the sewage pipes to be collected separately at the treatment plant (Harder, 2012). This technology only exists on the drawing table and has not been tested.

Another interesting development that has already been applied commercially is the Organica botanical garden in a green house. Treatment consists of solids removal, fixed-bed biofilm activated sludge, phase separation and optional disinfection (Organica Water Inc, 2016c). It treats combined streams of sewage by and does not recover nutrients, save water, but does create appealing nature that is perceived as an added value to residents nearby (Organica Water Inc, 2016a). Organica botanical gardens can be designed to meet the same standards for effluent as conventional wastewater treatment plants and an appropriate cordon sanitaire of usually 50 meters is put in place to ensure public health is optimized (Organica Water Inc, 2016b). Hence it can also be applied on a community scale.

Stepping stone technology 2: Vacuum system for black water

Black water, greywater and rain water are source-separated. Rain water is transported to local surface water by a separate gravity sewer or can be infiltrated when the soil is suitable. Black water, including kitchen refuse from kitchen grinders is transported in a vacuum system (vacuum toilets, vacuum stations and vacuum pipes with an under pressure of 0.5 – 0.6 bar). Flush water is minimized. Greywater is collected separately and transported by gravity sewer to a greywater collection well, from where it will be transported to local treatment.

The black water and kitchen refuse stream is anaerobically digested in a heated UASB. No cellulose recovery is applied. In the UASB, under oxygen free conditions, organic matter is converted to biogas, which contains 60% to 70% methane. Nitrogen and phosphate are converted to soluble ammonium and soluble phosphate, which will partially precipitate with calcium, magnesium and iron in the UASB sludge (De Graaff et al., 2010). The main technical challenge of this process is the start-up phase, as not all homes are connected simultaneously, but gradually over several years and the Oxygen Limited Autotrophic Nitrification Denitrification (OLAND) and UASB reactors will be under loaded in this period, as pilot projects have shown (Londong, 2013, De Graaf and Van Hell, 2014). This is more problematic for the OLAND reactor than for the UASB reactor. The UASB can be operated at a lower temperature during start-up. Subsequently, nitrogen is removed with the energy efficient biological OLAND process, as the effluent from the UASB will be low in organic matter. A combination of aerobic and anaerobic bacteria converts high concentrations of ammonium and nitrite into harmless nitrogen gas (De Graaf and Van Hell, 2014, Vlaeminck et al., 2009).

By adding magnesium salt to the effluent of the OLAND reactor, struvite (magnesium-ammonium-phosphate) crystals are formed. If the OLAND reactor removes too much ammonium it is possible to make magnesium-potassium-phosphate, which is also a useable fertilizer (De Graaf and Van Hell, 2014).

The effluent of the struvite reactor, which is still warm from the heated UASB, and the greywater influent, which is cool due to residing in the greywater collection well, are treated together in a biological aerobic process to remove organic matter, nitrogen and phosphorous simultaneously. The first step is a high loaded A-stage. Here colloidal, floating and some soluble material is adsorbed to sludge flocks. This bioflocculation stage is sensitive to under loading, which means optimal performance is not reached until the system is fully loaded. In the second step, the low loaded activated sludge B-stage, air is blown in to create aerobic conditions that remove the remaining organic matter and convert ammonium to mainly nitrate through nitrification. Both N and P are removed. The effluent of the AB-stage process is fed through a heat pump to recover direct heat to be used in the connected homes (De Graaf and Van Hell, 2014, Hernandez Leal et al., 2007, Tervahauta, 2014). The effluent is then infiltrated in the soil if the type of soil is suitable, or it is discharged on local surface water. The heat embedded in greywater as it leaves the homes cannot be used as it cools down too much in the collection well. However, heat exchangers are applied to all showers to directly reuse heat. The heat recovery from the heat pump in the effluent of the AB process recovers the added heat from the AB process and UASB stage. As heat exchangers are designed to incorporate fouling, and thus are oversized, they should meet their design requirements during their technical lifetime (Beggs, 2009).

Sludge from the OLAND reactor can be digested in the UASB reactor and UASB sludge will be used for agriculture after a tertiary hygienisation step of composting (Arthurson, 2016). Co-composting of black water sludge is proposed by Butkovskyi (2015) as this not only kills pathogens, but also degrades several types of micropollutants from 87% to 99%, although some types of micropollutants cannot be readily degraded and their addition to black water should be avoided as much as possible. Sludge from the AB process is incinerated until a technique becomes available that can remove metals and micropollutants that currently render the sludge safe for agricultural application. Wastewater treatment sludge is incinerated in a dedicated incineration plant which allows it to be further processed to recover phosphate, although the phosphate content will be limited due to the struvite precipitation of black water and low phosphate content of greywater (Ecophos, 2016). Under current regulations even the sludge from the UASB and OLAND reactors, which originates from only black water, contains too many heavy metals to be allowed for soil application. However, as Tervahauta (2014) argues, these heavy metals can be traced back to the food that was consumed, so the regulations are too strict and should become more lenient towards reuse of black water sludge. Greywater sludge, does however contain non-food related heavy metals, which may hinder the application on arable land.

In summary, there is source separation of black water with kitchen refuse, greywater and rain water to enable recovery of biogas for heat, synthetic fertilizer as struvite, direct heat reuse and rain water to replenish local surface water (see figure 23). The approach is completely decentralized, community-on-site, high-tech and there is high awareness and community support, although there is some concern over vacuum noise of the toilets and grinder (De Graaf and Van Hell, 2014). Transport is arranged through a local vacuum system for black water and kitchen refuse and local conventional gravity sewers for greywater and rain water. AB process sludge is transported by truck to the incineration plant.

This SST concept is modelled after the Waterschoon project in Sneek, The Netherlands.

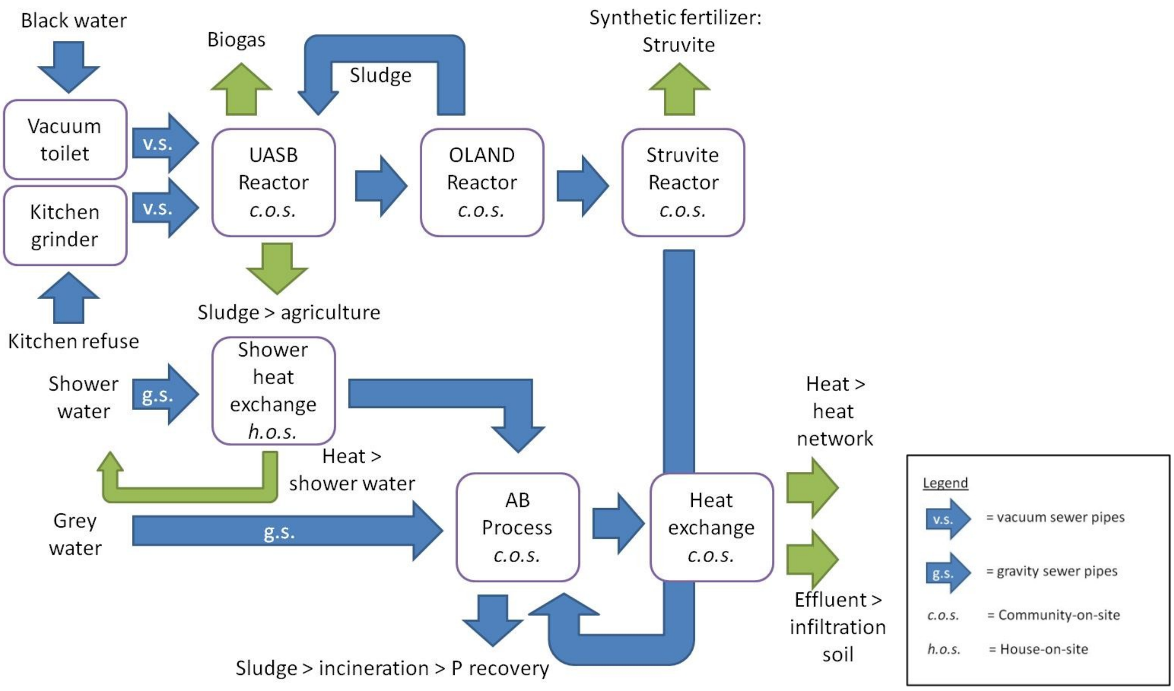


FIGURE 23: SCHEMATIC REPRESENTATION OF STEPPING STONE TECHNOLOGY 2: VACUUM SYSTEM FOR BLACK WATER. ALL SYSTEMS ARE COMMUNITY-ON-SITE.

Future options SST2

Should effluents need to be hygienised further, or should further removal of metals and micropollutants become imminent to meet new standards, for example, an activated coal filter can be placed after the heat exchange to adsorb these substances (EPA, 2016). For removal of metals and micropollutants from sludge no technical solution is available. Two possible ways to develop a solution for the future are the addition of granular activated coal, which has been shown to be effective in the case of its addition to a UASB reactor, and subsequent removal of the activated coal with adsorbed micropollutants (Butkovskyi, 2015); or the addition of reusable magnetic microsorbents for micropollutants and their removal with magnets, which has shown to work in lab experiments for the separation, concentration and recovery of phosphate from wastewater (Drenkova-Tuhtan et al., 2016). Combining both ideas, magnetic carbon is a promising development to tackle the hygienisation and removal of micropollutants from sludge.

Another promising development that is being tested on pilot scale is the growth of algae on the effluent of an UASB. This creates additional biomass that can be used directly as an organic fertilizer or as a feedstock for bioplastics, for example (Fernandes et al., 2015, Fernandes, 2012) (see figure 24).

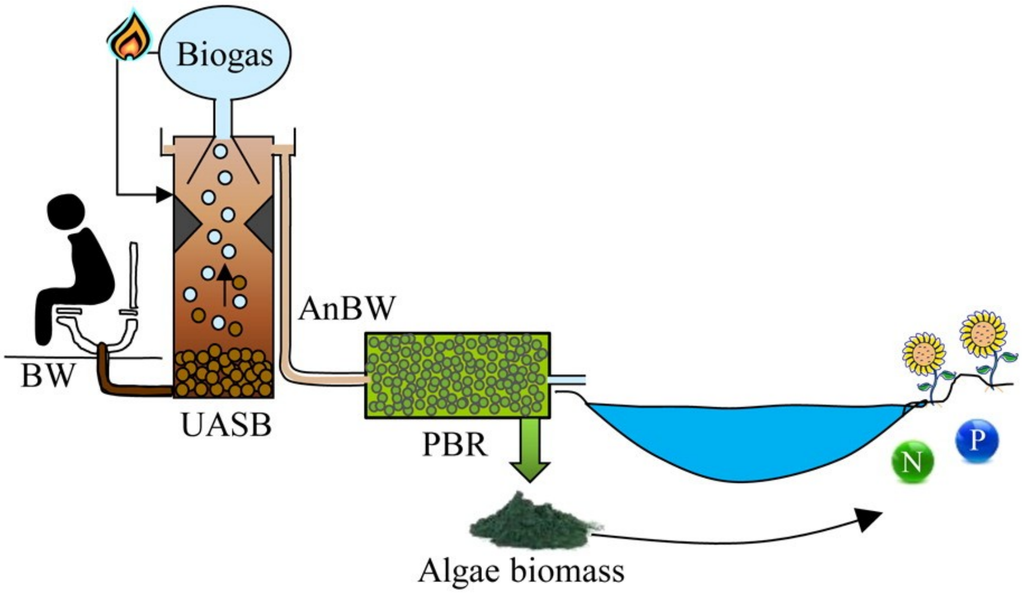


FIGURE 24: EXAMPLE OF THE NIOO BUILDING WHERE BLACK WATER (URINE, FAECES AND FLUSH WATER) IS TREATED ON-SITE WITH AN UASB TO GENERATE BIOGAS AND SUBSEQUENTLY SENT TO AN ALGAE GROWTH REACTOR TO RECOVER NUTRIENTS FOR ORGANIC FERTILIZER OR INDUSTRIAL FEEDSTOCK, COPIED FROM *CLOSING DOMESTIC NUTRIENT CYCLES USING MICROALGAE* BY FERNANDES ET AL. (2015).

A smart house connection is also a possibility for applying SST2 to existing homes. This is a theoretical source separation technique that has not been applied in The Netherlands (Weijma, 2016). This connection diverts black water and greywater into different pipes by using a sensor or signal from the user to know which wastewater stream should go in which pipe. The drawback of the system is that it still has to be tested, conventional toilets in homes use more water than vacuum toilets, thus diluting black water more, and cross contamination of streams is likely (Harder, 2012).

The Greenhouse Village concept could also be applied in this SST2. The goal is to close heat, carbon, water and mineral cycles by intertwining agrarian and urban functions into a mutually beneficial balance. In this concept, the black water and kitchen refuse are also led to a UASB, but the resulting effluent plus greywater are reprocessed to become nutrient rich irrigation water for the greenhouse-on-site (Wortmann and Kruseman, 2005).

Stepping stone technology 3: Composting dry toilets with urine storage

Black water and kitchen refuse, greywater and rain water are source-separated. Rain water is partly collected in underground cisterns for reuse for irrigation and party directly infiltrated in the soil. Black water and toilet paper are collected per household in a composting toilet system with one or two toilets and a composting container in the basement (SuSanA, 2009b). The number of toilets connected depends on whether the upper floor toilets are situated exactly above the ground floor toilet. No cellulose is collected separately. Commonly applied composting toilets allow for connection of up to four toilets without urine separation. However, in this stepping stone technology, no-mix composting toilets are used to separate faeces from urine to improve the handling of the compost, reduce smell, volume and chance for flies, and improve the composting process (Jönnson and Vinneras, 2007). The handling of pure urine is also easier, as it only requires six months of storage at 4 degrees Celsius before it is safe to apply as an organic fertilizer for food crops to be processed or fodder crops. Six months at 20 degrees Celsius renders it safe for all crops (Schönning, 2001). Micropollutants are not removed as current Dutch standards do not require this.

Ventilation with an electric fan in a pipe to the roof of the compost compartment removes 80% to 100% of the liquids that inadvertently end up in the compost compartment, and ensures no odours escape the toilet and compost compartment. For surplus leachate (liquids that did not evaporate through ventilation pipe) a separation chamber is installed where it can be collected (SuSanA, 2009b).

About one hour of labour is needed per month to maintain the compost toilet, although under the right conditions earthworms can take over some of the work (Berger Biotechnik GmbH, 2006, Berger, 2003). For optimal pathogen removal, secondary composting is done as a tertiary hygienisation step (Arthurson, 2016) outside, together with kitchen and garden waste. This saves a lot of labour, because kitchen and garden waste otherwise has to be cut in very small pieces to fit through the compost toilet.

To make optimal use of all resources, shower water is led through a shower heat exchanger to recover direct heat (Milieu Centraal, 2016a). Greywater is first led through an Imhoff tank, a settling tank similar to a septic tank, for grease removal. Subsequently, the water is fed through a vertical flow willow filter with drainage that ensures more recovery of biomass and also has an appealing nature quality (Global Wetlands, 2016). The effluent is subsequently polished in a polishing pond. Lastly, the effluent is infiltrated in the soil if the type of soil is suitable and enough surface space is available, or it is discharged on local surface water. The sludge from the Imhoff tank originates from greywater and is hence too polluted with metals and micropollutants to use as organic fertilizer (Tervahauta, 2014). Therefore, the Imhoff tank sludge is incinerated in a dedicated wastewater sludge incineration plant, allowing it to be further processed to recover phosphate (Ecophos, 2016). Transport to the plant is by truck.

Organic fertilizer and willow biomass can be used in the community itself or can be supplied to nearby farmers. Previous projects have shown that residents generally appreciate the direct contact with farmers (Jönsson et al., 2010).

In summary there is source separation of black water with kitchen refuse, greywater and rain water to enable recovery of organic fertilizer and rain water to replenish local surface water (see figure 25). The approach is completely decentralized. The no-mix toilet, urine storage and shower heat exchange are house-on-site technology and the remaining technology is community-on-site. The approach is also mid-tech and there is high awareness and community support to be expected in eco-minded communities although the elderly may have some concerns over maintaining the compost toilet themselves (SuSanA, 2009b). Londong (2013) believes that dry sanitation could find acceptance in Germany, although considerable improvement of the concept is needed. Presumably, the Dutch would be likewise inclined to accept dry sanitation.

Transport of faeces from the no-mix compost toilet, and kitchen and garden waste from the homes to the community-on-site secondary compost heap is done by human labour. Urine is transported from the no-mix toilet to the house-on-site urine storage by small diameter gravity pipes. In case local arable land requiring fertilisation is too small, liquid organic fertilizer is collected and transported by truck to suitable agricultural land. Rain water is transported by small gravity pipes and channels to the irrigation site. Greywater is transported by small diameter gravity pipes to and from the Imhoff tank whereas the Imhoff tank sludge is transported by truck to the wastewater sludge incineration plant.

This system is modelled after the ecological settlement in Allermöhe Hamburg, Germany.

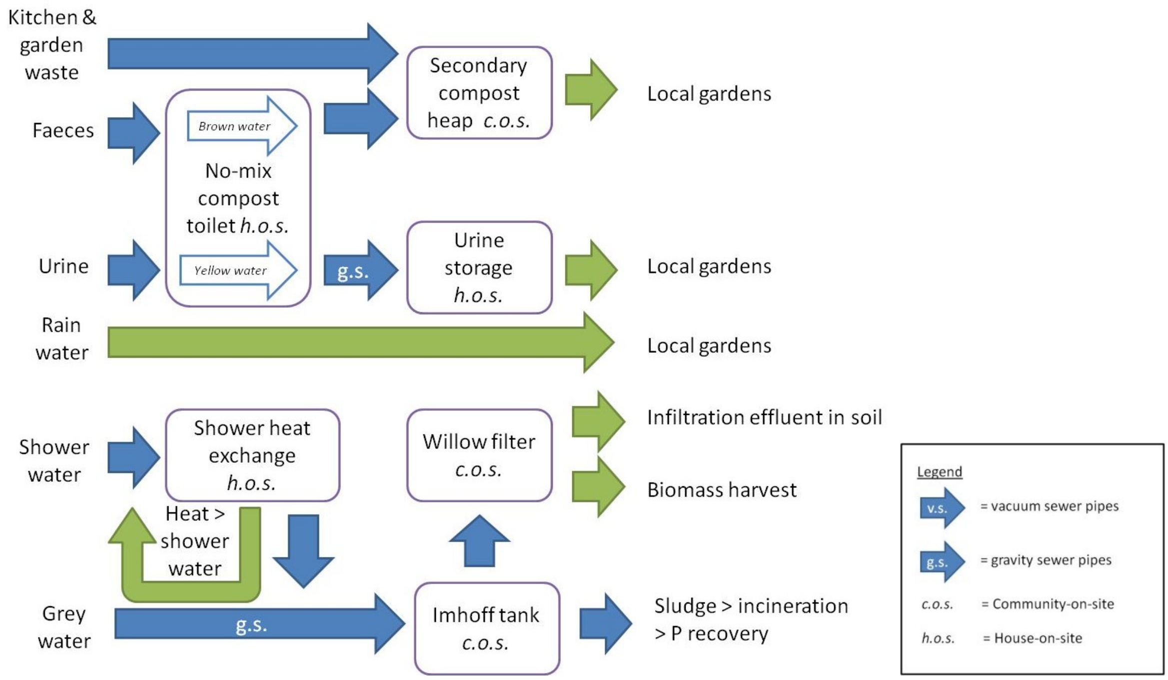


FIGURE 25: SCHEMATIC REPRESENTATION OF STEPPING STONE TECHNOLOGY 3: COMPOSTING DRY TOILETS WITH URINE STORAGE. THE NO-MIX TOILET, URINE STORAGE AND SHOWER HEAT EXCHANGE ARE HOUSE-ON-SITE, THE REMAINDER COMMUNITY-ON-SITE.

Future options SST3

Should effluents need to be hygienised further, or should further removal of metals and micropollutants from effluent or liquid fertilizer become imminent to meet new standards, an activated coal filter can be placed before the willow filter to adsorb these substances (EPA, 2016).

Different types of dry composting toilets could be applied (Matthijssen, 2016). A toilet with a valve and a non-stick coating to avoid filth will increase comfort, according to Zeeman (2016a The addition of anaerobic solid waste digestion to produce biogas is also possible on house-on-site scale. There are also options that have the composting chamber outside, rather than inside the house. This means daily emptying is necessary, which is not an improvement in the contemporary Dutch context, but may be an improvement in the future and allows for homes without a cellar to be connected. Active vermicomposting, with worms, is also possible. Research showed that pathogens are reduced to safe levels using vermiculture (Eastman et al., 2001). Metals in brown and yellow water, as well as kitchen refuse should not be a problem as they originate from human food (Tervahauta, 2014) and micropollutants likewise originate from human consumption. The use of a urine bag for users of not readably degradable pharmaceuticals, which is incinerated after use, may be a solution to avoid most of the contamination of the organic fertilizer. Only the portion that is excreted in faeces will end up in organic fertilizers (Waterschap Groot Salland and Deventer Ziekenhuis, 2015). Also, the prescription of less environmentally harmful pharmaceuticals will lower the micropollutant load in organic fertilizers (Stockholm County Council, 2012).

Another theoretical technology that can be applied to SST3 is the dry sealing toilet. Urine and faeces are sealed by the toilet after each use. Bags can be disposed through pneumatic pipes connected to the toilet or by hand into a compost or collection bin outside. Challenges future designers of this technology face are: a solution for when the toilet has run out of bagging material or has a malfunction, and making the pneumatic system function properly (Harder, 2012).

Lastly, it may be possible in the future to recover nitrogen by adding technology to the compost chamber ventilator in the house.

Stepping stone technology 4: Willow filter with ABR

Rain water is transported to infiltrate if the soil type permits it or flows to local surface water by separate channels. Black water and greywater are collected separately with water-saving appliances. Toilets use 3.5 to 4 litres per flush. Both streams are source-separated and transported in separate small diameter gravity sewers to the local treatment. Due to lower water flow, stream accelerators are placed in the sewers. Black water is treated in a cold Anaerobic Baffled Reactor (ABR) septic tank, with settling compartment for organic matter removal. The ABR combines the principles of a septic tank, moving bed reactor and UASB, and allows for biogas recovery. The size will be quite large due to the absence of heating; hence no greywater is led to the ABR, as this stream has a low concentration organic matter and would require an even bigger size ABR (Nguyen et al., 2010). The biogas will be used, for example, to power street lighting on-site. The difference between an ABR and UASB is the design principle, as the latter is designed vertically and for (vacuum collected) black water treatment heating can be applied to optimize the digestion process and reduce the reactor size. The former is designed horizontally and when designed without heating the ABR is easier to construct and maintain. Without heating, the size of the ABR and UASB is a lot bigger. As the ABR in SST4 is not heated, the biogas yield will be lower than that of a heated UASB, especially in the winter. No ABRs are currently in operation in The Netherlands.

Shower water is led through a shower heat exchanger to recover direct heat (Milieu Centraal, 2016a). The ABR effluent is combined with the greywater which is treated in an Imhoff tank for settling and grease removal (Stauffer and Spuhler, 2016), then led to a vertical flow willow filter with drainage (Otte and Boosten, 2014) and is infiltrated if the soil is suitable, or discharged to local surface water (see figure 26) (Gemeente Groningen, 2014, Telkamp, 2015b). The willow filter ensures more recovery of biomass, reuse of nutrients and has an appealing nature quality (Global Wetlands, 2016). When carefully designed for the specific location, climate and type of wastewater the willow filter will comply with current Dutch standards for nutrient concentrations for effluent (Otte and Boosten, 2014). Kitchen refuse and garden waste are composted separately from the wastewater streams.

Cellulose recovery is not applied, because of the trade-off between cellulose recovery and biogas production. As the ABR is not heated, it will already provide a low biogas yield. If part of the feedstock of organic matter is sieved out beforehand as cellulose, not enough biogas may be produced to be worth the investment. Moreover, the amount of cellulose that is produced on a community scale may also not be sufficient to put to functional use. Sludge from the ABR can be reused in agriculture after a secondary composting step with kitchen and garden waste that stabilizes the sludge (Arthurson, 2016, Butkovskyi, 2015).

In summary, there is source separation of black water, greywater and rain water to optimally treat each stream (see figure 26). In this system nutrients are recovered as biogas, willow biomass and organic fertilizer from the compost heap. The approach is completely decentralized, with the shower heat exchange as house-on-site solution and the remainder of the concept community-on-site, mid-tech and there will be active communication of the sustainable solutions that are implemented for inhabitants. Transport of the kitchen and garden waste to the compost heap is done by human labour. Black water and greywater are transported by small diameter gravity pipes to community-on-site treatment. Rain water is transported by small gravity pipes and channels to the irrigation site. The Imhoff tank sludge is transported by truck to the wastewater sludge incineration plant.

This system is modelled after the planned new sanitation concept in the district of Groningen Drielanden, The Netherlands, which in the end did not implement the ABR due to an unexpected financial setback.

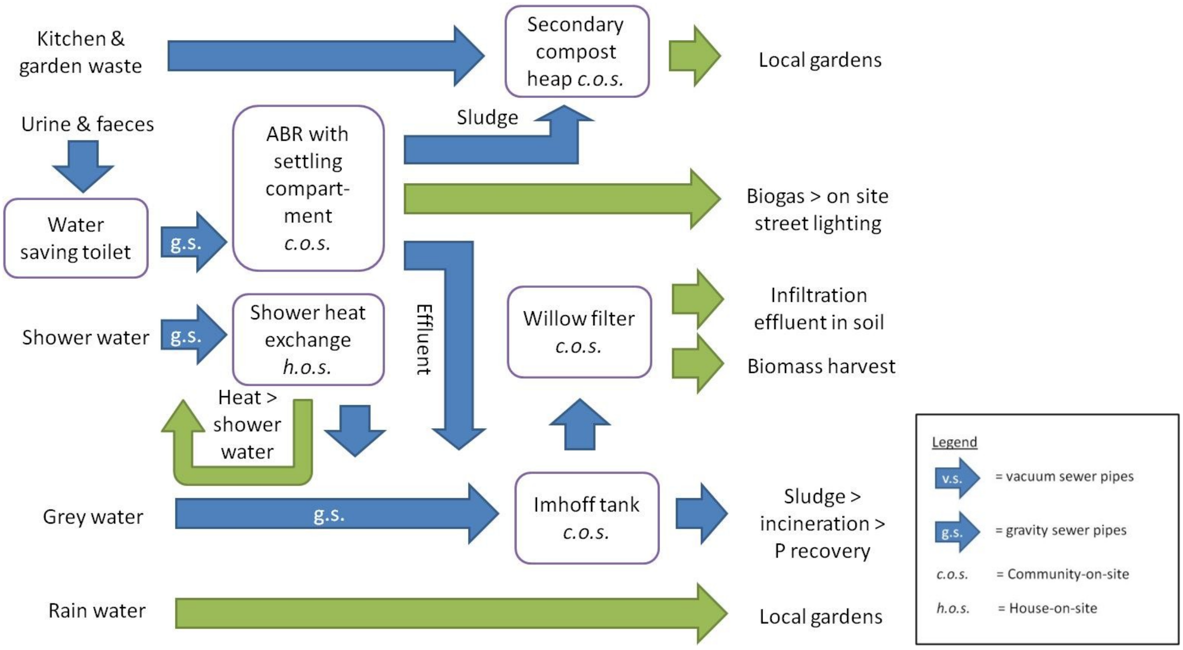


FIGURE 26: SCHEMATIC REPRESENTATION OF STEPPING STONE TECHNOLOGY 4: WILLOW FILTER WITH ABR, ADAPTED FROM *DRIELANDEN BY* TELKAMP (2015B). ALL TECHNOLOGIES ARE COMMUNITY-ON-SITE EXCEPT THE SHOWER HEAT EXCHANGES WHICH ARE HOUSE-ON-SITE.

Future options SST4

Should effluents need to be hygienised further, or should further removal of metals and micropollutants become imminent to meet new standards, an activated coal filter can be placed before the willow filter to adsorb these substances (EPA, 2016).

For further water-savings and a more concentrated black water stream, the application of pressure toilets and sewers or water-saving gravity toilets with pressure sewers that start outside of the house can be considered. There is not much experience with this type of system (Harder, 2012).

Theoretically, a wet sealing toilet could also be applied to collect black water separately. However, this is not compatible with the small diameter pipes and stream accelerators proposed in SST4, as the technology calls for a special sealing toilet that sends "packets" of urine or faeces down the sewage pipes to be collected separately at the treatment location. These sealed packets will not fit in small diameter pipes (Harder, 2012). This technology only exists on the drawing table and has not been tested. Perhaps more suitable, but also a theoretical technology that can be applied to SST4 is the dry sealing toilet, as has been explained in the paragraph on future options for SST3 (Harder, 2012).

In both cases the bags are made of bioplastic, which disintegrates by itself and does not need to be opened and disposed of separately.

In the future, when more concentrated wastewater is produced, a heated ABR or UASB may also be possible. Another option is a UASB co-digester, which energy efficiently boosts the soluble organic matter removal in the UASB, by recycling the UASB sludge to a heated digester and back to the UASB (Zhang et al., 2013b). This somehow increases the technical complexity (Tilley et al., 2008) so the mid-tech character of this SST4 will change to high-tech.

Stepping stone technology 5: Urine separation systems

The houses will be equipped with no-mix flush toilets. Even though in some projects the no-mix toilets did not function as expected, in the example case of the community house 't Natuurlijk Huus in Raalte, The Netherlands and the Eawag building Forum Chriesbach in Switzerland, the toilets work fine. However, the toilets that were applied are not produced anymore. Lienert and Larsen (2009) also show that high acceptance is to be expected if several preconditions are met. Rural and urban surroundings have a different approach to the treatment of each stream due to spatial constraints.

In the rural case, there is complete source separation of streams of yellow water, brown water, greywater and rain water, although some cross contamination of yellow and brown water is unavoidable. Each stream is treated separately. Yellow water is stored house-on-site for six months to ensure all pathogens are killed and urine is suitable for use as organic fertilizer for food crops to be processed or fodder crops. Six months at 20 degrees Celsius renders it safe for all crops (Schönning, 2001). Micropollutants are not removed as current Dutch standards do not require this. Shower water is led through a house-on-site shower heat exchanger to recover direct heat (Milieu Centraal, 2016a). It is then combined with the remaining greywater. Brown water is treated in a septic tank. Septic tanks will be connected to a cluster of homes, which means several will be placed in the community. Small diameter sewers connect the homes to the septic tank (Vreeburg, 2016). Greywater and septic tank effluent is led to an Imhoff tank and subsequently to a community-on-site vertical flow willow filter with drainage and rain water is collected house-on-site to use for watering plants. The willow filter will be considerably smaller than in SST4 because the nutrients in urine are not treated by the willows (Otte and Boosten, 2014). Rain water is not pumped back into the homes for use as flush water due to the material and energy intensity of this solution.

This concept enables the recovery of two types of organic fertilizer: the stored urine, which can be applied to local crops and the sludge from the septic tank, which is emptied when it is full; generally a matter of years depending on size and production. It can then be applied to agricultural land. This is possible because the only source of metals and micropollutants is human consumption, as has been explained in the previous SSTs (Tervahauta, 2014, Stockholm County Council, 2012). The treated greywater is infiltrated into local soil if the soil condition permits, or discharged on local surface water ('t Natuurlijk Huus, 2016). The sludge from the Imhoff tank originates from greywater and is hence too polluted with metals and micropollutants to use as organic fertilizer (Tervahauta, 2014). Therefore, the Imhoff tank sludge is incinerated in a dedicated wastewater sludge incineration plant, which allows it to be further processed to recover phosphate (Ecophos, 2016). Transport to the plant is by truck. Kitchen refuse and garden waste as well as septic tank sludge are composted community-on-site, separate from the wastewater streams.

In summary, for the rural case there is source separation of yellow water, brown water, greywater and rain water to optimally treat each stream (see figure 27). Nutrients are recovered as organic fertilizer, biomass is harvested and rain water is used to water plants. The approach is completely decentralized, with shower heat exchangers, rain water reuse and urine collection and storage house-on-site, several septic tanks dispersed throughout the community and the willow filter and compost heap for kitchen and garden waste community-on-site. The approach is also mid-tech and there is active education and involvement of the inhabitants in the sustainable solutions. Transport is arranged through small gravity pipes for urine collection and storage, separate small diameter gravity pipes for brown water to the septic tanks, and small diameter gravity pipes for the greywater and septic tank effluent to the willow filter. Kitchen and garden waste is transported by human labour to the community-on-site compost heap. Sludge from the Imhoff tank is transported by truck.

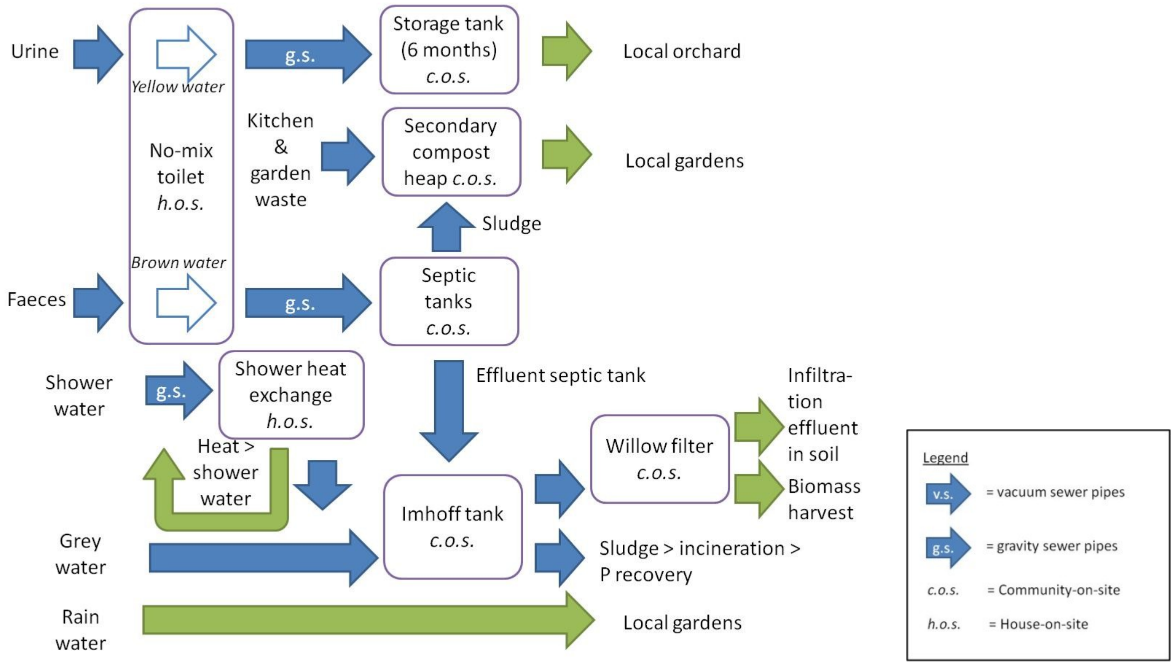


FIGURE 27: SCHEMATIC REPRESENTATION OF STEPPING STONE TECHNOLOGY 5 FOR THE RURAL CASE: URINE SEPARATION SYSTEMS

For the urban setting, this stepping stone technology is modified. The brown water and greywater will be discharged into the public sewer and will be treated in a centralized wastewater treatment plant (see SST1). Because brown water has low nutrient pollution levels compared to yellow water, it will mean the loading of the wastewater treatment plant is reduced and energy savings will be made (Wilsenach, 2006). Yellow water is not stored as in the rural case, but transported within the building to the struvite reactor by gravity pipes and then made into the dry fertilizer struvite (Boller, 2013). The effluent of the struvite reactor is led trough an ammonium air stripper with adsorption in acid that will recover nitrogen as a synthetic fertilizer solution for agricultural use. This is a proven technology that is suitable for a community-on-site reactor for the yellow water stream of several hundreds of people (Siegrist et al., 2013, GMB, 2016a). Its effluent is then discharged to the public sewer for transport to the centralized wastewater treatment plant. Lastly, a green roof with calcite free substrate collects rain water which is transported by gravity pipes to a collection tank in the building and from there to toilets for flushing. This ensures minimal dual piping is needed for reuse of rain water. Kitchen waste and garden waste is collected separately from wastewater by trucks and is processed to compost at separate centralized composting plants.

In summary, for the urban case there is source separation of yellow water and rain water. Brown water and greywater are not separated (see figure 28). Nutrients are recovered as synthetic fertilizer and rain water to flush toilets. The approach is partially decentralized, with yellow water treated community-on-site and rain water reuse as well, high-tech and there is active education to the inhabitants necessary about the use of no-mix toilets (Lienert and Larsen, 2009). Transport is arranged through small diameter pipes for urine and conventional large diameter sewer pipes to the centralized wastewater treatment facility. Kitchen and garden waste is collected by truck.

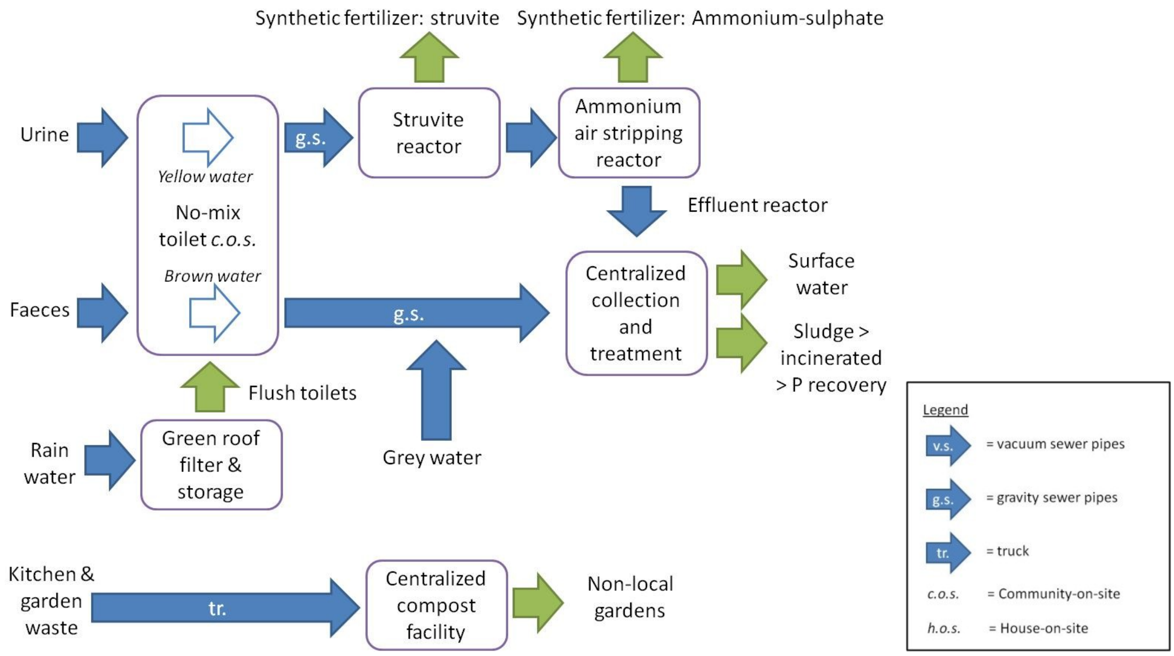


FIGURE 28: SCHEMATIC REPRESENTATION OF STEPPING STONE TECHNOLOGY 5 FOR THE URBAN CASE: URINE SEPARATION SYSTEMS

This system is modelled after the new sanitation concept in the community house 't Natuurlijk Huus in Raalte, The Netherlands and the Eawag building Forum Chriesbach in Switzerland.

Future options SST5

Should effluents in the rural case need to be hygienised further, or should further removal of metals and micropollutants from effluents or from liquid urine fertilizer become imminent to meet new standards, an activated coal filter can be placed before the willow filter to adsorb these substances (EPA, 2016).

In the rural case it may also be possible to sieve out cellulose if the amount to be recovered is high enough to offset the energy required for recovery and transport to a processing facility to make it into a useful product such as isolation material or bioplastics.

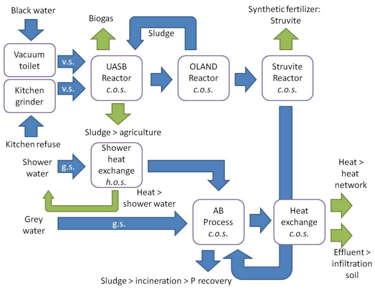
The septic tanks in the rural case may be substituted in the future by one heated community-on-site ABR or UASB septic tank. Biogas will become available for cooking or lighting. This increases the technical complexity (Tilley et al., 2008) so the mid-tech character of this SST4 will change to high-tech. Moreover, a suitable transport mechanism has to be found to ensure that concentrated brown water can be transported to the community-on-site location without problems. A possible solution is the transport of wastewater through small diameter gravity sewage pipes, designed to meet hydraulic performance indicators, that "uncouple household wastewater" (more commonly referred to as uncoupling of rain water) (Vreeburg, 2015a). The system should be closed, to avoid cross contamination with rain water and to keep the concentration of resources high. This makes transport and treatment more efficient. These small diameter sewage pipes may also be applied to the urban concept for transport of sewage to a centralized wastewater treatment plant.

For future options of the centralized treatment in the urban case see SST1. For the decentralized treatment of urine three future options have been identified: the first is growing algae on urine analogous to growing algae on black water as was discussed in SST2 (Tuantet et al., 2013). This creates additional biomass that can be used directly as an organic fertilizer or as a feedstock for bioplastics. The second option is a bioelectrochemical system for energy and nutrient recovery: a microbial electrolysis cell for hydrogen production and ammonium recovery from urine (Arredondo et al., 2015, Zhang et al., 2014, Kuntke et al., 2014). Thirdly, removal of nitrogen by ammonia air stripping can also be replaced by the innovative technique of a bioelectrical fuel cell to treat urine for recovery of nitrogen and production of electricity (Wetsus, 2013, Arredondo et al., 2015).

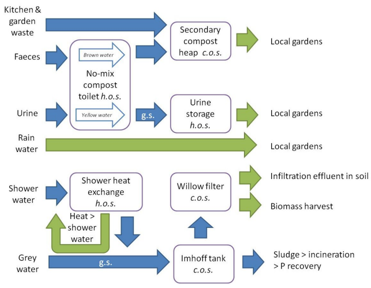
Practical feasibility of stepping stone concepts in the rural and urban case

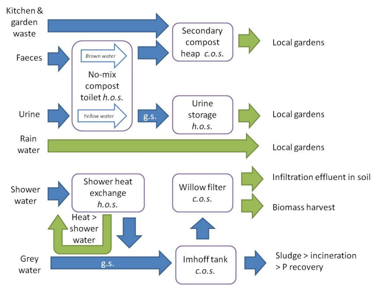
To select which stepping stone technologies to score for the rural and urban case two analyses have been made. First, the practical limitations and opportunities of the stepping stone technologies in both the rural and the urban case have been analysed. This is summarized in table 11.

Table 11: Practical limitations and opportunities of the stepping stone technologies in both the rural and the urban case

<table>
<tr><th></th><th>Rural case Exel</th><th>Urban case Centrumeiland IJburg</th></tr>
<tr><td>Stepping stone technology 1:
Centralized treatment with energy and nutrient reuse</td><td>Yes.
SST1 relies on combined streams for which internal and external infrastructure are already in place. So at present there are no limitations for implementation.</td><td>Yes.
SST1 relies on combined streams for which internal and external infrastructure are business as usual and can be easily realized. Care must be taken to plan gravity sewers favourably, or rely on pumps, due to the mound structure of the island.</td></tr>
<tr><td>Stepping stone technology 2:
Vacuum system for black water

</td><td>Yes.
Ground floor toilets can be connected to vacuum piping due to the ease of modification of the crawlspace and only 10%-15% of houses do not feature a crawl space (Harder, 2012). First floor toilets would require a total renovation of the bathroom (demolishing tiles) and piping shaft from the first floor to sewer connection of the house. Kitchen grinders cannot be connected without</td><td>Yes.
The internal infrastructure can be completely rearranged and vacuum pipes offer architectural flexibility due to their small diameter which means the lay outs of the apartments can all be different from one another if desired. No stack of sewer pipes is needed (Telkamp et al., 2008). Some care needs to be taken to place the vacuum toilets in a location where the possible vacuum noise has the least</td></tr>
</table>

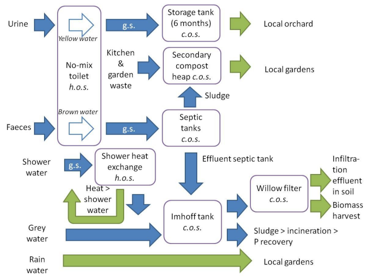
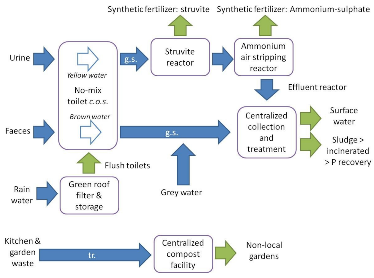
	extensive renovation. Based on the amount of primary energy that can be produced by digesting the black water of the connected vacuum toilets and the energy requirement of heating the UASB reactor to 25° Celsius, the application of an UASB for recovery of biogas is advisable, as just over 423% of primary energy is covered by produced biogas. There is a surplus of biogas (see annex 10). *Future: Yes.* Theoretically in 25 years all bathrooms and kitchens will be renovated as this is the average economic lifetime of a bathroom. Kitchens have a lifespan of 15 years (Huur Commissie, 2011). Pipe in pipe systems may also be possible for upstairs toilets after positive results from testing the technology (Harder, 2012). Alternatively, kitchen refuse may be added and grinded in a different way outside the house, if users are willing to take the effort to deposit it at an outside collection location, thereby increasing the strength of the wastewater. Another alternative to vacuum technology for not connected toilets is that in the future anaerobic treatment of low strength wastewater may more favourable (Kato et al., 1997) by applying co-digestion (Zhang et al., 2013b) and also at low temperatures (Mahmoud et al., 2004). Low flush toilets may then also be connected.	impact (De Graaf and Van Hell, 2014). The external infrastructure can be planned as needed, as there is a clean slate. But vacuum pipes may be favourable due to the mound of the island as they can also transport sewage uphill (Harder, 2012).
Stepping stone technology 3: Composting dry toilets with urine storage	***Partially.*** Ground floor toilets can be connected to the composting toilet due to the ease of modification of the crawlspace	***No.*** The reference project uses composting toilets with a composting compartment in the basement – which reduces

	as described by as Harder (2012) and most houses feature a crawlspace (only 10%-15% of houses do not have one). Depending on the size and shape of the crawl space a no-mix composting toilet and composting container can be selected. Kitchen refuse can be added to the secondary composting community-on-site. A separate container will be placed for urine storage. There is no constraint on small or large volumes/ concentrations produced, this just determines the size of the container and/or the residence time of the compost in the composter. The container in the crawlspace needs to be sized large enough that if a second floor toilet is situated directly above the first floor toilet, it can be connected at a later time. However, care needs to be taken that the compost is not too wet, so a ventilation pipe to the roof of the house has to be installed with an electric fan to ensure sufficient evaporation of liquid and gasses and a leachate container needs to be installed to collect surplus liquids. Direct heat recovery in the showers is possible when the bathroom is being renovated as some piping has to be redirected. *Future: Possibly yes.* The upstairs toilet can be connected in the future, if toilets are stacked and when renovation of the upstairs bathroom is undertaken (Berger, 2003). Another option is installation of toilets that need daily emptying, as this requires no piping and no in-	handling to one hour per month. The apartment buildings do not have cellars and already have small living spaces of 75 m^2 on average plus a ground floor store room. The store room is the only option to install a composting toilet, but this decreases the useable surface of the apartment and devalues the apartments accordingly (Rijksoverheid, 2016). *Future: Possibly yes.* Sealing toilets with central disposal sites may make composting possible, if suitable sealing mechanisms and materials for bags are developed and residents are willing to manually take backs from inside to an outside collection point (Harder, 2012). Or smaller composting toilets have to be invented that take very little handling or a lifestyle change is required towards less comfort and daily emptying of the toilet to an outside location.

<table>
<tr>
<td></td>
<td>house storage compartment and thus no renovation. It does however require a substantial lifestyle adjustment.</td>
<td></td>
</tr>
<tr>
<td>Stepping stone technology 4:
Willow filter with ABR


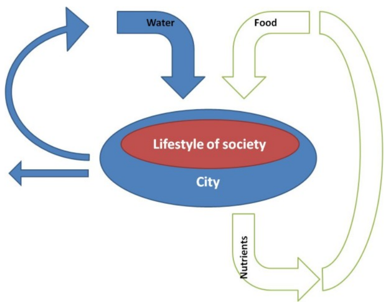
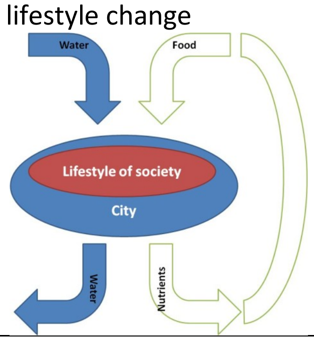
</td>
<td>Partially.
Only ground floor toilets can be connected to a black water circuit with small diameter gravity sewers due to the ease of modification of the crawlspace and only 10%-15% of houses do not feature a crawl space (Harder, 2012). The toilet does not have to be replaced, just the connection of the toilet to the conventional sewer has to be removed. This results in a separate concentrated black water stream that will be transported to and treated in an ABR. The effluent of the ABR is treated in a willow filter. The greywater will be combined with the black water from the upstairs toilet and is treated by the willow filter as well, although design and dimensions have to be adjusted to account for higher pollution levels from black water. A pre-treatment for solids is to be applied, which is the settling of solids in the greywater collection tank (Woonvereniging Polderdrift, 2016).

Future: Possibly yes.
After positive results testing smart housing connections (a valve in the sewer just outside the house with a sensor that detects if black or greywater is being transported and opens to the black water or greywater sewer accordingly) this could be applied to separate streams outside of the house and capture a larger part of the black water to the</td>
<td>No.
Due to the required size of the willow filter on site which is of equal size up to four times larger than a constructed wetland (Tauw, 2016) and cannot be constructed to float on surface water, which a constructed wetland can (geWoonboot, 2016), it is not possible to implement this technology. Changing the concept to a constructed wetland is not desirable, because the latter does not take up nutrients into biomass to be recycled like a willow filter.
Moreover, the ABR needs to be dimensioned for the lowest temperature, which means it will be quite large to ensure removal in winter, as it is not heated. It is questionable if enough space is available in the densely populated urban area of Centrumeiland IJburg.</td>
</tr>
</table>

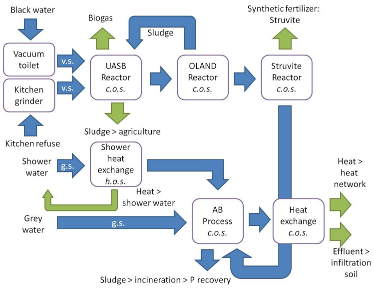
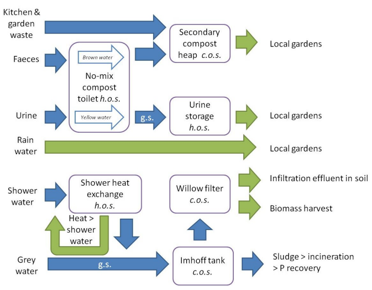
	ABR, however, cross contamination of streams is a real possibility which has to be incorporated in the design parameters (Harder, 2012). When bathrooms are remodelled first floor toilets can also be connected. The smaller diameter pipes needed to transport lower volume black water (due to water-saving toilets of 3.5 to 4 litres per flush) can be placed at a bit larger slope because there is more space if a small diameter is applied. This probably removes black water even more efficiently (Vreeburg, 2016)	
Stepping stone technology 5: Urine separation systems **Rural**  **Urban**  	***Partially.*** Ground floor toilets need to be replaced by no-mix toilets and connected to two separate piping systems which is possible due to the ease of modification of the crawlspace and only 10%-15% of houses do not feature a crawl space (Harder, 2012). Yellow water will be stored in small tanks one for each home to keep pipes as short as possible and to prevent scaling (Eawag et al., 2016). Separated brown water from all the homes will be treated in septic tanks (septic tanks will be connected to a cluster of homes to ensure transport distances by small diameter pipe are short). The remaining greywater combined with black water from upstairs toilets can be treated by the willow filter, although pre treatment is necessary for solids and design and dimensions have to be adjusted to account for higher pollution levels from black water (Woonvereniging Polderdrift, 2016).	***Yes.*** The internal infrastructure can be completely rearranged and new toilets are going to be placed, and a green roof can be added as well as an open tank as part of the landscape for rain water collection. In this case there is sufficient space to lay out bigger diameter gravity pipes (compared to vacuum pipes) anywhere in the apartments. The gravity pipes with rain water from the roof which is collected and stored in a tank below the roof to the toilets for flushing can also be fitted in. So lay outs of all apartments can be different if desired (Telkamp et al., 2008). As conventional toilets are used, no noise hindrance is to be expected (as with vacuum toilets). The external infrastructure can be planned as needed, as there is a clean slate. But gravity sewer pipes may need to be supplemented with pumps as the island is shaped in a mound and sewers may have to go uphill (Harder, 2012)

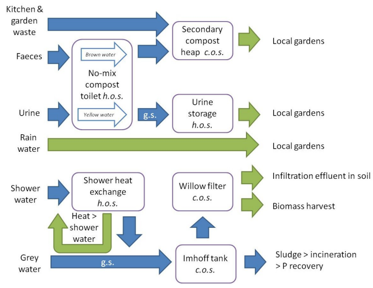
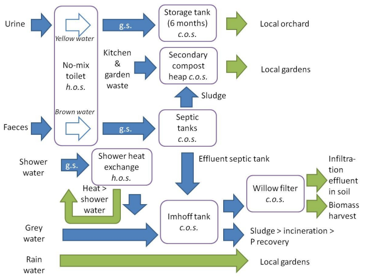
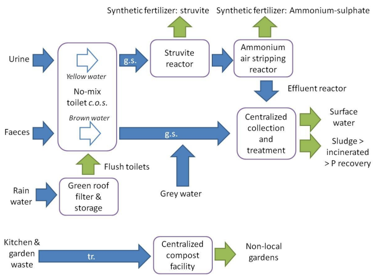
To evaluate if the stepping stone technologies comply with the chosen visions for the rural and urban case each combination has been analysed (see table 12). This is also the score on the first criterion for sustainability: A **vision for** the long-term of **60 years**[19] **in the future** is selected that fits the specific opportunities and challenges of waste (water) infrastructure the case at hand. (Scored ++, +, +-, - or --.) On three issues the match of the vision with the concept was scored: water use, nutrient recovery and local reuse.

TABLE 12: EVALUATION OF CRITERION 1: HOW WELL DO THE SST CONCEPTS FIT WITH THE FUTURE VISION FOR THE RURAL AND URBAN CASE?

	Vision rural case Exel: Dry sanitation system as maximum eco-efficient water metabolism  	**Vision urban case Centrumeiland** **IJburg:** Separated water and nutrient reuse infrastructures with lifestyle change 
Stepping stone technology 1: Centralized treatment with energy and nutrient reuse	**Score: --** <u>Water use</u> Nutrients are not uncoupled from water as the gravity sewers still require water for transport. <u>Resource recovery</u> If resource recovery is applied fully at WWT it mostly fits with the vision, but this may be difficult due to the low concentrations. <u>Local reuse</u> Moreover, as distances to WWT facilities are often big, local nutrient reuse is not likely.	**Score: +-** <u>Water use</u> Nutrients are diluted in water as the conventional large diameter gravity sewers still require water for transport. <u>Resource recovery</u> If resource recovery is applied fully at WWT, this means biogas, phosphate (from incinerated sludge), cellulose and alginate recovery, it somewhat fits with the vision, but recovery of other nutrients (nitrogen and potassium) remains impossible due to the low concentrations. <u>Local reuse</u> Moreover, as distances to WWT facilities are often big,

[19] 60 years in the future, as this is how long average Dutch sewers last, which is the longest asset in the wastewater chain OOSTEROM, E. & HERMANS, R. 2013. Riolering in beeld - Benchmark rioleringszorg 2013. Ede: RioNED.

<table>
<tr><td></td><td></td><td>local nutrient reuse is not likely.</td></tr>
<tr><td>Stepping stone technology 2: Vacuum system for black water

</td><td>Score: +-
<u>Water use</u>
Vacuum systems use water for flushing and washing down kitchen refuse down grinder (De Graaf and Van Hell, 2014).
<u>Resource recovery</u>
High concentrations of nutrients in water allow for reuse of biogas, direct heat and synthetic fertilizer.
<u>Local reuse</u>
Recovered nutrients/resources are available for local reuse.</td><td>Score: ++
<u>Water use</u>
Source separated streams have considerable lower water use than conventional systems.
<u>Resource recovery</u>
High concentrations of nutrients in water allow for reuse of biogas, direct heat and synthetic fertilizer.
<u>Resource recovery</u>
Recovered nutrients can be used locally and if the synthetic fertilizer is not needed for urban farming it is efficient to transport outside the city as it completely dry.</td></tr>
<tr><td>Stepping stone technology 3: Composting dry toilets with urine storage

</td><td>Score: ++
<u>Water use</u>
Water and nutrient loops are completely separate.
<u>Resource recovery</u>
Dry sanitation allows for full nutrient recovery as compost (organic fertilizer and soil conditioner).
<u>Local reuse</u>
Organic fertilizer and soil conditioner can be applied locally.</td><td>Score: +-
<u>Water use</u>
Water and nutrient loops are completely separated at the source. However, even though this is very sustainable, it does not fit the vision which envisions wet sanitation to achieve nutrient reuse.
<u>Resource recovery</u>
Dry sanitation allows for full nutrient recovery as compost (organic fertilizer and soil conditioner).
<u>Local reuse</u>
Local reuse of nutrients is probably not possible, as there is probably not enough urban farming land (Wielemaker, 2014). There is also a spatial challenge inside and outside buildings to fit in compost</td></tr>
</table>

		chambers. Transportation of the relatively wet brown fraction over long distances by truck to a suitable compost site is not advisable from the standpoint of hygiene and public health.
Stepping stone technology 4: Willow filter with ABR 	**Score: +-** <u>Water use</u> Still uses considerable amounts of water for transport in separated gravity pipes. <u>Resource recovery</u> High nutrient and resource recovery as biogas, woody biomass and direct heat. <u>Local reuse</u> Recovered nutrients can be reused locally, avoiding long-distance transport.	**Score: +** <u>Water use</u> Water use is relatively high due to conventional gravity piping. <u>Resource recovery</u> High nutrient and resource recovery as biogas, woody biomass and direct heat. <u>Local reuse</u> Recovered nutrients, except perhaps woody biomass, can be reused locally, avoiding long-distance transport.
Stepping stone technology 5: Urine separation systems **Rural**  **Urban** 	**Score: +** <u>Water use</u> Water use is reduced, as only flush water is needed for the faeces part, not for urine. <u>Resource recovery</u> Fairly good nutrient and resource recovery from urine (fully used as organic fertilizer), faeces (sludge as organic fertilizer), direct heat from shower water and rain water for local garden irrigation. Willow biomass is also harvested. <u>Local reuse</u> Nutrients can be used locally.	**Score: +** <u>Water use</u> Water use is reduced, as only flush water is needed for the faeces part, not for urine. Moreover, rain water is used for flushing and water-saving toilets are applied. <u>Resource recovery</u> A struvite reactor to produce synthetic dry fertilizer allows for non-local application of synthetic fertilizer, as it can be efficiently transported over larger distances. The ammonium air stripper produces liquid ammonium sulphate fertilizer. The remaining wastewater is transported by gravity sewer to the central wastewater plant, which does do some nutrient recovery and has a reduced load and energy consumption due to the removal of mostly phosphorous in struvite and nitrogen by air stripping community-on-site. <u>Local reuse</u>

		Resource products will not be available for local reuse.

Not all stepping stone technologies can be applied because of either practical constraints or an ill fit with the chosen vision for the case. From the analysis on the practical limitation and opportunities of the stepping stone technologies in both the rural and urban case (see table 11) it becomes clear that in the rural case implementation of SST1 and partial implementation of SST2, SST3, SST4 and SST5 are possible. This is due to the step by step renovation of ground bound houses and total replacement of the mechanized pressure sewer connecting the community to the centralized wastewater treatment plant. The bottom floor toilet in homes with a crawl space is able to be connected right away and the top floor toilets will follow when a renovation of the second floor bathroom is undertaken by the individual homeowners. In the urban case, SST1, SST2 and SST5 can be fully implemented. SST3 is not able to be implemented due to spatial constraints in the homes, which prohibits the installation of composting toilets with an indoor compost compartment. Moreover, SST4 is also not able to be implemented due to the outdoor special constraints of the urban environment. A large ABR and willow filter will not fit on Centrumeiland IJburg.

From the analysis on how well the SST concepts fit with the future vision of the rural and urban case (see table 12), it can be concluded that in the rural case SST3 is most fitting and SST1 does not fit at all. Therefore, SST1 is excluded from further analysis. In the urban case SST2 fits the best, but the other four SSTs also somewhat fit. Hence none of the SSTs are excluded from the analysis of the urban case.

In summary, the following SSTs are appropriate to assess on how future proof they by using the sustainability criteria:

Rural case Exel, Lochem:

- Stepping stone technology 2: Vacuum system for black water
- Stepping stone technology 3: Composting dry toilets with urine storage
- Stepping stone technology 4: Willow filter with ABR
- Stepping stone technology 5: Urine separation systems

Urban case Centrumeiland IJburg, Amsterdam:

- Stepping stone technology 1: Centralized treatment with energy and nutrient reuse
- Stepping stone technology 2: Vacuum system for black water
- Stepping stone technology 5: Urine separation systems

Scoring on indicators of selected stepping stone technologies for the rural and urban case

Scoring of SSTs for Exel

The stepping stone technologies for the rural case were scored on the 24 criteria. The criteria are not weighted, so for each criterion the SST that scores the best is awarded one point. When two or three stepping stone technologies score equally well they all get one point. This yields one preferred SST based on sustainability principles of TNS and the cradle to cradle design concept. In annex 11 for SST2, annex 12 for SST3, annex 13 for SST4 and annex 14 for SST5 the argument for the score of each indicator for the rural case is given.

TABLE 13: SCORING OF INDICATORS OF THREE SELECTED STEPPING STONE TECHNOLOGIES FOR THE CASE OF RURAL EXEL

	Stepping stone technology 2: Vacuum system for black water	**Stepping stone technology 3:** Composting dry toilets with urine storage	**Stepping stone technology 4:** Willow filter with ABR	**Stepping stone technology 5:** Urine separation systems
#2 Total **phosphorous** (P) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) since phosphorous is a fossil resource (Cordell, 2013). Scored as percentage (of kg P input).	**Overall score: 43.9% P recovery of [kg P y^{-1}] input.** *Due to partial connection.*	**Overall score: 39.0% P recovery of [kg P y^{-1}] input.** *Due to partial connection.*	**Overall score: 39.0% P recovery of [kg P y^{-1}] input.** *Due to partial connection.*	**Overall score: 39.0% P recovery of [kg P y^{-1}] input.** *Due to partial connection.*
#3 Total **nitrogen** (N) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) – or – removed without the formation of reactive nitrogen, since reactive nitrogen, which is a small by-product from wastewater treatment, unbalances the natural nitrogen cycle (Erisman and Larsen, 2013). Scored as percentage kJ saved by RECOVERY (of kJ N baseline embedded energy input) .	**Overall score: 0% energy saved [kJ y^{-1}] for N recovery.** *Due to partial connection.*	**Overall score: 26.1% energy saved [kJ y^{-1}] for N recovery.** *Due to partial connection.*	**Overall score: 24.4% energy saved [kJ y^{-1}] for N recovery.** *Due to partial connection.*	**Overall score: 22.9% energy saved [kJ y^{-1}] for N recovery.** *Due to partial connection.*
#4 Total **potassium** (K) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) since potassium is a fossil resource (Zeeman, 2016b).	**Overall score: 3.3% K recovery of [kg K y^{-1}] input.**	**Overall score: 38.9% K recovery of [kg K y^{-1}] input.**	**Overall score: 38.9% K recovery of [kg K y^{-1}] input.**	**Overall score: 38.9% K recovery of [kg K y^{-1}] input.**

Scored as percentage (of kg K input).	*Due to partial connection.*	*Due to partial connection.*	*Due to partial connection.*	*Due to partial connection.*
#5 If cellulose is recovered as a separate stream[20]: Total **cellulose** entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as useful product which can be cellulose, biogas – when combined with other organic matter - or another resource) since cellulose in wastewater mostly originates from toilet paper which is mostly made from virgin wood (Wüstenberg, 2015). Scored as percentage (of kg Cellulose input).	No separate cellulose recovery.	No separate cellulose recovery.	No separate cellulose recovery.	No separate cellulose recovery.
#6 Total **organic matter** entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse, as biogas, fertilizer, or bio-building block for bio plastics e.d. (EFGF, 2016e, Zeeman, 2016b). Scored as percentage (of kg organic matter input)	**Overall score: 17.3% OM recovery of [kg OM y^{-1}] input.** *Due to partial connection.*	**Overall score: 8.7% OM recovery of [kg OM y^{-1}] input.** *Due to partial connection.*	**Overall score: 23.1% OM recovery of [kg OM y^{-1}] input.** *Due to partial connection.*	**Overall score: 8.7% OM recovery of [kg OM y^{-1}] input.** *Due to partial connection.*
#7 **Nutrient/resource input[21]** needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with TNS's four sustainability principles. Scored ++, +, +-, - or --.	**Overall score: +-**	**Overall score: ++**	**Overall score: +**	**Overall score: +**
#8 **Quality of effluent or residual waste** from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem by applicable governmental standards [22]. Scored ++, +, +-, - or -- [23].	**Overall score: +-**	**Overall score: +-**	**Overall score: +**	**Overall score: +**
#9 Recovered nutrient is free of unnatural and persistent substances such as **micropollutants** (from pharmaceuticals, hormones, and	**Overall score: +**	**Overall score: +-**	**Overall score: +-**	**Overall score: +-**

[20] If cellulose is not recovered as a separate stream it is added to total organic matter, indicator #6.
[21] Materials and chemicals (not energy).
[22] Please note, as micropollutants currently are not regulated in The Netherlands, their presence in effluent or residual waste does not influence this indicator.
[23] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources including nutrient deposits. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of **metals** (Tervahauta, 2014) or other unwanted by-products from treatment[24]. Scored ++, +, +-, - or --.				
#10 Total **direct heat** energy content from natural gas entering the residential building and exiting the combined sanitation & kitchen waste (water) stream recovered for reuse since direct heat recovery lowers the household demand for natural gas which is currently the main source of heating for water in The Netherlands (Milieu Centraal, 2016b). Scored as percentage direct heat recovery (of GJ direct heat input from natural gas in households).	**Overall score: 5.4% direct heat recovery of [GJ natural gas y-1] input.**	**Overall score: 0.5% direct heat recovery of [GJ natural gas y-1] input.**	**Overall score: 0.5% direct heat recovery of [GJ natural gas y-1] input.**	**Overall score: 0.5% direct heat recovery of [GJ natural gas y-1] input.**
#11 **Energy** generated (or lost) by collection, transport, treatment, and recovery of the combined sanitation & kitchen waste (water) stream. Scored ++, +, +-, - or -- [25].	**Overall score: ++**	**Overall score: +-**	**Overall score: +**	**Overall score: +-**
#12 The **trade-off** between **energy** production and production of **recovered nutrients** has been given consideration with regard to optimizing positive environmental impact[26]. Scored ++, +, +-, - or --.	**Overall score: ++**	**Overall score: +**	**Overall score: +**	**Overall score: +**
#13 **Technical knowhow** to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.	**Overall score: --**	**Overall score: ++**	**Overall score: +**	**Overall score: ++**

[24] This is excluding recovery of micropollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scales.
High purity and low toxicity can be reached by avoiding the entrance of micropollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.
[25] When there is more energy used for collection, transport, treatment, and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.
[26] For example, does energy recovery from incinerating sludge mean that fossil, mined phosphorous becomes difficult, impossible, or very energy intensive to recover? This would be conflicting with TNS's sustainability principle 1.

Scored ++, +, +-, - or --.				
#14 **Benefits** from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources, or an attractive treatment facility that mimics nature[27] for recreation or landscape purposes, are allocated and accessible to the **communities** where the waste (water) originates from. Scored ++, +, +-, - or --.	**Overall score: +**	**Overall score: ++**	**Overall score: ++**	**Overall score: ++**
#15 **Users accept the system**, the possible extra handling/monitoring weight against the benefits it gives the users and the community. Scored ++, +, +-, - or --.	**Overall score: +**	**Overall score: +**	**Overall score: ++**	**Overall score: +**
#16 The stepping stone technology/process has **high convenience** in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved). Scored ++, +, +-, - or --.	**Overall score: +**	**Overall score: +-**	**Overall score: ++**	**Overall score: +**
#17 The chosen system/process is **robust**: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction. Scored ++, +, +-, - or --.	**Overall score: +**	**Overall score: +**	**Overall score: +**	**Overall score: +**
#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence **public health is optimized**. Scored ++, +, +-, - or --.	**Overall score: ++**	**Overall score: +**	**Overall score: ++**	**Overall score: +**
#19 If locally there is poor, infertile soil, the waste (water) effluent is used to **increase local soil fertility**. Scored ++, +, +-, - or --.	**Overall score: +-**	**Overall score: ++**	**Overall score: +**	**Overall score: +**
#20 Relevant **stakeholders** are actively involved in the design process.	**Overall score: +**	**Overall score: ++**	**Overall score: ++**	**Overall score: +**

[27] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

Scored ++, +, +-, - or --.				
#21 Investment in technology today does not block the future proof technical design implementation, so only investment in **flexible platforms**. Scored ++, +, +-, - or --.	**Overall score: +-**	**Overall score: ++**	**Overall score: +**	**Overall score: +**
#22 Investment in flexible platform technology today has a **good return on investment**[28]. Scored ++, +, +-, - or --.	**Overall score: +-**	**Overall score: ++**	**Overall score: +**	**Overall score: ++**
#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking **precaution**. Scored ++, +, +-, - or --.	**Overall score: +**	**Overall score: ++**	**Overall score: +-**	**Overall score: +-**
#24 Inaction or business as usual (BAU) is not undertaken without **conscious consideration** of the consequences **of inaction**. Scored ++, +, +-, - or --.	**Overall score: ++**	**Overall score: ++**	**Overall score: ++**	**Overall score: ++**
Total score (out of 24 maximum):	**9**	**14**	**11**	**7**

To determine which stepping stone technology (SST) is most fitting in the rural case of Exel, municipality Lochem, for each indicator an assessment has been made as to which SST scores the best on the sustainability criteria. When there is an equal score for two or three SSTs, they all receive a point. Based on the sum of these points the best scoring SST is that of SST 3: “Composting dry toilets with urine storage” with 14 out of 24 points. Second best is SST 4: “Willow filter with ABR “with 11 points. Third is SST2: “Vacuum systems for black water” with 9 points and last is SST 5: “Urine separation systems” with only 7 points.

Scoring of SSTs for Centrumeiland IJburg

Below are the scores for the selected stepping stone technologies for the urban case, which were scored on the 24 criteria. The criteria are not weighted, so for each criterion the SST that scores the best is awarded one point. When two or three stepping stone technologies score equally well they all get one point. This yields one preferred SST based on sustainability principles of TNS and the cradle to cradle design concept. In annex 15 for SST1, annex 16 for SST2 and annex 17 for SST5 the argumentation for the score of each indicator for the urban case is given.

[28] Refers to all types of value, including financial and investment in future technology development, but also prosperity in the broader sense than just financial profit.

TABLE 14: SCORING OF INDICATORS OF THREE SELECTED STEPPING STONE TECHNOLOGIES FOR THE CASE OF URBAN CENTRUMEILAND IJBURG

	Stepping stone technology 1: Centralized treatment with energy and nutrient reuse	**Stepping stone technology 2:** Vacuum system for black water	**Stepping stone technology 5:** Urine separation systems
#2 Total **phosphorous** (P) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product), as phosphorous is a fossil resource (Cordell, 2013). Scored as percentage (of kg P input).	**Overall score: 81.8% P recovery of [kg P y^{-1}] input.**	**Overall score: 88.3% P recovery of [kg P y^{-1}] input.** *(Assuming a fully loaded system.)*	**Overall score: 85.7% P recovery of [kg P y^{-1}] input.**
#3 Total **nitrogen** (N) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product) – or – removed without the formation of reactive nitrogen, as reactive nitrogen which is a small by-product from wastewater treatment unbalances the natural nitrogen cycle (Erisman and Larsen, 2013). Scored as percentage kJ saved by RECOVERY (of kJ N baseline embedded energy input.	**Overall score: 0.0% energy saved [kJ y^{-1}] for N recovery.**	**Overall score: 0.0% energy saved [kJ y^{-1}] for N recovery.**	**Overall score: 0.0% energy saved [kJ y^{-1}] for N recovery.**
#4 Total **potassium** (K) entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as combined or singular recovery product), as potassium is a fossil resource (Zeeman, 2016b). Scored as percentage (of kg K input).	**Overall score: 2.1% K recovery of [kg K y^{-1}] input.**	**Overall score: 7.3% K recovery of [kg K y^{-1}] input.**	**Overall score: 2.1% K recovery of [kg K y^{-1}] input.**
#5 If cellulose is recovered as a separate stream[29]: Total **cellulose** entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse (as useful product which can be cellulose, biogas – when combined with other organic matter - or another resource), as cellulose in wastewater mostly originates from toilet paper which is mostly made from virgin	**Overall score: 42.0% Cellulose recovery of [kg Cellulose y^{-1}] input.**	No separate cellulose recovery.	**Overall score: 42.0% Cellulose recovery of [kg Cellulose y^{-1}] input.**

[29] If cellulose is not recovered as a separate stream it is added to total organic matter, indicator #6.

wood (Wüstenberg, 2015). Scored as percentage (of kg Cellulose input).			
#6 Total **organic matter** entering the residential building and exiting in the combined sanitation & kitchen waste (water) stream recovered for reuse, as biogas, fertilizer or bio-building block for bio plastics e.d. (EFGF, 2016e, Zeeman, 2016b). Scored as percentage (of kg organic matter input)	**Overall score: 13.3% OM recovery of [kg OM y^{-1}] input.**	**Overall score: 43.3% OM recovery of [kg OM y^{-1}] input.**	**Overall score: 13.3% OM recovery of [kg OM y^{-1}] input.**
#7 **Nutrient/resource input**[30] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS. Scored ++, +, +-, - or --.	**Overall score: --**	**Overall score: +-**	**Overall score: +-**
#8 **Quality of effluent or residual waste** from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem[31]. Scored ++, +, +-, - or -- [32].	**Overall score: +-**	**Overall score: +-**	**Overall score: +-**
#9 Recovered nutrient is free of unnatural and persistent substances such as **micropollutants** (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of **metals** (Tervahauta, 2014) or other unwanted by-products from treatment[33]. Scored ++, +, +-, - or --.	**Overall score: +-**	**Overall score: +**	**Overall score: +-**
#10 Total **direct heat** energy content from natural gas entering the residential building and exiting the combined sanitation & kitchen waste (water) stream recovered for reuse, as direct heat recovery lowers the household demand for natural gas which is currently the main source of heating water in The Netherlands (Milieu Centraal, 2016b). Scored as percentage direct heat recovery (of GJ direct heat input from natural gas	**Overall score: 0.0% direct heat recovery of [GJ natural gas y-1] input.**	**Overall score: 3.3% direct heat recovery of [GJ natural gas y-1] input.**	**Overall score: 0.3% direct heat recovery of [GJ natural gas y-1] input.**

[30] Materials and chemicals (not energy).
[31] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.
[32] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources, including nutrient deposits. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.
[33] This is excluding recovery of micropollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micropollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

in households).			
#11 **Energy** generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream. Scored ++, +, +-, - or -- [34].	**Overall score: +-**	**Overall score: ++**	**Overall score: +**
#12 The **trade-off** between **energy** production and production of **recovered nutrients** has been given consideration with regard to optimizing positive environmental impact[35]. Scored ++, +, +-, - or --.	**Overall score: -**	**Overall score: ++**	**Overall score: +-**
#13 **Technical knowhow** to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design. Scored ++, +, +-, - or --.	**Overall score: --**	**Overall score: --**	**Overall score: --**
#14 **Benefits** from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[36] for recreation or landscape purposes, are allocated and accessible to the **communities** the waste (water) originates from. Scored ++, +, +-, - or --.	**Overall score: --**	**Overall score: +**	**Overall score: +-**
#15 **Users accept the system**, the possible extra handling/monitoring weight against the benefits it gives the users and the community. Scored ++, +, +-, - or --.	**Overall score: ++**	**Overall score: +**	**Overall score: +**
#16 The stepping stone technology/process has **high convenience** in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved). Scored ++, +, +-, - or --.	**Overall score: ++**	**Overall score: +**	**Overall score: +**
#17 The chosen system/process is **robust**: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it	**Overall score: ++**	**Overall score: +**	**Overall score: +**

[34] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.

[35] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

[36] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

is not vulnerable and it is resilient in recovery from malfunction. Scored ++, +, +-, - or --.			
#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence **public health is optimized**. Scored ++, +, +-, - or --.	**Overall score: ++**	**Overall score: ++**	**Overall score: ++**
#19 If locally there is poor, infertile soil, the waste (water) effluent is used to **increase local soil fertility**. Scored ++, +, +-, - or --.	**Overall score: --**	**Overall score: +-**	**Overall score: -**
#20 Relevant **stakeholders** are actively involved in the design process. Scored ++, +, +-, - or --.	**Overall score: --**	**Overall score: +**	**Overall score: +-**
#21 Investment in technology today does not block the future proof technical design implementation, so only investment in **flexible platforms**. Scored ++, +, +-, - or --.	**Overall score: --**	**Overall score: +-**	**Overall score: +-**
#22 Investment in flexible platform technology today has a **good return on investment**[37]. Scored ++, +, +-, - or --.	**Overall score: -**	**Overall score: +-**	**Overall score: +-**
#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking **precaution**. Scored ++, +, +-, - or --.	**Overall score: -**	**Overall score: +**	**Overall score: +-**
#24 Inaction or business as usual (BAU) is not undertaken without **conscious consideration** of the consequences **of inaction**. Scored ++, +, +-, - or --.	**Overall score: -**	**Overall score: ++**	**Overall score: ++**
Total score (out of 24 maximum):	**8**	**20**	**7**

[37] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

To determine which stepping stone technology (SST) is most fitting to the urban case of Centrumeiland IJburg, municipality Amsterdam, for each indicator an assessment has been made which SST scores the best on the sustainability criteria. When there is an equal score for two or three SSTs, they all receive a point. Based on the sum of these points the best scoring SST is that of SST 2: “Vacuum system for black water” with 20 out of 24 points. Second best is a tie between SST 1: “Centralized treatment with energy and nutrient reuse” with 8 points and SST 5: “Urine separation systems” is last with 7 points.

Summary selected stepping stone technologies

In summary, in the rural case SST3: “Composting dry toilets with urine storage,” and the urban case SST2: “Vacuum system for black water,” were selected as the most sustainable stepping stone technologies.

Stakeholder feedback on selected stepping stone technologies

A questionnaire (see annex 19) explaining the case parameters, long-term sustainability vision and proposed stepping stone technology was sent out to 88 stakeholders. The purpose of the questionnaire was the collection of qualitative data from experts. There is no focus on quantitative data because the sample size is too small to permit reliable quantitative statistical analysis, the chosen stakeholder group was not representative of all parties, such as inhabitants and architects, involved in the project, and focusing on closed questions would hamper the collection of detailed feedback (Rattray and Jones, 2007).

The 33 responding stakeholders were from water boards (34%), municipalities (21%), the scientific community (7%), consultancies (21%) and other sectors (17%), such as a combined water board and drinking water company, the province, inhabitants, owner of a constructed wetland and an association of decentralized governments. Even though these respondents are not representative of a typical stakeholder group in a new sanitation project, they do encompass a wealth of knowledge of what needs to be considered to ensure short term implementation of the stepping stone technologies in both cases.

In both the rural and urban case the majority of respondents see a fit between the vision and the case. However, the implementation of SST2 in the urban case seems a lot more feasible to respondents than the implementation of SST3 in the rural case. This is in spite of a good fit between the stepping stone technology and the chosen vision in both cases and a belief that the chosen visions are achievable within 60 years, according to the majority of respondents. In both cases almost 70% of respondents see a conflict of interest, which will hamper actual implementation of the stepping stone technology.

In the rural case, the main concerns are about motivating inhabitants to accept and support the required significant lifestyle change and thus breaking through cultural and institutional resistance against dealing with faeces and urine. Alternative sanitation systems proposed are all water-based. Many helpful suggestions are made on how to successfully implement composting dry toilets with urine storage in Exel.

In the urban case, the main concerns relate to taking advantage of economies of scale and the perceived proneness to failure of the stepping stone technology. Respondents are also worried that the proposed vacuum system for black water is not flexible enough due to its lifespan of 30 years. A stepping stone technology with a shorter lifespan would be preferable. Alternative sanitation systems proposed are various forms of centralized treatment of source-separated streams and foregoing the connection to the heat network, as this creates unnecessary complexity. Several helpful suggestions are made on how to bring all stakeholders and interests together to implement a vacuum system for black water in Centrumeiland IJburg.

In both cases, the inhabitants are paramount in the success of the applied stepping stone technology, and with their support the system has to be designed. The reasoning is that part of the stepping stone technologies constitutes a change of technologies behind the front door and inside the house, which requires a lifestyle change for dealing with urine, faeces and kitchen waste. A summary of the questionnaire results is given in annex 20.

Regardless of the concerns about the practical implementation of the selected stepping stone technologies for both cases, the general conclusion is that with the right approach and in due time a lot is possible. A dot on the horizon in terms of a long-term vision in 60 years will help stay the course.

Chapter 5: Discussion, recommendations and conclusion

To understand the full potential of the proposed stepping stone technology for the rural and urban case a water and nutrient MFA has been made assuming full connection of all households. This is followed by a discussion of the results of this thesis, the methods used and suggestions for future research. Finally, a conclusion of this thesis research is presented.

Future outlook: water and nutrient material flow analysis

Whereas the scoring on the criteria is done based on the toilets that are able to be connected at present, the material flow analyses (MFA) of the most sustainable stepping stone technology assume a *full connection of all toilets and all households*. For the rural case this means 186 inhabitants are fully connected to SST3: "Composting dry toilets with urine storage." In the urban case 543 inhabitants are fully connected to SST2: "Vacuum system for black water." The water MFA for SST3 in rural Exel is shown in figure 29 and the nutrient MFA for SST3 in rural Exel is shown in figure 31. The water MFA for SST2 in urban Centrumeiland IJburg is shown in figure 30 and the nutrient MFA for SST2 in urban Centrumeiland IJburg is shown in figure 32.

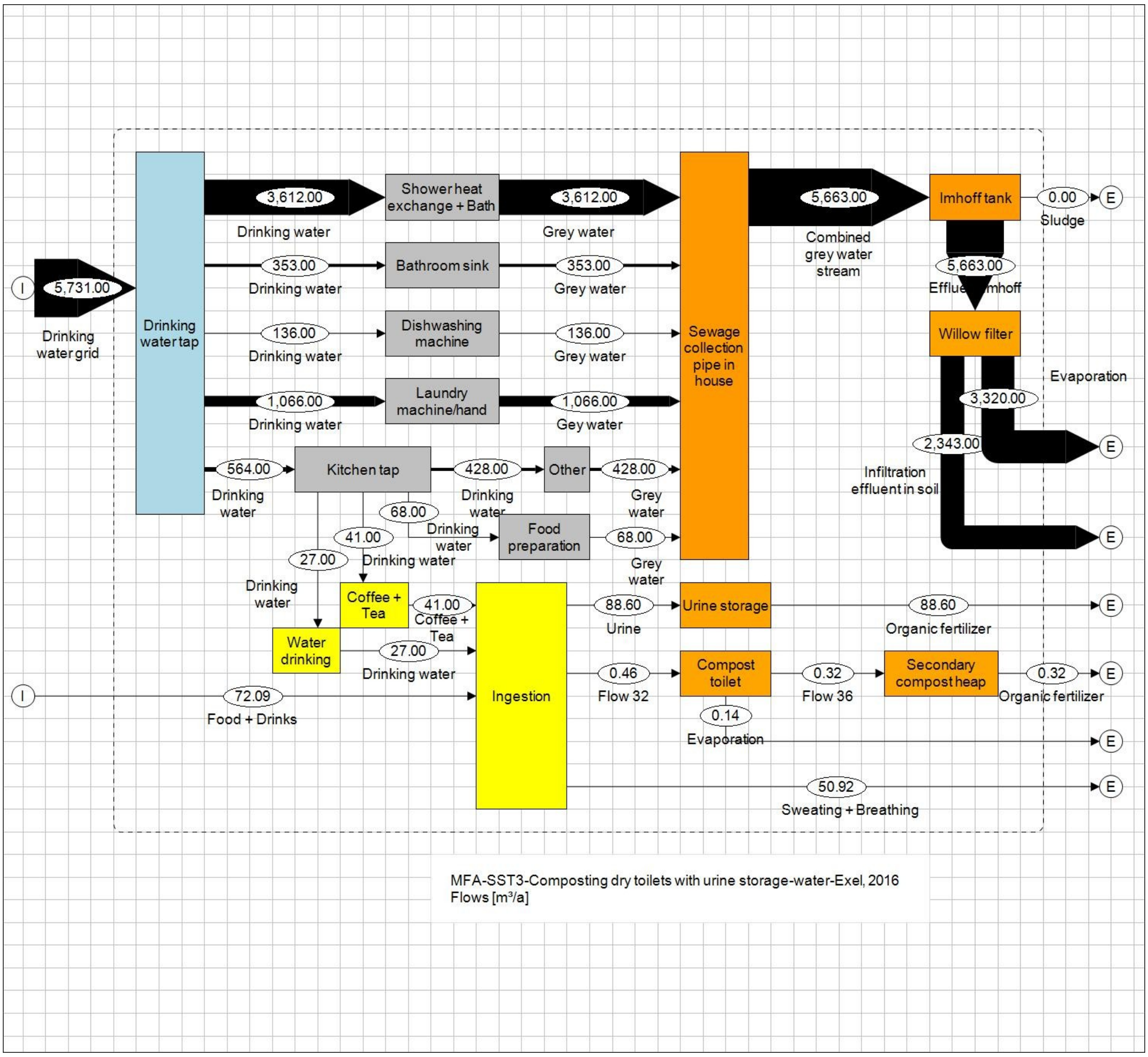


FIGURE 29: MFA WATER SST3 COMPOSTING DRY TOILETS WITH URINE STORAGE FOR EXEL, 186 INHABITANTS [M^3 Y^{-1}]

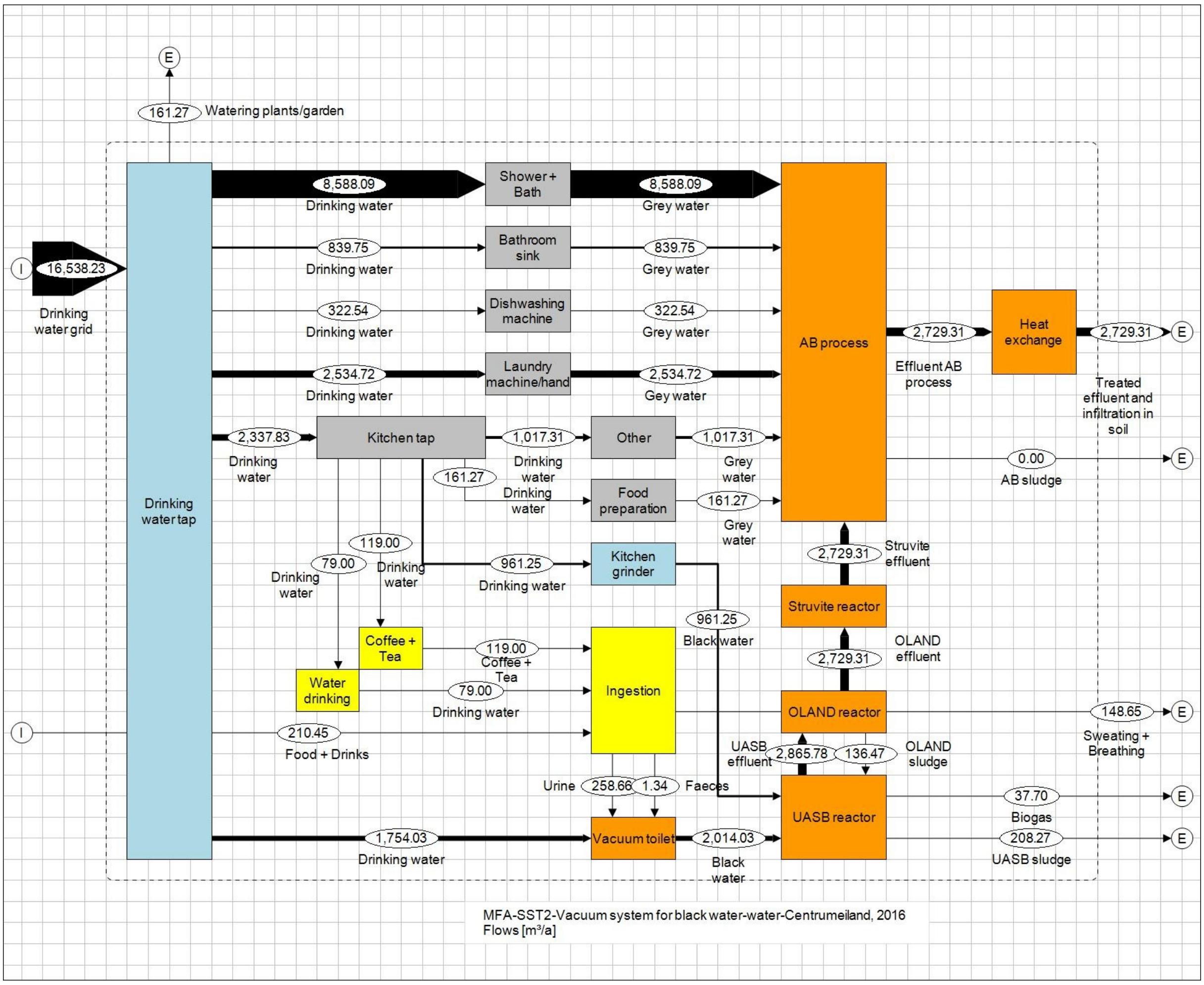


FIGURE 30: MFA WATER SST2 VACUUM SYSTEM FOR BLACK WATER FOR CENTRUMEILAND IJBURG, 543 INHABITANTS [M^3 Y^{-1}]

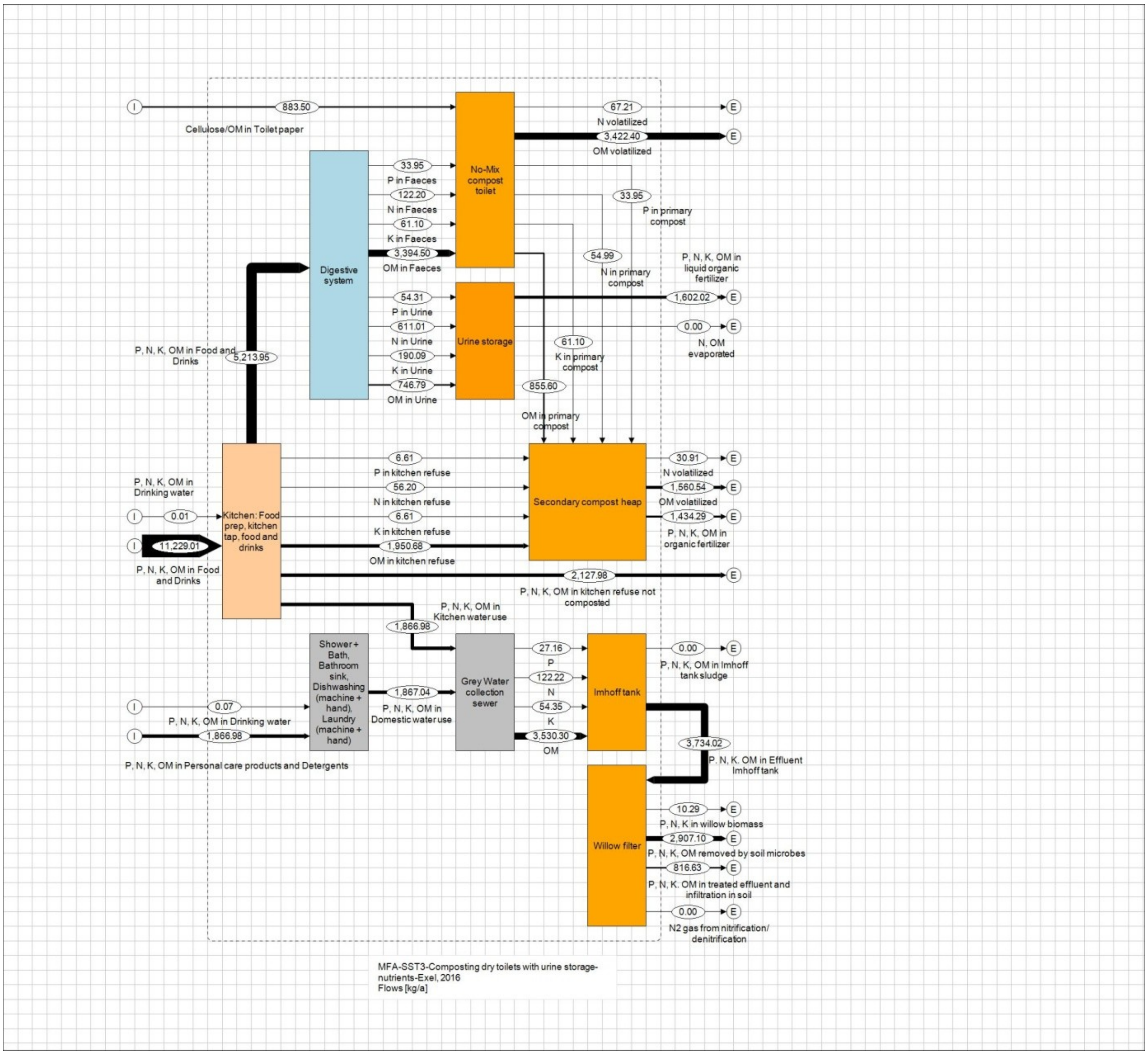


Figure 31: MFA SST3 Composting dry toilets with urine storage nutrients for Exel, 186 inhabitants [kg y^{-1}]. In some cases the P, N, K and OM flows are summed for readability. In annex 18 the separate streams are specified (see annex 18 for calculations and assumptions).

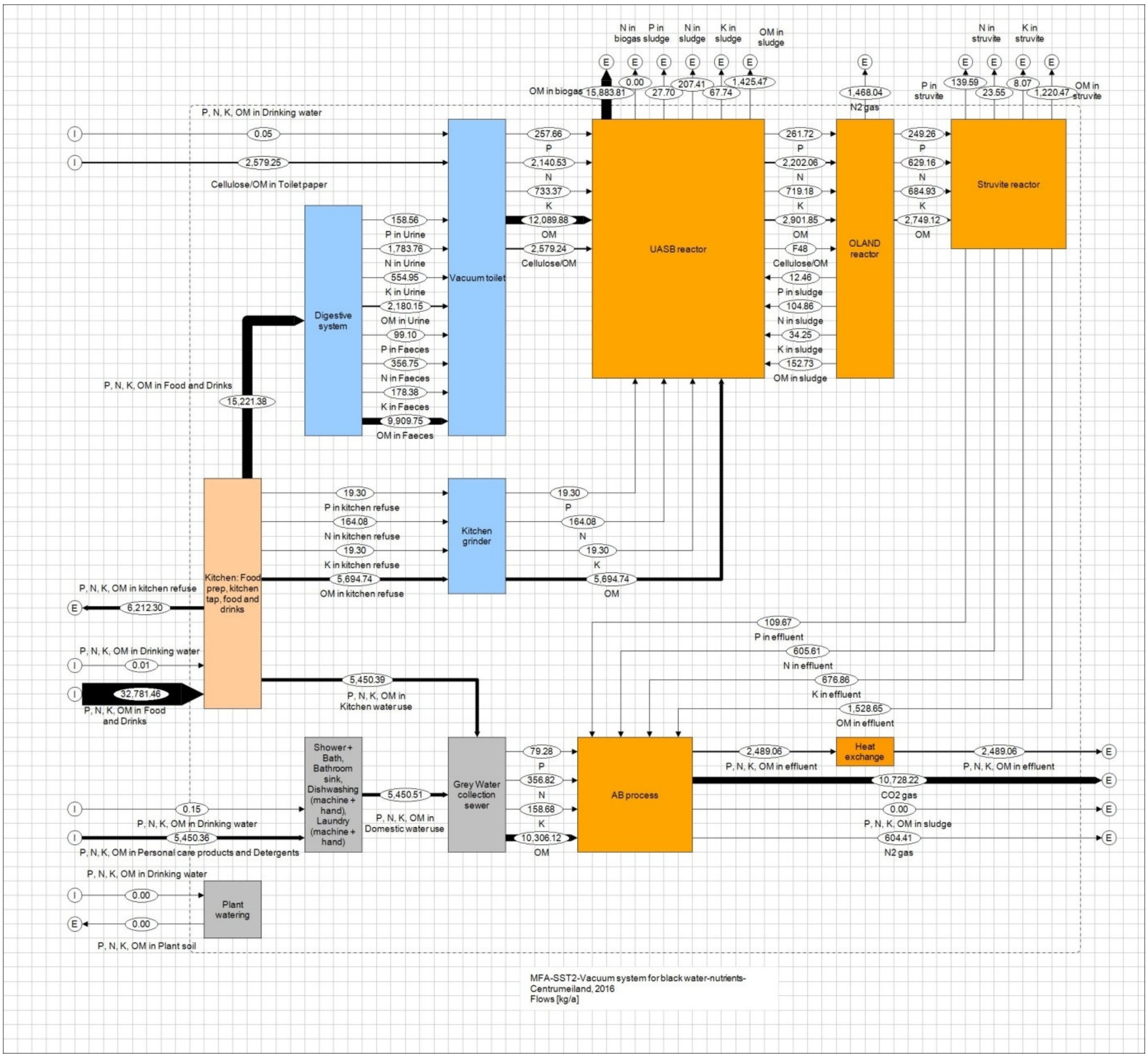


FIGURE 32: MFA NUTRIENTS SST2 VACUUM SYSTEM FOR BLACK WATER FOR APARTMENT COMPLEX CENTRUMEILAND IJBURG AMSTERDAM, 543 INHABITANTS [KG Y^{-1}]. IN SOME CASES THE P, N, K AND OM FLOWS ARE SUMMED FOR READABILITY. IN ANNEX 18 THE SEPARATE STREAMS ARE SPECIFIED (SEE ANNEX 18 FOR CALCULATIONS AND ASSUMPTIONS).

Comparing the baseline MFA's with the future proof MFA's, it is clear that recovery of nutrients is accomplished at a much higher degree in the future scenarios with a much lower use of drinking water. However, the number of technologies required house-on-site and community-on-site does increase in both the rural and urban case.

Discussion

The results and methods of this study can be interpreted in several ways. Therefore a discussion of the research questions, methods, results, impact of weight factors, level of detail of the case descriptions, drawbacks of the quantitative and qualitative indicators and implications of excluding financial aspects follows.

Were research questions answered?

At the start of this thesis research four research questions were formulated. Below each question is listed followed by a summary of the answer and assessment if the question is sufficiently answered.

RQ1: What criteria can be defined based on the TNS and C2C frameworks for selecting technologies for a future proof design for closing water and nutrient loops (collection, transportation, treatment, and reuse) in households to be renovated in The Netherlands?

In chapter 2 of this thesis research a list of 24 criteria for evaluating wastewater infrastructure were developed from an extensive analysis of the TNS and C2C frameworks. Even though they cover a substantial portion of the important ideas of both frameworks pertaining sanitation, the list of criteria is not exhaustive. An attempt was made to strike a balance between the theoretical concepts important to test versus the availability of data in practice. Moreover, the completeness of covering all ideas of the sustainability frameworks was balanced with the length of the list deemed practically applicable (Wang et al., 2012).

RQ2: According to the defined criteria, what is the best future proof (conceptual) design for closing water and nutrient loops in a) renovation of the sewer system and possibly some in-house piping of a small cluster of existing Dutch residential buildings in a rural setting and b) total renovation of a Dutch residential apartment building in an urban setting?

It was not possible within the boundaries of this thesis research to involve stakeholders in a physical get together. Therefore a backcasting process, as is prescribed by the TNS framework (Holmberg, 1998), which would result in a broad consensus on the future vision for closing water and nutrient loops in the rural and urban context, was not executable. Therefore a literature review was conducted to find well substantiated future visions for wastewater infrastructure. A thorough report by Beck (2011) formed the basis for four future visions, of which one was selected as most suitable for the rural case and one for the urban case. These visions form an acceptable answer to this research question within the scope of this thesis research. However in a real application of the criteria, the backcasting process with stakeholders should be undertaken. This will ensure almost all stakeholders see a fit between the vision and case, instead of a mere majority as was shown by the questionnaire results.

RQ3: What stepping stones, or flexible platforms, can be selected today to ensure current developments in wastewater collection, transport, treatment and reuse enable future innovations that aim towards a (more) fully sustainable future can be implemented?

After extensive analysis of available wastewater treatment technologies and nutrient and resource recovery techniques, five sustainable stepping stone technologies were elaborated. For both the rural and urban context the 24 future proof criteria were scored for each stepping stone, excluding those stepping stone technologies that were practically unable to be implemented. Based on the total scores for both the rural and urban context one stepping stone technology was clearly most suitable. As flexibility was one of the 24 equally weighted criteria, the selected stepping stone technologies may be the most sustainable, but could potentially temporarily block future development (Spiller et al., 2015). This is dependent on the future technology development and if this is in line with the chosen stepping stone technology. However, it is also dependent on the lifespan of the chosen technology. The latter could be given more weight in the total scoring which would ensure that a truly flexible technology is selected.

RQ4: What is the feedback of stakeholders on the sustainability criteria and design of the rural and urban case? Can stakeholders provide practical improvement suggestions?

The questionnaire as a tool to request feedback from stakeholders has several drawbacks. The first is that the sample size was too small to make a statistical analysis possible and the distribution amongst stakeholder groups was not even (Rattray and Jones, 2007). Second, the questionnaire did not allow for questioning on the future proof sustainability criteria, due to the limited time respondents are known to want to spend on answering (Bogen, 2016). Thirdly, it was impossible for respondents to ask clarifying questions in a one-way, online questionnaire. With a complicated subject that introduced many new concepts and terms this is a serious drawback. However, the questionnaire did yield a lot of practical advice and implementation suggestions. The answers to open questions showed that a majority of the respondents did understand the meaning of the questions and presented results. Considering the scope of the thesis research this research question was answered fairly well, but in an ideal case this question should be answered by a stakeholder feedback meeting instead of a questionnaire.

Is the systemic future proof method the right method to answer the research questions?

In this thesis the question what is future proof and sustainable was answered from a systems level perspective, instead of mechanistic classical scientific thinking that zooms in on one or several specific parts of sustainability (Capra, 1985). The Natural Step and cradle to cradle were not used before in evaluating sustainability from a systems perspective in the wastewater sector. Partial sustainability studies have been plentiful though. The entire Dutch water chain has been analyzed in terms of energy in order to become energy neutral (Blom et al., 2010) and resources to be recovered (STOWA, 2013, Blankesteijn et al., 2015). Moreover, an interesting international study looked at both environmental burdens and resource recovery, while simultaneously assessing more standard requirements such as treatment efficiency and effluent quality (Wang et al., 2012).

The goal of this thesis research was to determine a future proof way for closing water and nutrient loops for renovation of buildings and sewers in a rural and urban household wastewater context. Closing cycles means applying cradle to cradle and circular economy principles, which both imply a systems perspective (EMF, 2013). It was therefore not possible to answer research question 1 by applying an indicator set based solely on quantifiable, limited set of isolated sustainability issues.

The compilation of new sanitation technologies into five future proof wastewater treatment technologies, or stepping stone technologies, followed a logical step by step method, based on thorough analysis of all publicly available information on wastewater treatment innovations. For the scope of this study the selected technologies had to be already a promising pilot or commercial state of development. The description of future options for each stepping stone technology shows that there are also many promising developments in the lab and theory that could come to fruition in the coming decades. Hence, to come to truly future proof designs in a practical application of the proposed assessment in this research, it may be needed to include more future technologies in the stepping stone technology designs. This could lead to more future proof designs and a more detailed answer to research question 2 and 3.

The use of MFAs the baseline situation and the final future proof design as a way to understand the material metabolism within the boundaries of the rural and urban context (Zeschmar-Lahl, 2004) was useful to understand the implications of the old and new design. The baseline MFA was also useful in making the calculations for the quantitative indicators. Likewise, the SST MFAs might be useful as a starting point to make calculations for actual implementation. Different assumptions may be needed though, as the SST MFAs now assume full connection of all households. Making a plan for implementation was not part of this thesis research. However, when comparing the baseline MFA with the SST MFA for each context, it is not possible to draw meaningful detailed conclusions on the assessment method and an answer to research question 1, 2 and 3. For this the schematic depiction of the SST and the table with scores per indicator is more useful.

The final question of this thesis research was what the feedback of stakeholders is on the criteria and what practical improvement suggestions they have. The proposed method of holding a stakeholder meeting would have rendered a more elaborate and meaningful response than the questionnaire which has been sent out as an alternative, due to time constraints. In spite of the three drawbacks of the questionnaire that were identified, meaningful results were obtained with a relative high response rate of 33%.

Are the results in line with previous findings?

Tervahauta (2014) evaluated several new sanitation concepts for household wastewater in The Netherlands on their environmental performance. Based on a quantitative study of the primary energy consumption and indirect energy savings, the most sustainable concept is the community-on-site source-separation of urine, faeces, kitchen refuse and greywater with vacuum sewers. This is in line with the findings for the urban case. The studied concept is quite similar to the stepping stone technology “Vacuum system for black water” selected for Centrumeiland IJburg. However, urine separation could decrease overall primary energy consumption of the Centrumeiland IJburg concept further. Urine separation reduces the flow of water to treatment and hence increases the concentration of nutrients in the flow. A smaller volume leads to a smaller UASB reactor volume and thus less energy needed to heat up the reactor (Thibodeau et al., 2011, Tervahauta, 2014).

In the rural case urine separation is part of the selected stepping stone technology “Composting dry toilets with urine storage” for Exel. However compost toilets have not been evaluated by Tervahauta (2014) although she does acknowledge that is of growing interest in certain do-it-yourself communities. A review study by Anand and Apul (2014) on composting toilets has found hardly any peer reviewed literature on the topic. Moreover, even though they conclude the technology is a sustainable alternative to more commonly used sanitation methods in the global North, there are several barriers that have halted its implementation. Barriers include lack of awareness amongst sanitation engineers, perceived odour and maintenance issues, required active management by users, and perception of compost toilets as second-class technology. It is therefore not surprising that compost toilets as a serious alternative for water-based sanitation have not been studied extensively to date. However Anand and Apul (2014) recommend that research on this promising sustainable technology, especially for application in urban areas in the global North, is extended. Therefore the stepping stone technology is in line with recommendations in previous literature.

What is the difference in renovation versus new developments?

The proposed method for sustainability analysis for the wastewater sector can be applied to both renovation, as was done in this thesis research, or to new developments. In renovation, the practical limitations of the buildings and their surroundings, the willingness to cooperate of inhabitants, housing corporations or other types of building owners and the required lifestyle change of inhabitants for using the new technologies form a big challenge. In new developments there is no issue with practical limitations of existing buildings, as these are to be newly built whilst accommodating the technologies. Existing inhabitants also do not form a barrier for implementation. However, another group of stakeholders can present an equally difficult barrier, such as the project developers, housing corporations or future inhabitants who commission the new development. Lastly, the future inhabitants of a new development with new sanitation should not be deterred by the required lifestyle change, as they choose to live in the new development while knowing upfront which technologies are planned. Stakeholder feedback also pointed at these issues in renovation as one of the major challenge of the practical applicability of the proposed stepping stone technologies in both cases.

What is the impact of weight factors?

No weight factor was awarded to the individual criteria. The reason is that there is no recommended weight factor for all 24 indicators in literature. This is due to the novel systematic approach to sustainability. Moreover, appropriating a weight to each criterion is deemed controversial by Wang et al. (2012) as social, political and ethical values come into play. Three ways to assign weights are employed in environmental systems analysis to make multi criteria analyses. These are distance to target, no significant adverse effect level and the panel method (Fortuin, 2014). As the first two are only applicable to quantitative indicators, the panel method is the only way to assign weights to the majority of the sustainability criteria developed in this thesis research. This can be done by inviting a representative group of stakeholders or experts to agree on the relative importance of each criterion for reaching full sustainability. When the criteria are used to make a selection between technologies in practice, this step is necessary. In addition, stakeholders or experts can help determine at which minimum score a stepping stone technology is deemed future proof. A minimum score will presumably stimulate the development of stepping stone technologies with a substantially higher sustainability score.

What detail of the case descriptions is really needed to make the analysis?

A lot of detailed data was collected to describe the rural and urban case. Some of this data has been input to the qualitative indicators and MFAs. Other data served to provide the context in which the qualitative indicators were evaluated and to provide data to expert stakeholders in order to give their opinion on the suitability of the results within the case. Some data was not used in any analysis and is therefore completely redundant. This is however only a small portion of the total data collected for each case description. Truly redundant data is the figures of the Exel map with current household sewer connections and the layout of a Centrumeiland IJburg standard apartment. Moreover, some data presented in tables was not used in either rural or urban case. This is the total surface, land and inland water kilometre of the total municipality and the housing stock. Also, the surface use of the municipality pertaining to total traffic area, total built up and semi built up area and all five categories of the recreation area are superfluous. In sum, the elaborate case study descriptions as were presented in this thesis research for both the rural and urban case are largely required for a well rounded quantitative and qualitative evaluation of indicators.

Are there drawbacks of the quantitative and qualitative sustainability indicators?

This research shows that it is possible to make a list of criteria for the purpose of assessing how future proof a technical design is for closing nutrient and water loops in Dutch residential buildings, based on the sustainability and guiding principles of TNS and the cradle to cradle design concept. The resulting criteria can be used in other projects to assess the degree of sustainability of a number of technical solutions for wastewater infrastructure in order to select the most fitting one. The assessment of indicators should be permanently preceded by an analysis of the practical suitability of the technical concepts. This way the scoring of a technology that is unfit is avoided.

The sustainability criteria are not a quick checklist, as several criteria require an extensive calculation and others require data collection and analysis. It is possible to develop a Microsoft Office Excel model that requires only the input of some numbers and not an intellectual analysis of the entire stepping stone technologies. However, this assumes that treatment technology does not advance and that the chosen five stepping stone technologies are a viable solution to all current and near future Dutch new sanitation challenges. Moreover, presenting a turnkey Excel model will prevent the project team from fine tune the stepping stone technology while they are making the extensive analysis. This may cause missed opportunities to grow the stepping stone technology toward a more sustainable and well-balanced concept.

The qualitative criteria are difficult to score as an outsider with only scientific literature and grey literature from credible institutions to rely upon. Comparable to the panel approach for the multi criteria analysis weighting factors, it is necessary to include all stakeholders in a project team which evaluates all qualitative indicators.

What are the implications of excluding financial aspects?

Even though in this research economic aspects are completely excluded from the analysis as to which stepping stone technology is most appropriate for the rural and urban case, it is important to find a way to finance the implementation of the chosen stepping stone technology under current market conditions. As Nijhof (2016) states, there are three steps to achieve successful financing of sustainable initiatives. The first is to make an immediate inventory of interests of all involved stakeholders. The second is defining measures that promote these interests in a way that serves both people now and in the future. The third is looking for (innovative) financing models that allow for investment in these measures.

By starting at the interests of stakeholders, actions are defined that promote their interests. As soon as people perceive something helps solve their problems or helps them achieve their ideals, an inner desire is awaken to make it reality. This widens the willingness and resolution space for creatively looking for innovative financing models (Van Hall, 2014). An example of such a financing model is crowdfunding. Hörisch (2015) found that crowdfunding of sustainability initiatives has a great potential that has not been fully taken advantage of by initiators of sustainability projects. He offers advice on how to successfully crowdfund an endeavour for sustainable development. This additional cash flow of from people who really care for the success of a project may overcome the problem of double costs in the transition period from an old to a new system.

To implement the stepping stone technologies within the communities of the rural and urban case, a participation process has to be initiated, which should definitely include the end users. This process should run through the same steps as were undertaken in this research: setting a long-term vision for 60 years from now, selecting a shortlist of stepping stone technologies, choosing a method to weigh the criteria, and selecting the minimum score for a technology to be considered sustainable and flexible. The stepping stone technologies then have to be checked on their practical feasibility and scored on their sustainability. As a last step the question of financing and practical implementation in terms of lifestyle adjustments should be raised. This approach will greatly increase the chance of actual implementation of the new sanitation system, which benefits both the community in question as well as encourage innovation in the realm of new sanitation at large.

Future research

To further refine the sustainability criteria that were developed based on theory they should be applied in practice. Application in a real community facing renovation of sewers with involvement of all stakeholders, according to the stepwise process described above is therefore needed. Such a practical application could greatly benefit from the suggestions made by respondents to the questionnaire (see annex 20).

Furthermore, research on the behaviour of potassium in wastewater systems and the options for recovery should be undertaken. It is largely omitted from current performance analyses of new sanitation projects as well as centralized wastewater treatment. Another interesting compound is humic acid, which only recently became a compound of interest for recovery in centralized wastewater treatment for use as organic soil conditioner. It is already recovered and reused in the production of drinking water (Vitens, 2016). It is possible to filter out humic acid with a membrane bioreactor, but simpler filtration techniques are currently being tested (Van den Bulk, 2016).

Lastly, the stepping stone technologies that were selected can be further elaborated and described in more detail. Also, stepping stone technologies can be added or taken away from the list to fit the scope of a specific project. Moreover, the future options that were listed for each stepping stone technology could be further researched and perhaps added to the actual stepping stone technology. Several developments currently in a promising lab scale are small diameter sewage pipes (Vreeburg, 2015a), growing algae on anaerobically treated black water (Fernandes et al., 2015), avoiding pharmaceutical micropollutants in wastewater streams by means of different prescription drugs and using a urine bag for medicine users (Stockholm County Council, 2012, Waterschap Groot Salland and Deventer Ziekenhuis, 2015), UASB co-digestion (Zhang et al., 2013b), and bioelectrical systems for energy and nutrient recovery (Arredondo et al., 2015, Zhang et al., 2014, Kuntke et al., 2014). These developments should be prioritized when expanding the stepping stone technologies with future options.

Conclusion

The analysis of the business as usual (BAU) centralized wastewater treatment concept versus four new sanitation solutions shows that the BAU system is not future proof in both the studied rural and urban context. The list of 24 criteria which was developed based on sustainability frameworks TNS and cradle to cradle, shows the extent to which the selected alternative new sanitation concepts are future proof, fully excluding economic aspects. In the context of a long-term future vision for wastewater infrastructure for both the rural case of Exel and the urban case of Centrumeiland IJburg, it was possible to determine the best-fitting new sanitation concept. These new sanitation concepts, which only partially realize the visions, are flexible platforms or stepping stone technologies from which, in theory, in the future the full realization of the vision is possible. In the rural case the vision for a *Dry sanitation system as maximum eco-efficient water metabolism* led to the selection of the stepping stone technology of *Composting dry toilets with urine storage*. In the urban case the vision for *Separated water and nutrient reuse infrastructures with lifestyle change* let to the selection of stepping stone technology *Vacuum system for black water*.

Feedback of stakeholders of both cases on the selected vision and stepping stone technology was predominantly positive. Good advice and ideas were given to make the implementation of the stepping stone technologies reality. It does become clear that the long-term vision and short-term stepping stone technologies which were selected based solely on their environmental and social merits do have a long way to go before they are realized. However, having an ambitious vision that is supported by stakeholders helps to stay on track.

The application of the developed criteria for selection of future proof sanitation concepts will help stakeholders in the selection and fine-tuning of sustainable stepping stone technologies in cases where renovation of sewers, residential buildings or both are imminent. Moreover, when coupled with a true stakeholder participation process, the vision selection, practical application analysis and criteria scoring as suggested in this research will help select the most future proof sanitation concept and conveniently simultaneously creates a solid basis for finding creative ways of financing the transition.

Annex 1: Further explanation on The Natural Step

The four system conditions for sustainability.

Further explanation of the four system conditions for sustainability is given below.

“In the sustainable society, nature is not subject to systematically increasing...

1. **Concentrations of substances extracted from the Earth’s crust.**
   The societal influence on the ecosphere due to accumulation of lithospheric material is covered by this principle. The balance of flows between the ecosphere and the lithosphere must be such that concentrations of substances from the lithosphere do not systematically increase in the whole ecosphere, or in parts of it. Besides the upstream influence on this balance through the amounts of mining and choices of mined minerals, the balance can be influenced by the quality of final deposits, and the societal competence to technically safeguard the flows through recycling and other measures. Due to the complexity and delay mechanisms in the ecosphere, it is often very difficult to foresee what concentration will lead to unacceptable consequences. A general rule is not to allow societal-caused deviations from the natural state that are large in comparison to natural fluctuations. In particular, such deviations should not be allowed to increase systematically. Therefore, what must at least be achieved is a stop to systematic increases in concentration.

2. **Concentrations of substances produced by society.**
   This principle implies that the flows of molecules and nuclides produced by society to the ecosphere must not be so large that they can neither be integrated into the natural cycles within the ecosphere nor be deposited into the lithosphere. The balance of flows must be such that concentrations of substances produced in the society do not systematically increase in the whole ecosphere or in parts of it. Besides the upstream influence on this balance through production volumes and characteristics of what is produced, such as degradability of the produced substances, the balance can be influenced by the quality of final deposits, and the societal competence to technically safeguard the flows through measures such as recycling and incineration.

3. **Degradation by physical means.**
   The societal influence on the ecosphere due to manipulation and harvesting of funds and flows within the ecosphere is covered by the third principle. It implies that the resource basis for:
   (i) productivity in the ecosphere such as fertile areas, thickness and quality of soils, availability of fresh water, and
   (ii) biodiversity is not systematically deteriorated by over-harvesting, introductions, mismanagement or displacement.

4. **And, in that society human needs are met worldwide.**
   Human needs refer to not only the basic needs to sustain life, but all needs to maintain health — including emotional and social needs (Ekins, 1986). These needs should not be confused with the cultural means by which we satisfy them […]” (Robèrt et al., 2002, p198-199).

The ABCD planning method

"The best guide for [the application of TNS framework], is a four step strategy (Holmberg and Robèrt, 2000) (Holmberg, 1998):

A. Shared mental model. The framework is explained and discussed between the participants in a planning process.

B. Looking at today's situation. Today's critical flows and problems with reference to the system conditions are listed. "In what ways, and to what extent, are we contributing to the violation of the system conditions today?" At this point, relevant indicators, concepts and tools to monitor the phase out of these contributions are also identified.

C. Thinking about tomorrow. Envisioning of a future, in which the actual firm or activity is no longer part of the problem. "How can the services we provide to humanity, and in which we are specialists, be provided in a way that does not contribute to the violation of the system conditions?" Possible solutions are listed, disregarding whether they are economically "realistic" or not, in the short term.

D. Design of a strategic program. Short term is now linked with long term by designing a program for change. In this way, such solutions from point C that are flexible platforms, as well as low hanging fruit, are selected as the first measures. As they are undertaken, more solutions from the list will appear financially realistic, become tomorrow's "low hanging fruit" and can be implemented" (Robèrt, 2000, p247).

Annex 2: Sources and calculations for MFA baseline water Exel

TABLE 15: WATER USAGE IN M3 PER PERSON PER YEAR IN EXEL (VAN THIEL, 2014)

Activity	Demand per time	Usage frequency	Demand	Yearly Demand	Yearly demand
	[l]	[times p-1 d-1]	[l p-1 d-1]	[l p-1 y-1]	[m3 p-1 y-1]
Shower	71.39	0,72	51,40	18,761.00	18.76
Toilet flushing conventional toilet	5.73	5.90	33.80	12,337.00	12.34
Laundry machine	51.07	0.28	14.30	5,219.50	5.22
Laundry by hand	35.00	0.04	1.40	511.00	0.51
Bathroom sink	4.00	1.30	5.20	1,898.00	1.90
Kitchen tap total	-	-	9.30	3,394.50	3.39
For Dishwashing by hand	9.23	0.39	3.60	1,314.00	1.31
For Food preparation	0.30	3.30	1.00	365.00	0.37
For Cleaning	0.33	3.00	1.00	365.00	0.37
For Washing hands	0.09	5.40	0.50	182.50	0.18
For Watering plants/garden	0.36	2.80	1.00	365.00	0.37
For Coffee/Tea	0.15	3.90	0.60	219.00	0.22
For Washing/ Soaking clothes	0.17	2.40	0.40	146.00	0.15
For Water drinking	0.10	4.10	0.40	146.00	0.15
For Other	0.24	3.30	0.80	292.00	0.29
Dishwashing machine	11.76	0.17	2.00	730.00	0.73
Bath	45.00	0.04	1.80	657.00	0.66
Total in Litre	234.93	-	119.20	43,508.00	43.51
Total in m3 (1 litre = 0,001 m3)	0.23	-	0.12	43.51	-

Please note: An inconsistency was found in the sum in the TNS Nipo report, they add the total kitchen tap use to 9 (page 69), whereas it is in fact 9.3 (page 58). The number of 9.3 is used as kitchen tap water is split up in the separate uses in this table.

TABLE 16: CALCULATIONS ON NUMBER OF INHABITANTS AND YEARLY DRINKING WATER DEMAND IN EXEL

Inhabitants per home	3	
Number of homes	62	Including the school which is currently used as housing
Number of inhabitants	186,00	
Yearly drinking water demand homes Exel [m3 y-1]	8.092	*Please note: in MFA 8,094 due to rounding differences*

TABLE 17: WATER USAGE FOR DIFFERENT ACTIVITIES IN M3 PER YEAR PER TOTAL INHABITANTS OF EXEL

Activity	Yearly demand	Yearly demand homes Exel

	[m3 p-1 y-1]	[m3 inhabitants Exel-1 y-1]
For Watering plants/garden	0.37	68
Shower + Bath	19.42	3,612
Bathroom sink	1.90	353
Dishwashing (machine)	0.73	136
Laundry (machine + hand)	5.73	1,066
Kitchen tap other (dishwashing, cleaning, hands washing, soaking clothes, other)	2.30	428
Kitchen tap total	-	496
For Food preparation	0.37	68
For Coffee/Tea	0.22	41
For Water drinking	0.15	27
Toilet flushing conventional toilet	12.34	2,295

TABLE 18: INFORMATION ABOUT THE WATER CONTENT OF FAECES AND URINE (ROSE ET AL., 2015)

Excreted wet weight faeces [l p-1 d-1]	0.128
Excreted dry weight faeces [l p-1 d-1]	0.029
Excreted water in faeces [l p-1 d-1]	0.099
Excreted wet weight urine [l p-1 d-1]	1.42
Excreted dry weight urine [l p-1 d-1]	0.059
Excreted water in urine [l p-1 d-1]	1.361
Total per day wet fraction urine + wet fraction faeces [l p-1 d-1]	1.46
Percentage water in black water stream originating from faeces, excluding flush water	6.8%
Percentage water in black water stream originating urine, excluding flush water	93.2%

TABLE 19: VOLUME IN M3 PER YEAR PER EXEL INHABITANTS OF FAECES, URINE, SWEAT AND FOOD + DRINKS INGESTED

	Volume	**Volume**	**Volume incl. solids**	**Water content**
	[l p-1 d-1]	[m3 p-1 y-1]	[m3 inhabitants Exel y-1]	[m3 inhabitants Exel y-1]
Faeces (Tervahauta, 2014)	0.1	0.04	6.79	0.46
Urine (Tervahauta, 2014)	1.4	0.51	95.05	88.60
Sweat (Merck Research Laboratories, 2003)	0.75	0.27	50.92	50.92
Total food + drinks ingested (excluding	-	-	-	72.09

drinking water)				

Annex 3: Sources and calculations for MFA baseline water Centrumeiland IJburg

TABLE 20: WATER USAGE IN M3 PER PERSON PER YEAR IN APARTMENT COMPLEX CENTRUMEILAND IJBURG (VAN THIEL, 2014)

Activity	**Demand per time**	**Usage frequency**	**Demand**	**Yearly Demand**	**Yearly demand**
	[l]	[times p-1 d-1]	[l p-1 d-1]	[l p-1 y-1]	[m3 p-1 y-1]
Shower	71.39	0,72	51,40	18,761.00	18.76
Toilet flushing conventional toilet	5.73	5.90	33.80	12,337.00	12.34
Laundry machine	51.07	0.28	14.30	5,219.50	5.22
Laundry by hand	35.00	0.04	1.40	511.00	0.51
Bathroom sink	4.00	1.30	5.20	1,898.00	1.90
Kitchen tap total	-	-	9.30	3,394.50	3.39
For Dishwashing by hand	9.23	0.39	3.60	1,314.00	1.31
For Food preparation	0.30	3.30	1.00	365.00	0.37
For Cleaning	0.33	3.00	1.00	365.00	0.37
For Washing hands	0.09	5.40	0.50	182.50	0.18
For Watering plants/garden	0.36	2.80	1.00	365.00	0.37
For Coffee/Tea	0.15	3.90	0.60	219.00	0.22
For Washing/ Soaking clothes	0.17	2.40	0.40	146.00	0.15
For Water drinking	0.10	4.10	0.40	146.00	0.15
For Other	0.24	3.30	0.80	292.00	0.29
Dishwashing machine	11.76	0.17	2.00	730.00	0.73
Bath	45.00	0.04	1.80	657.00	0.66
Total in Litre	234.93	-	119.20	43,508.00	43.51
Total in m3 (1 litre = 0,001 m3)	0.23	-	0.12	43.51	-

Please note: An inconsistency was found in the sum in the TNS Nipo report, they add the total kitchen tap use to 9 (page 69), whereas it is in fact 9.3 (page 58). The number of 9.3 is used as kitchen tap water is split up in the separate uses in this table.

TABLE 21: CALCULATIONS ON NUMBER OF INHABITANTS AND YEARLY DRINKING WATER DEMAND IN APARTMENT COMPLEX CENTRUMEILAND IJBURG

Inhabitants per home	1.81
Number of homes	300
Number of inhabitants	543
Yearly drinking water demand apartment complex Centrumeiland IJburg [m3 y-1]	23,625

TABLE 22: WATER USAGE FOR DIFFERENT ACTIVITIES IN M3 PER YEAR PER TOTAL INHABITANTS OF APARTMENT COMPLEX CENTRUMEILAND IJBURG

Activity	**Yearly demand**	**Yearly demand apartment complex**

		Centrumeiland IJburg
	[m3 p-1 y-1]	[m3 inhabitants Centrumeiland-1 y-1]
For Watering plants/garden	0.37	198
Shower + Bath	19.42	10,544
Bathroom sink	1.90	1,031
Dishwashing (machine)	0.73	396
Laundry (machine + hand)	5.73	3,112
Kitchen tap other (dishwashing, cleaning, hands washing, soaking clothes, other)	2.30	1,249
Kitchen tap total	-	1,447
For Food preparation	0.37	198
For Coffee/Tea	0.22	119
For Water drinking	0.15	79
Toilet flushing conventional toilet	12.34	6,699

TABLE 23: INFORMATION ABOUT THE WATER CONTENT OF FAECES AND URINE (ROSE ET AL., 2015)

Excreted wet weight faeces [l p-1 d-1]	0.128
Excreted dry weight faeces [l p-1 d-1]	0.029
Excreted water in faeces [l p-1 d-1]	0.099
Excreted wet weight urine [l p-1 d-1]	1.42
Excreted dry weight urine [l p-1 d-1]	0.059
Excreted water in urine [l p-1 d-1]	1.361
Total per day wet fraction urine + wet fraction faeces [l p-1 d-1]	1.46
Percentage water in black water stream originating from faeces, excluding flush water	6.8%
Percentage water in black water stream originating urine, excluding flush water	93.2%

TABLE 24: VOLUME IN M3 PER YEAR PER APARTMENT COMPLEX CENTRUMEILAND IJBURG INHABITANTS OF FAECES, URINE, SWEAT AND FOOD + DRINKS INGESTED

	Volume	Volume	Volume incl. solids	Water content
	[l p-1 d-1]	[m3 p-1 y-1]	[m3 inhabitants Centrumeiland y-1]	[m3 inhabitants Centrumeiland y-1]
Faeces (Tervahauta, 2014)	0.1	0.04	19.82	1.34
Urine (Tervahauta, 2014)	1.4	0.51	277.47	258.66
Sweat (Merck Research Laboratories, 2003)	0.75	0.27	148.65	148.65

Total food + drinks ingested (excluding drinking water)	-	-	-	210.45

Annex 4: Sources and calculations for MFA baseline nutrients Exel

Two main sources provided information on the concentrations and volumes of nutrients in brown, yellow, black and greywater and kitchen refuse. Tervahauta (2014) and Jönsson et al. (2005) were compared and the numbers are very similar. As Jönsson et al. (2005) is tailored to the Swedish situation and Tervahauta (2014) to the Dutch situation, for all streams except cellulose in toilet paper the Tervahauta (2014) numbers from table 2.2 in her work were used.

Table 25: Concentration of nutrients in drinking water of Exel, based on averages in its municipality Lochem (Vitens, 2015)

Nutrient	**Concentration**	**Concentration**
	[mg L-1]	[kg m3-1]
Total organic carbon (COD)	1.7	0.0000017
Phosphate (TP)	0.25	0.00000025
Nitrate	3.82	0.00000382
Nitrite	0.01	0.00000001
Nitrogen (TN)	3.83	0.00000383
Potassium (TK)	7.26	0.00000726

Table 26: Water usage for different activities in m3 per year per total inhabitants of Exel, source annex 2

Toilet flush water: Drinking water used for flush water in toilets for all Exel inhabitants per year		
2,295	[m3 Exel inhabitants-1 y-1]	

Kitchen water: Drinking water used for cooking for all Exel inhabitants per year		
496	[m3 Exel inhabitants-1 y-1]	
Consists of:		
Food preparation	68	[m3 Exel inhabitants-1 y-1]
Other kitchen tap	428	[m3 Exel inhabitants-1 y-1]

Greywater: Drinking water used for all other purposes for all Exel inhabitants per year		
5,166	[m3 Exel inhabitants-1 y-1]	
Consists of:		
Shower + Bath	3,612	[m3 Exel inhabitants-1 y-1]
Bathroom sink	353	[m3 Exel inhabitants-1 y-1]
Dishwashing (machine)	136	[m3 Exel inhabitants-1 y-1]
Laundry (machine + hand)	1,066	[m3 Exel inhabitants-1 y-1]

Garden water: Does not enter wastewater streams		
68	[m3 Exel inhabitants-1 y-1]	
Consists of:		
For Watering plants/garden	68	[m3 Exel inhabitants-1 y-1]

Table 27: Mass nutrients in kg in drinking water per total inhabitants of Exel per year

	Mass nutrients in drinking water
	[kg Exel inhabitants-1 y-1]

Kitchen water	OM	0.00
	P	0.00
	N	0.00
	K	0.00
	total	0.01
Greywater	OM	0.01
	P	0.00
	N	0.02
	K	0.04
	total	0.07
Flush water	OM	0.00
	P	0.00
	N	0.01
	K	0.02
	total	0.03
Garden water	OM	0.00
	P	0.00
	N	0.00
	K	0.00
	Total	0.00

TABLE 28: MASS OF NUTRIENTS IN FAECES, URINE, KITCHEN REFUSE AND GREYWATER IN G; AND VOLUME OF FAECES, URINE, KITCHEN REFUSE AND GREYWATER IN L (TERVAHAUTA, 2014)

		Faeces	**Urine**	**Kitchen refuse**	**Greywater**
Volume	[L p-1 d-1]	0.1	1.4	0.2	79.0
TP	[g p-1 d-1]	0.5	0.8	0.2	0.4
TN	[g p-1 d-1]	1.8	9.0	1.7	1.8
TK	[g p-1 d-1]	0.9	2.8	0.2	0.8
OM (COD)	[g p-1 d-1]	50.0	11.0	59.0	52.0

Please note, the greywater volume number is not used for calculations, instead the number from the MFA water baseline is used based on (Van Thiel, 2014).

TABLE 29: MASS OF NUTRIENTS IN FAECES, URINE, KITCHEN REFUSE AND GREYWATER IN KG; AND VOLUME OF FAECES, URINE, KITCHEN REFUSE AND GREYWATER IN M3 (TERVAHAUTA, 2014)

		Faeces	**Urine**	**Kitchen refuse**	**Greywater**
Volume	[m3 p-1 d-1]	0.0001	0.0014	0.0002	0.0790
TP	[kg p-1 d-1]	0.0005	0.0008	0.0002	0.0004
TN	[kg p-1 d-1]	0.0018	0.0090	0.0017	0.0018
TK	[kg p-1 d-1]	0.0009	0.0028	0.0002	0.0008
OM (COD)	[kg p-1 d-1]	0.0500	0.0110	0.0590	0.0520

Table 30: Mass of nutrients in faeces, urine, kitchen refuse and greywater in kg per inhabitants Exel per year; and volume of faeces, urine, kitchen refuse and greywater in m3 per inhabitants Exel per year

	Unit	Faeces	Urine	Kitchen refuse	Greywater	Greywater from kitchen	Greywater from domestic uses	Greywater including drinking water
Volume	[m3 Exel inhabitants-1 y-1]	6.79	95.05	13.58	5,363.31	-	-	-
Total nutrients in drinking water	[kg Exel inhabitants-1 y-1]	-	-	-	-	0.01	0.07	-
TP		33.95	54.31	13.58	27.16	13.58	13.58	27.16
TN		122.20	611.01	115.41	122.20	61.10	61.10	122.22
TK		61.10	190.09	13.58	54.31	27.16	27.16	54.35
OM (COD)		3,394.50	746.79	4,005.51	3,530.28	1,765.14	1,765.14	3,530.30
Total nutrients		3,611.75	1,602.20	4,148.08	3,733.95	1,866.98	1,867.04	3,734.03
Total nutrients faeces + urine				[kg Exel inhabitants-1 y-1]	5,213.95			
Total nutrients faeces + urine + kitchen refuse					9,362.03			

Assumptions:

- *50% of greywater originates from kitchen water and 50% of greywater originates from other domestic uses.*
- *The OM in Greywater including drinking water had to be rounded up by 0.01 to account for rounding differences.*

Table 31: Mass of nutrients in toilet paper in kg per inhabitants Exel per year

	Mass nutrients from Jönsson et al. (2005)	Calculated mass for Exel based on Jönsson et al. (2005)	Difference between mass nutrients and calculated mass based on Jönsson et al. (2005) is cellulose in toilet paper[38]
	[kg p-1 y-1]	[kg Exel inhabitants-1 y-1]	[kg Exel inhabitants-1 y-1]
TP	0.18	33.48	-
TN	0.5	93	-
TK	0.33	61.38	-
OM (COD)	23	4,278	883.50

[38] A negative difference has been explained as a negligible or not present amount of this nutrient in toilet paper.

TABLE 32: MASS NUTRIENTS IN TOILET WATER INCLUDING TOILET PAPER, DRINKING WATER, FAECES AND URINE IN KG PER INHABITANTS EXEL PER YEAR

	Unit	Toilet paper	Toilet flush drinking water	Faeces	Urine	Total
TP	[kg Exel inhabitants-1 y-1]	-	0.00	33.95	54.31	88.26
TN		-	0.01	122.20	611.01	733.22
TK		-	0.02	61.10	190.09	251.21
OM (COD)		-	0.00	3,394.50	746.79	4,141.29
Cellulose OM (toilet paper)		883.50	-	-	-	883.50

Annex 5: Sources and calculations for MFA baseline nutrients Centrumeiland

Two main sources provided information on the concentrations and volumes of nutrients in brown, yellow, black and greywater and kitchen refuse. Tervahauta (2014) and Jönsson et al. (2005) were compared and the numbers are very similar. As Jönsson et al. (2005) is tailored to the Swedish situation and Tervahauta (2014) to the Dutch situation, for all streams except cellulose in toilet paper the Tervahauta (2014) numbers from table 2.2 in her work were used.

TABLE 33: CONCENTRATION OF NUTRIENTS IN DRINKING WATER OF CENTRUMEILAND IJBURG, BASED ON NUMBERS IN ITS MUNICIPALITY AMSTERDAM (VITENS, 2015, WATERNET, 2015)

Nutrient	Concentration	Concentration
	[mg L-1]	[kg m3-1]
Total organic carbon (COD)	2	0.000002
Phosphate (TP)	0.25	0.00000025
Nitrate	4.24	0.00000424
Nitrite	0.007	0.000000007
Nitrogen (TN)	4.247	0.000004247
Potassium (TK)	7.26	0.00000726

TABLE 34: WATER USAGE FOR DIFFERENT ACTIVITIES IN M3 PER YEAR PER TOTAL INHABITANTS OF THE APARTMENT COMPLEX IN CENTRUMEILAND IJBURG, SOURCE ANNEX 3

Toilet flush water: Drinking water used for flush water in toilets for all Centrumeiland IJburg apartment complex inhabitants per year	
6,699	[m3 Centrumeiland inhabitants-1 y-1]

Kitchen water: Drinking water used for cooking for all Centrumeiland IJburg apartment complex inhabitants per year		
1,447	[m3 Centrumeiland inhabitants-1 y-1]	
Consists of:		
Food preparation	198	[m3 Centrumeiland inhabitants-1 y-1]
Other kitchen tap	1,249	[m3 Centrumeiland inhabitants-1 y-1]

Greywater: Drinking water used for all other purposes for all Centrumeiland IJburg apartment complex inhabitants per year		
15,083	[m3 Centrumeiland inhabitants-1 y-1]	
Consists of:		
Shower + Bath	10,544	[m3 Centrumeiland inhabitants-1 y-1]
Bathroom sink	1,031	[m3 Centrumeiland inhabitants-1 y-1]
Dishwashing (machine)	396	[m3 Centrumeiland inhabitants-1 y-1]
Laundry (machine + hand)	3,112	[m3 Centrumeiland inhabitants-1 y-1]

Garden water: Does not enter wastewater streams		
198	[m3 Centrumeiland inhabitants-1 y-1]	
Consists of:		
For Watering plants/garden	198	[m3 Centrumeiland inhabitants-1 y-1]

Table 35: Mass nutrients in kg in drinking water per total inhabitants of apartment complex Centrumeiland IJburg per year

		Mass nutrients in drinking water
		[kg Centrumeiland inhabitants-1 y-1]
Kitchen water	OM	0.00
	P	0.00
	N	0.01
	K	0.01
	total	0.02
Greywater	OM	0.03
	P	0.00
	N	0.06
	K	0.11
	total	0.21
Flush water	OM	0.01
	P	0.00
	N	0.03
	K	0.05
	total	0.09
Garden water	OM	0.00
	P	0.00
	N	0.00
	K	0.00
	Total	0.00

Table 36: Mass of nutrients in faeces, urine, kitchen refuse and greywater in g; and volume of faeces, urine, kitchen refuse and greywater in L (Tervahauta, 2014)

		Faeces	Urine	Kitchen refuse	Greywater
Volume	[L p-1 d-1]	0.1	1.4	0.2	79.0
TP	[g p-1 d-1]	0.5	0.8	0.2	0.4
TN	[g p-1 d-1]	1.8	9.0	1.7	1.8
TK	[g p-1 d-1]	0.9	2.8	0.2	0.8
OM (COD)	[g p-1 d-1]	50.0	11.0	59.0	52.0

Please note, the greywater volume number is not used for calculations, instead the number from the MFA water baseline is used based on (Van Thiel, 2014).

Table 37: Mass of nutrients in faeces, urine, kitchen refuse and greywater in kg; and volume of faeces, urine, kitchen refuse and greywater in m3 (Tervahauta, 2014)

		Faeces	Urine	Kitchen refuse	Greywater
Volume	[m3 p-1 d-1]	0.0001	0.0014	0.0002	0.0790
TP	[kg p-1 d-1]	0.0005	0.0008	0.0002	0.0004
TN	[kg p-1 d-1]	0.0018	0.0090	0.0017	0.0018
TK	[kg p-1 d-1]	0.0009	0.0028	0.0002	0.0008

OM (COD)	[kg p-1 d-1]	0.0500	0.0110	0.0590	0.0520

Table 38: Mass of nutrients in faeces, urine, kitchen refuse and greywater in kg per apartment complex Centrumeiland IJburg inhabitants per year; and volume of faeces, urine, kitchen refuse and greywater in m3 per apartment complex Centrumeiland IJburg inhabitants per year

	Unit	Faeces	Urine	Kitchen refuse	Greywater	Greywater from kitchen	Greywater from domestic uses	Greywater including drinking water
Volume	[m3 Centrumeiland inhabitants-1 y-1]	19.82	277.47	39.64	15,657.41	-	-	-
Total nutrients in drinking water	[kg Centrumeiland inhabitants-1 y-1]	-	-	-	-	0.02	0.21	-
TP		99.10	158.56	39.64	79.28	39.64	39.64	79.28
TN		356.75	1,783.76	336.93	356.75	178.38	178.38	356.82
TK		178.38	554.95	39.64	158.56	79.28	79.28	158.68
OM (COD)		9,909.75	2,180.15	11,693.51	10,306.14	5,153.07	5,153.07	10,306.17
Total nutrients		10,543.97	4,677.40	12,109.71	10,900.73	5,450.38	5,450.57	10,900.95

Total nutrients faeces + urine	[kg Centrumeiland inhabitants-1 y-1]	15,221.38
Total nutrients faeces + urine + kitchen refuse		27,331.09

Assumptions:

- *50% of greywater originates from kitchen water and 50% of greywater originates from other domestic uses.*

Table 39: Mass of nutrients in toilet paper in kg per apartment complex Centrumeiland IJburg inhabitants per year

	Volume from Jönsson et al. (2005)	Calculated mass for apartment complex Centrumeiland IJburg inhabitants based on Jönsson et al. (2005)	Difference between mass nutrients and calculated mass based on Jönsson et al. (2005) is cellulose in toilet paper[39]
	[kg p-1 y-1]	[kg Centrumeiland inhabitants-1 y-1]	[kg Centrumeiland inhabitants-1 y-1]
TP	0.18	97.74	-

[39] A negative difference has been explained as a negligible or not present amount of this nutrient in toilet paper.

TN	0.5	271.5	-
TK	0.33	179.19	-
OM (COD)	23	12,489	2,579.25

Table 40: Mass nutrients in toilet water including toilet paper, drinking water, faeces and urine in kg per inhabitants apartment complex Centrumeiland IJburg per year

	Unit	Toilet paper	Toilet flush drinking water	Faeces	Urine	Total
TP	[kg Centrumeil and inhabitants-1 y-1]	-	0.00	99.10	158.56	257.66
TN		-	0.03	356.75	1,783.76	2,140.53
TK		-	0.05	178.38	554.95	733.37
OM (COD)		-	0.01	9,909.75	2,180.15	12,089.91
Cellulose OM (toilet paper)		2,579.25	-	-	-	2,579.25

Annex 6: Heat balance baseline Exel calculations

To see where it may be possible to recover direct heat, the temperatures of different streams were looked up and the overall theoretical temperature was calculated.

Table 41: Temperatures of different waste (water) streams in Exel, right after production and before treatment (Tervahauta, 2014, Vitens, 2015)

	Volume including solids	**Temperature**	**Source**
	[m3 inhabitants Centrumeiland-1 y-1]	*[degrees Celsius]*	
Greywater	5,594.14	32.0	(Tervahauta, 2014)
Brown water	2,464.41	13.4	
Faeces	6.79	37.0	(Tervahauta, 2014)
Urine	95.05	37.0	(Tervahauta, 2014)
Flush water	2,294.68	12.4	(Vitens, 2015)
Food prep water	67.89	12.4	(Vitens, 2015)
Kitchen refuse	13.58	20.0	(Tervahauta, 2014)
Total	10,536.53	-	
Average temperature in sewage right outside the house		20.2	

Annex 7: Heat balance baseline calculations Centrumeiland IJburg

To see where it may be possible to recover direct heat, the temperatures of different streams were looked up and the overall theoretical temperature was calculated.

TABLE 42: TEMPERATURES OF DIFFERENT WASTE (WATER) STREAMS IN CENTRUMEILAND IJBURG, RIGHT AFTER PRODUCTION AND BEFORE TREATMENT (TERVAHAUTA, 2014, WATERNET, 2015)

	Volume including solids	**Temperature**	**Source**
	[m3 inhabitants Centrumeiland-1 y-1]	*[degrees Celsius]*	
Greywater	16,331.27	32.0	(Tervahauta, 2014)
Brown water	7,194.48	18.2	
Faeces	19.82	37.0	(Tervahauta, 2014)
Urine	277.47	37.0	(Tervahauta, 2014)
Flush water	6,698.99	17.5	(Waternet, 2015)
Food prep water	198.20	13.1	(Waternet, 2015)
Kitchen refuse	39.64	20.0	(Tervahauta, 2014)
Total	30,759.86	-	
Average temperature in sewage right outside the house		21.3	

Annex 8: New sanitation projects in The Netherlands and Europe

Centralized collection, transport, treatment and reuse technologies						
Pilot, demonstration or implementation project *(country)*	**Focus** *(source separation, removal, recovery, decentralization; high/mid/low tech; community support)*	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ resources**	**Sources**
Conventional water treatment, business as usual (NLD) Housing, offices, recreational, some industry.	No source separation. Nutrient and pollutant removal. Centralized. High-tech. No active support or awareness general public.	Conventional toilet and appliances.	Gravity sewers mixed with storm water (68.2 %) or not mixed (27.3%). Or mechanical sewers (3.9%).	Nitrogen removal by sequential biological nitrification and de-nitrification, releasing N2-gas. Phosphorous is captured in the sludge by precipitation or by the Enhanced Biological P Removal (EBPR) process.	Clean effluent to surface water.	(Oosterom and Hermans, 2013) (ValueFromUrine, 2016)

Energy and resources factory (NLD) For example Fosfaatje – Amsterdam (NLD) Treatment facility.	No source separation. Balance between energy and resource recovery. Centralized. High-tech. No active support or awareness general public.			Biological treatment for removal, see above, combined or adjusted with: Struvite reactor. Cellulose sieving. Anaerobic digestion for biogas. Or Nereda® biological treatment adjusted with: Alginate recovery.	Clean effluent to surface water. Synthetic fertilizer. Cellulose. Biogas for energy. Clean effluent to surface water. Alginate.	(EFGF, 2016e) (STOWA, 2016d)
Saniphos, Zutphen (NLD) Treatment facility.	Source separation urine. Centralized. Phosphorous and some Nitrogen nutrient recovery. High-tech. Some awareness general public at collection points	Separate urine collection toilets (pharmaceutical industry, sport events, music concerts).	Tanker trucks.	Struvite (precipitation with magnesium to form magnesium ammonium phosphate). Ammonium Sulphate (NH_3 stripper & NH_3 absorber).	Synthetic fertilizer.	(GMB, 2016c) (GMB, 2016a) (GMB, 2016b)

Urine separation systems

Pilot, demonstration or implementation project	Focus	Collection technology	Transport technology	Treatment technology	Reuse nutrients/ Resources	Sources
The Hague ministry Infrastructure and the Environment (NLD) Office.	Source separation urine, black water and greywater. Resource recovery and nutrient removal. Decentralized. High-tech. Some awareness general public at collection points.	Waterless urinals. Vacuum toilets.	Vacuum pipes black water. Probably gravity pipes urinals	Bioelectrical fuel cell to treat urine, recovery nitrogen and produce electricity. UASB concentrated black water. Struvite precipitation UASB effluent and urine treatment effluent.	Electricity production. Ammonium/Nitrogen recovery. Biogas for energy. Phosphate recovery as struvite.	(Wetsus, 2013) (Arredondo et al., 2015)
Heineken Music Hall, Amsterdam (NLD) Event/recreation location.	Source separation urine. Resource recovery. Decentralized. High-tech. Some awareness general male public at collection points.	Waterless urinals. Conventional toilets and treatment for remainder faeces and urine.	Storage underneath the building. Transport by truck to water treatment facility.	Struvite reactor for phosphorous and some nitrogen recovery.	Synthetic fertilizer.	(STOWA, 2016e) (Stichting Waternet, 2016)
Natuurlijk Huus – Raalte (NLD)	Source separation urine, brown water	No-mix toilets (brand Sealskin).	Separate urine, brown water and	Urine water: storage.	Organic fertilizer (for orchard).	('t Natuurlijk Huus, 2016)

Community house.	and greywater. Resource recovery. Decentralized. Mid-tech. Active education to general public.		grew water pipes.	Brown water: Septic tank. Greywater: activated carbon bed.	Organic fertilizer. Clean effluent to surface water.	
Remaining projects: Waterschapskantoor Reest en Wieden – Meppel, NLD (well functioning urine separation toilets of brand Gustavsberg, urine goes to water treatment facility); Waterschapskantoor Rijn en IJssel – Doetinchem, NLD (badly functioning urine separation toilets of brand Sealskin, have been replaced); Windesheim – Zwolle, NLD (badly functioning urine separation toilets of brand Sealskin, have been replaced); Provincie Huis Drenthe – Assen, NLD (well functioning urine separation toilets of brand Gustavsberg, urine goes to water treatment facility).						(STOWA, 2016f)
Composting dry toilets						
Pilot, demonstration or implementation project	**Focus**	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ Resources**	**Sources**

Hamburg Allermöhe (DLD) Housing.	Source separation black water and greywater. Recovery compost. Decentralized. Mid-tech. High awareness and community support.	Composting toilets for urine, faeces and kitchen waste (no urine source separation, but surplus leachate – liquids that did not evaporate through ventilation pipe – are diverted to separation chamber where it can be collected). Greywater as separate stream.	Tapping liquids and applying to garden if leachate occurs. Removing finished compost material for application as fertilizer every 1-2 years (depends on the incoming quantities of organic material).	Levelling, mixing and aerating the compost heap with added kitchen and garden refuse to improve its structure and avoid densification inside composting toilet (about 1 labour hour per month). Constructed wetland.	Organic fertilizer. Clean effluent to surface water	(Londong, 2013) (SuSanA, 2009b) (Berger Biotechnik GmbH, 2006)
De Ceuvel, Amsterdam (NLD) Office.	Source separation Black and greywater. Recovery compost and struvite. Nutrient and pollutant removal. Decentralized. Mid-tech. High awareness	Urine separation in one building and composting toilets (without urine separation) in remainder. Greywater as separate stream.	Moving compost container to compost site. Tapping liquids of compost toilet and use it to fertilize garden. Pipes from urine separation toilets to local struvite reactor.	Small struvite reactor. Composting toilets. Constructed wetland.	Synthetic fertilizer. Organic fertilizer. Clean effluent to surface water	(Metabolic Lab, 2016)

	and community support.					
Aardenhuizen, Olst (NLD) Housing.	Source separation black and greywater. Recovery compost. Decentralized. Low-tech. High awareness and community support.	Dry composting toilet for urine and faeces. Greywater as separate stream.	Carrying/ wheeling container to compost site frequently (no indoor composting). Tapping or separating liquids.	Composting and storage outside (to ensure pathogens are harmless). Constructed wetland.	Organic fertilizer. Clean effluent to surface water.	(Vereniging Aardehuis Oost Nederland, 2016) (De Waard, 2015)
Het Groene Dak, Utrecht (NLD) Housing.	Source separation black waste and kitchen refuse. Recovery compost. Decentralized. Low-tech. High awareness and community support.	Dry composting toilet for urine and faeces and kitchen waste.	Compost would stay in place for 10 years (in the cellar). No tapping of liquids. Toilets were removed after 8 years because composting process did not work, probably due to low temperature and too much liquid.	Composting and storage.	Organic fertilizer.	(Het Groene Dak, 2000) (Clivus Multrum, 2016)

Vacuum System for Black water

Pilot,	**Focus**	**Collection**	**Transport**	**Treatment**	**Reuse nutrients/**	**Sources**

demonstration or implementation project		technology	technology	technology	Resources	
Waterschoon, Sneek (NLD) Housing.	Source separation grey and black water. Resource recovery and removal. Decentralized. High-tech. High awareness and community support (some concern over vacuum noise).	Vacuum toilets and kitchen grinder as one stream. Greywater as separate stream.	Vacuum pipes for black water and kitchen waste. Gravity pipes for greywater.	Anaerobic digestion in UASB for biogas. Struvite precipitation with magnesium. Oxygen Limited Autotrophic Nitrification Denitrification for Nitrate (OLAND) removal. Greywater heat exchanger and aerobic treatment for nutrient removal.	Biogas for heat production. Synthetic fertilizer Direct heat from greywater	(De Graaf and Van Hell, 2014)
Floriade - Venlo (NLD) Office.	Source separation grey and black water. Resource recovery and removal. Decentralized. High-tech.	Vacuum toilets and waterless urinals. Greywater as separate stream.	Vacuum pipes for black water and kitchen waste. Gravity sewer for yellow water urinals.	Anaerobic digestion in UASB for biogas (black water, yellow water, kitchen waste, green waste surrounding horticulture). Constructed wetland for greywater.	Biogas for energy. Clean effluent to surface water.	(STOWA, 2016i)

	High awareness at office employees (active education).					
Arbeiten & Wöhnen, Freiburg im Breisgau (DLD) Housing.	Source separation grey and black water. Resource recovery and removal. Decentralized. High-tech. High awareness and community support.	Vacuum toilets. Greywater as separate stream. Rain water as separate stream.	Vacuum pipes for black water.	Biogas CSTR installation. Greywater treatment installation.	Biogas for energy. Clean effluent to surface water. Rain water reuse.	(Koetse, 2005)
HAMBURG Water Cycle® Jenfelder Au, Hamburg (DLD) Housing.	Source separation black water, greywater and rain water. Resource recovery and removal. Decentralized. High-tech. High awareness and community support.	Vacuum toilets for black water. Greywater conventional pipes, separate from black water. Wadis for rain water.	Vacuum pipes black water. Gravity pipes greywater. Channels for rain water.	Anaerobic digester for black water, additional fat and organic waste Greywater treatment facility on site. Infiltration from	Biogas for energy. Greywater could be reused for toilets (but is not planned). Currently: Clean effluent to surface water. Rain water directly refills local surface water and aquifers.	(Van der Burg, 2014) (Londong, 2013)

				wadis.		
Lübeck Flintenbreite (DLD) Housing.	Source separation black water, greywater and rain water. Resource recovery and removal. Decentralized. High-tech. High awareness and community support.	Vacuum toilets. Greywater conventional pipes, separate from black water.	Vacuum pipes black water. Gravity pipes greywater. Rain water gravity pipes.	Community on-site CSTR anaerobic digester for black water and additional bio-waste (once enough households were connected to the system). Greywater constructed wetland treatment facility on site. Local infiltration rain water.	Energy from biogas Plant biomass constructed wetland and digester sludge to agriculture. Rain water to ground water.	(SuSanA, 2009a) (Londong, 2013)
Armhoede Concept 1: source separation (NLD) Housing.	Source separation yellow water, brown water and greywater. No recovery currently, but options are being considered. Nutrient removal. Decentralized. High-tech.	Waterless urinals and water-saving toilets.	Smaller diameter gravity pipes, separated for urine, brown water and greywater.	Storage for urine. Constructed wetland with fat separator for effluent UASB and greywater.	Optional reuse stored urine in the garden or transport to struvite precipitation facility. Optional reuse of effluent constructed wetland for toilet flush (currently infiltrated to prevent drying out).	(Weijma and Nanninga, 2012) (Swart, 2015)

	High awareness and community support.			UASB septic tank for concentrated brown water.		
Armhoede Concept 2: adjustment sewer and decentralized treatment (NLD) Housing.	Source separation outside the house. No recovery currently, but options are being considered. Nutrient removal. Decentralized. High-tech. High awareness and community support.	Conventional toilets and appliances.	Three way valve with heat sensor to separate greywater from black water.	UASB septic tank for concentrated black water. Constructed wetland with fat separator for effluent UASB and greywater.	Optional reuse of effluent constructed wetland for toilet flush (currently infiltrated to prevent drying out).	(Weijma and Nanninga, 2012) (Clean Water Components, 2016) (Swart, 2015)
Casa Vita, Deventer (NLD) Housing.	No source separation. Nutrient and pollutant removal. Centralized. High-tech. No active support	Vacuum toilets and pipes for black water. Vacuum toilets and pipes for **architectural flexibility** – no resource recovery.	From vacuum station into gravity sewer, see “Conventional water treatment”.	See “Conventional water treatment”.	None.	(Telkamp et al., 2008)

	or awareness general public.					
Remaining projects: De Groene Hoven – Apeldoorn, NLD (small demonstration project in community house); Village Blankenham, NLD (plan was decentralized treatment in constructed wetland and reuse of biomass, but plans were not executed); Compostmeer – Schagen, NLD (exploring same solution as Village Blankenham)						(STOWA, 2016f) (Swart, 2015)
Vacuum System for Black water with algae nutrient recovery						
Pilot, demonstration or implementation project	**Focus**	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ Resources**	**Sources**
NIOO – Wageningen (NLD) Office.	Source separation black water, greywater and rain water. Resource recovery and removal. Decentralized. High-tech. Limited community support. Some educational activity has been undertaken but the building is not frequented by the general public.	Vacuum toilets and pipes for black water. Separate greywater circuit. Separate rain water circuit.	Vacuum pipes for black water to on-site treatment facility. Separate pipes for rain water and greywater circuits.	Black water: UASB biogas reactor and algae growing on effluent UASB. Remaining effluent in constructed wetland on-site Greywater: On-site constructed wetland. Local infiltration rain water.	Algae for use as direct organic fertilizer or as input chemical/food industry. Biogas for energy. Clean effluent to surface water. Rain water to ground water.	(Fernandes et al., 2015) (Fernandes, 2012)

Remaining developments: **Algae growth on source-separated urine** for nutrient (N and P) recovery is possible in Dutch conditions, but not implemented on pilot scale yet.	(Tuantet, 2015)

Constructed wetland systems

Pilot, demonstration or implementation project	Focus	Collection technology	Transport technology	Treatment technology	Reuse nutrients/ Resources	Sources
Culemborg – Lanxmeer (NLD) Housing.	Source separation black water, greywater and rain water. Nutrient and pollutant removal. Decentralized & centralized. High-tech. High, inhabitants district are aware of sustainable solutions implemented.	Separate collection black water with conventional toilet and greywater (double piping).	Gravity sewers (double for black water and greywater).	Constructed wetland for greywater. No treatment black water (goes to conventional wastewater treatment plant)	Clean effluent to surface water.	(BEL, 2016)
Groningen – Drielanden (NLD) Housing.	Source separation black water, greywater and rain water. Nutrient and pollutant removal.	Separate collection greywater and black water (double piping).	Gravity sewers (double for black water and greywater).	Vertical constructed wetland for greywater and pre-treated black water (effluent septic tank).	Clean effluent to surface water.	(Gemeente Groningen, 2014)

	Decentralized. Mid-tech. High, inhabitants district are aware of sustainable solutions implemented.					
Gewoonboot – Amsterdam (NLD) Housing.	Combined black water and greywater. Rain water source-separated. Decentralized. Low-tech. High, visitors on location are aware of sustainable solutions implemented.	Conventional toilet and appliances.	Conventional piping (combined).	Floating constructed wetland for treatment combined stream. Rain water filtering through green roof.	Clean effluent to use for domestic purposes. Rain water for domestic uses (greywater and toilet flush).	(geWoonboot, 2016)
Zorgboerderij "De Noaberhoeve" – Echten (NLD) Farm and three houses.	No source separation. Nutrient and pollutant removal. Decentralized.	Conventional toilet and appliances.	Conventional piping (combined).	Septic tank. Constructed wetland. *Results were monitored*	Clean effluent to surface water.	(STOWA, 2016b)

	Low-tech. Low community awareness and support.					
Remaining projects: Conferentieoord ZIN – Vught, NLD (constructed wetland for monastery and conference venue), De Bussumse watertoren, NLD (Constructed wetland on roof of newly built annex building), Kantoor Van Helvoirt Groenprojecten, NLD (Constructed wetland on the roof due to space constraints), Dairy Campus - Leeuwarden, NLD (dairy cattle company with constructed wetland), Green Meets resort – Erica, NLD (recreational business with constructed wetland).						(STOWA, 2016f)

"Natural" filter systems

Pilot, demonstration or implementation project	**Focus**	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ Resources**	**Sources**
Willow Filter – Biesbosch museum – Werkendam (NLD) Museum.	No source separation. Resource recovery and removal. Decentralized. Low-tech. Education is actively given to the visitors of the museum.	Conventional toilets (combined wastewater).	Gravity sewer.	Uptake of nutrients and metals by willows.	Biomass is harvested (shoots from willows) every 2 years and used as firewood for the biomass heater.	(STOWA, 2016a) (Global Wetlands, 2016)
Fungi filter – Glas Zuiver Water –	No source separation.	Developed for horticulture, not	Not applicable.	Combination of plants and fungi to		(STOWA, 2016g)

Emmen (NLD) Horticulture.	Nutrient and pollutant removal. Decentralized. High-tech. No community awareness or support.	applied in houses (yet).		remove nutrients and pesticides Uptake of pesticides by fungi (Fungi are good at breaking down oil, pesticides, medicine remains and heavy metals).		

Direct heat collection

Pilot, demonstration or implementation project	**Focus**	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ Resources**	**Sources**
Uilenstede – Amsterdam (NLD) Housing.	Direct heat recovery from shower water. Decentralized. High-tech. No active support or awareness general public	Shower heat exchanger (incoming water to the shower is preheated by exiting water after 2 minutes of pre-heating).	In-house piping and installations.	None.	Direct heat.	(STOWA, 2016h) (Milieu Centraal, 2016a)

Local wastewater treatment hospital

Pilot, demonstration or	**Focus**	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ Resources**	**Sources**

implementation project						
Pharmafilter – The Hague (NLD) Hospital.	No source separation but integration of shower, sink and toilet water with ground food and bio plastic remains. Nutrient and pollutant removal. Decentralized. High-tech. Some awareness by visitors hospital.	Conventional toilets and appliances and additional grinders for bio waste. Conventional gravity sewer.	Gravity sewer to on-site treatment facility.	Digester and purification treatment for effluent complying with effluent standards (with regard to pathogens, micro-pollutants and metals for example).	Clean effluent to surface water.	(STOWA, 2012)

Local greywater treatment for local low quality water reuse

Pilot, demonstration or implementation project	Focus	Collection technology	Transport technology	Treatment technology	Reuse nutrients/ Resources	Sources
Polderdrift – Arnhem (NLD) Housing.	Source separation black water, greywater and rain water Resource recovery and removal.	Conventional toilets and appliances.	Double piping (for rain water, and combined grey and black water). On-site combined grey and black water pipe to	Constructed wetland for grey and black water treatment. Untreated rain water.	Reuse effluent constructed wetland for toilet flushing Reuse rain water for washing machines	(Woonverenigi ng Polderdrift, 2016)

	Decentralized. Mid-tech. High, inhabitants district are aware of sustainable solutions implemented.		treatment and treated water pipe back to toilet reservoirs.			
Interart - Heeswijk – Dinther (NLD) Art gallery.	No source separation. Resource recovery and removal. Decentralized. Mid-tech. Low, visitors of gallery are passively informed of the system.	Conventional toilets and appliances. Conventional piping (combined grey and black water).	On-site combined grey and black water pipe to treatment and treated water pipe back to toilet reservoirs.	Constructed wetland for grey and black water treatment.	Reuse effluent constructed wetland for toilet flushing.	(Ecofyt, 2016)

Theoretical ideas for new sanitation

Pilot, demonstration or implementation project	**Focus**	**Collection technology**	**Transport technology**	**Treatment technology**	**Reuse nutrients/ Resources**	**Sources**
Theoretical drainage concepts **inside** existing buildings.	Source separation. High-tech.	Modifications of the crawl space to allow for a different type of collection toilet on	Small diameter pipe within existing pipe.			(Harder, 2012) (Harder et al., 2013)

Housing.		the ground floor. Wet sealing toilet. Dry sealing toilet. New toilet outside of the house (in garage for example).	Pressure collection inside buildings (currently only applied when sanitary appliances lie below flood level or below the main sewer line).			
Theoretical drainage concepts **outside** existing buildings. Housing.	Source separation. High-tech.	Smart house connection that diverts black water and greywater into different directions outside of the house.	Smaller diameter sewer inside existing sewer. Smart sewer connection that diverts black water and greywater into different directions of a group of homes or apartments. Sealing house connection. Pressure collection outside buildings (collecting tank, a (grinder) pump and pipes to the sewer/treatment) has been applied sporadically.			(Harder, 2012) (Harder et al., 2013)

			Pneumatic systems (can be combined with pressure systems for hybrid systems).			
Vermicomposting (with worms). Housing.	Resource recovery.			Bio solids from composting toilets or sludge from other treatment methods can be treated by worm substrate to eliminate pathogens.	Organic fertilizer.	(Eastman et al., 2001)

Annex 9: Nutrients/resources that can be produced from wastewater in the Dutch situation

Nutrients/resources selected				
Nutrient/ Resource	**Applications & value estimate in Dutch context**	**Recovery technology** (phase technology development)	**Sustainability principles of TNS**[40]	**Sources**
Phosphate	Applications: Synthetic or organic fertilizer. Markets: Farmers. Value: Medium.	Struvite precipitation (commercial) Wastewater treatment sludge based fertilizers and soil conditioners (commercial/lab) Electrochemical precipitation of phosphate from urine (lab) From incinerated sludge ash with Ecophos process (commercial) Composting and application as organic fertilizer (commercial) Straw filter before constructed wetland for application as organic fertilizer (commercial for manure application)	**Principle 1:** Currently extracted from phosporite (phosphate rock), a fossil, mined scarce source. **Principle 2:** Mined phosphorous is of increasingly lower quality due to metal contamination which ends up in fertilizers. **Principle 3:** Degradation of ecosystems at mining sites.	(EFGF, 2016f) (SuSanA, 2009b) (Udert et al., 2013) (Regelink, 2016) (Ecophos, 2016)

[40] How does the nutrient/resource affect one or more TNS sustainability principles if it is not recovered and collected, transported, reused and treated conventionally in the Dutch situation – thus by centralized aerobic wastewater treatment?

		Concentration processes, such as freeze and thaw, electro dialysis reverse osmosis, distillation (commercial/lab) Algae nutrient recovery technology (lab)		(UNEP, 2001) (Agnew et al., 2010) (Kabdasli et al., 2013) (Tervahauta, 2014)
Nitrate/ Ammonia	Applications: Fertilizers, animal feeds, refrigerants, dyes, pharmaceuticals, cosmetics, nylon, rayon, plastics. Markets: Farmers, chemical and pharmaceutical industry. Value: Low.	Ammonia air stripping/passive stripping urine/digester supernatant for high concentrations – generally 5 g N L^{-1} (commercial/lab) Struvite precipitation, but only removes low N concentrations (commercial) Distillation of nitrified urine (lab) Power-to-Protein: Using hydrogen as an energy source powering a highly efficient microbial resynthesis process with a mixed culture of bacteria which up cycles N directly as microbial	**Principle 1:** Nitrogen is not scarce as it is abundant in the atmosphere as N_2 gas, but recovery of nitrogen from the atmosphere takes a lot of energy, which makes this an energy challenge in addition to a pollution challenge. **Principle 2:** The nitrogen cycle has been altered by human systems which increased production of reactive nitrogen (all N forms except atmospheric N_2) by 1.5 to 2 times the natural production. Effects on the environment include loss of biodiversity, pollution of groundwater, eutrophication, higher atmospheric ammonia, nitrogen oxide, nitrous oxide and aerosol levels with	(Erisman and Larsen, 2013) (STOWA, 2013) (Udert and Jenni, 2013) (Siegrist et al., 2013) (KWR, 2016)

		protein (lab) Wastewater treatment sludge based fertilizers and soil conditioners (commercial/lab) Composting and application as organic fertilizer (commercial) Ion exchange with zeolite (lab) Concentration processes, such as Eutectic Freeze Crystallization (EFC), electro dialysis reverse osmosis, distillation (commercial/lab) Algae nutrient recovery technology (lab)	impacts on climate change and human health.	(Regelink, 2016) (Otterpohl and Buzie, 2013) (Kabdasli et al., 2013) (WERF, 2011) (De Graaff, 2012)
Potassium	Applications: Synthetic or organic fertilizer. Markets: Farmers. Value: Low.	Wastewater treatment sludge based fertilizers and soil conditioners (commercial/lab) Ion exchange with zeolite, need large amounts of zeolite so commercially not yet feasible (lab) Precipitation of magnesium potassium	**Principle 1:** Currently extracted from potash ore (potassium containing compounds), from mines (fossil resource), salt lake deposits or solar evaporation ponds. Not a scarce resource. **Principle 3:** Degradation of ecosystems at production sites. Accumulation of salt tailings, fines or brines at	(Regelink, 2016) (Lenntech, 2016)

		phosphate hexahydrate (commercial/lab) Concentration processes, such as freeze and thaw, electro dialysis reverse osmosis, distillation (commercial/lab)	production sites, backfilling or deep injection of tailings or release in water bodies.	(Kabdasli et al., 2013) (Xu et al., 2015) (Kabdasli et al., 2013) (Baltussen, 2014) (UNEP, 2001)
Cellulose	Applications: Isolation material, padding and reinforcement. Raw material bio-ethanol, bio-plastics, biogas, sugar production. Viscosity damper. Dewatering sludge. Composting and digesting. Pyrolysis products. Markets: Building industry, asphalt production, wastewater treatment, bio energy and chemical industry. Value: Low-Medium.	Fine strainer/siever (commercial)	**Principle 3:** Virgin cellulose is mainly won from plants and trees resulting in overharvesting of these natural sources.	(EFGF, 2016c) (Wüstenberg, 2015)

Direct heat	Applications: Low temperature heat. Markets: District heating households, industry. Value: Low-Medium.	Heat exchanger, for example in shower (commercial) Heat pump for raising temperature (commercial)	**Principle 1:** The use of direct heat will lower the demand for (fossil) heat energy.	(Cipolla and Maglionico, 2014) (Kregting and De Brauw, 2011) (STOWA, 2016h)
Carbon source (Organic Matter)	Applications: Soil conditioner, organic fertilizer. Markets: Farmers, vegetable gardeners. Value: Low.	Direct application with or without storage (commercial) Composting and fermentation (commercial) Anaerobic Digestion (commercial) Wastewater treatment sludge based fertilizers and soil conditioners (commercial/lab)	**Principle 1:** Soil organic matter sequesters CO_2. **Principle 3:** Soil organic matter, increases soil biodiversity and resilience to pests. Dutch farmers have an increasing need for organic matter. Fibres are also of interest. Current challenges for reuse are hygienisation and heavy metals.	(Bot and Benites, 2005) (Jönsson and Vinneras, 2013) (Nutrient Platform, 2015) (Regelink, 2016) (Regelink, 2016)
Carbon Source (Bio	Applications: Bio plastics for biodegradable consumer products,	Bio refinery from rich or mixed-culture or specific type of bacteria	**Principle 4:** Current bio plastic production source (for PLA and PHA) is	(EFGF, 2016b)

plastics, bio thermo-plastics and fatty acids/lipids)	horticulture products and packaging. For example made from polyhydroxyalkanoates (PHA) and polylactic acid (PLA). Markets: Chemical, pharmaceutical, horticultural, building and packaging industry. Value: Medium.	(lab/pilot)	often carbon from potatoes or corn – which compete with food production.	(WERF, 2011) (STOWA, 2013) (STOWA, 2014) (Loge and Wolcott, 2010) (Heselmans, 2014)
Carbon source (Bio plastic Alginate/ Alginic Acid)	Applications: Surface treatment concrete - to increase technical life span. Markets: Building industry, paper and pharmaceutical industry. Value: High.	Nereda granular treatment process (commercial centralized technology)	**Principle 3:** Currently extracted from (wild) seaweed. Overharvesting of certain species of seaweed is possible.	(Van den Heuvel, 2012) (EFGF, 2016a) (FAO, 2016)
Carbon Source (Energy from biogas or syngas or	Applications: Biogas. Markets: Transportation sector and heat/electricity sector.	Anaerobic digestion (commercial)	**Principle 1:** Can help reduce human dependence on fossil fuels.	(EFGF, 2016d) (STOWA, 2013)

biogas as (transportation) fuel)	Value: Medium-High. Medium-high			(Rittmann, 2013)
Carbon Source (Methanol from Methane/ syngas)	Applications: Acetic acid, formaldehyde, MTBE, solvents, plastics. Markets: Chemical industry. Value: Low.	Digester methane gas (lab)	**Principle 1:** Methanol is currently produced from natural gas or other fossil sources.	(Taher and K., 2013) (WERF, 2011) (STOWA, 2013)

Nutrients/resources not selected				
Nutrient/ Resource	**Applications & value estimate in Dutch context**	**Recovery technology** (phase)	**Sustainability principles of TNS**[41]	**Sources**
Carbon source (Biomass growing on carbon source)	Applications: Most applications from carbon sources mentioned in this table can also be applied to mowing residues. Markets: Most markets from carbon sources mentioned in this table can also be applied to mowing residues. Value: Low-Medium.	Most technologies mentioned from carbon sources in this table can also be applied to mowing residues	Most principles mentioned from carbon sources in this table also apply to mowing residues	(Blankesteijn et al., 2015)
Carbon source (Humic acid)	Applications: Agricultural soil conditioner. Markets: Farmers. Value: Medium.	In drinking water production: efficient ion exchange (commercial) Humic acid removal by white rot fungi (lab)	**Principle 1:** Currently extracted from lignite (brown coal), a fossil, mined source.	(Vitens, 2016) (TU Delft, 2016)
Water (fresh water)	Applications: In water scarce regions for irrigation, domestic greywater use or drinking water (drinking water plants exist for example in Singapore, Orange County USA and more are being built). Markets: Farmers, households,	Extensive purification technologies: primary Microfiltration, secondary Reverse Osmosis and tertiary UV disinfection (commercial) Other (decentralized) membrane processes	In the Netherlands not (yet) applicable. **Principle 3 (in water scarce or saline regions):** Harvesting water from water scarce ecosystems may destabilize and degrade the ecosystem.	(PUB, 2015) (Blankesteijn et al., 2015)

[41] How does the nutrient/resource affect one or more TNS sustainability principles if it is not recovered and collected, transported, reused and treated conventionally in the Dutch situation – thus by centralized aerobic wastewater treatment?

	industry. Value: Low-Medium.	(commercial) Organica botanical garden (commercial)		(STOWA, 2013) (Leslie and Bradford-Hartke, 2013) (Little, 2015) (Organica Water Inc, 2016a)
Hydrogen (from syngas)	Applications: Hydrogen peroxide, polymers, solvent, pharmaceuticals Markets: Chemical and pharmaceutical industry. Value: Medium (no infrastructure exists for hydrogen in NLD so only for niche applications, not transport fuel).	Fermentative hydrogen production - Biomass is converted to fermentable feedstock which is processed to hydrogen (lab) Microbial electrolysis cell (lab) Biogas steam methane reforming (SMR) (commercial) Molten carbonate fuel cell biogas reforming (MCFC)	**Principle 1:** Currently mainly produced from natural gas, a fossil resource.	(STOWA, 2013) (WERF, 2011) (Claassen, 2016)

		(commercial)		(Bagchi et al., 2006) (Hong Jia et al., 2010) (Hatch et al., 2013)
CO_2	Applications: Plant growth in green houses, various industrial applications. Markets: Greenhouse farmers and industry. Value: Low.	Anaerobic digestion	None	(STOWA, 2013) (S. S. Gas Lab Asia, 2016)
Metals (various)	Applications: Various. Markets: Various. Value: Low-Medium (market prices are volatile).	Recovery from incineration ash (lab)	**Principle 2:** Sludge incineration ash currently contains most metals which are returned to the ecosphere by dumping (landfill) or reuse, increasing the concentration of these metals. So preventing contamination of ecosystems and protecting human health is the main concern with metals.	(STOWA, 2013) (WERF, 2011)
Aliphatic hydro-carbons	Applications: Manufacture of solvents, plastics and synthetic fibres, synthetic rubber.	Wastewater is contacted counter currently with stripping gas which is then passed over a bed of activated carbon	When these substances are present in high concentrations (not in Dutch residential wastewater) **principle 1 and 2:** Hydrocarbons are mostly	(WERF, 2011) (Von Klock

	Markets: Industry. Value: Low.	(patented technology applied in oil industry)	produced from fossil oil and thus their presence in wastewater effluent contributes to the increased concentration of human fabricated substances in the ecosphere.	and Patel, 1992)
Sulphur	Applications: Fertilizer and range of industrial products. Markets: Farmers and industry. Value: Low.	Recovery from biogas (commercial)	**Principle 1:** Currently sulphur production is a by-product from mining oil and natural gas.	(STOWA, 2013)
Synthetic petroleum (from syngas)	Applications: Liquefied fuel. Markets: Transportation sector. Value: Low (cheaper alternatives exist).	Gasification or supercritical water gasification (commercial)	**Principle 1:** Currently petroleum made from fossil sources using energy intensive Fischer – Tropsch process	(STOWA, 2013)
Carbon source (Lactic acid)	Applications: Food, cosmetics, pharmaceutical applications, chemical applications. Markets: Food, cosmetics, chemical and pharmaceutical industry. Value: Medium-High.	Production from cellulose fraction, fine strainer/siever (commercial) and then fermentation (lab)	**Principle 1:** Current production process uses a lot of (fossil) energy. **Principle 2:** Current production process uses a lot of chemicals. **Principle 4:** Current lactic acid production source (sugar beet for example) competes with food production.	(STOWA, 2013) (Martinez et al., 2013)

Annex 10: Calculations on limitations of Stepping Stone technology 2 in rural case Exel

TABLE 43: CALCULATIONS ON NUTRIENT INPUTS, NUMBER OF INHABITANTS IN EXEL AND WATER USE PER PERSON PER DAY FOR FLUSHING. ASSUMING EACH HOUSE HAS 2 CONVENTIONAL TOILETS CONNECTED TO THE CONVENTIONAL SEWER OF WHICH ONE IS CONVERTED TO VACUUM AND CONNECTED TO SST2 SYSTEMS. ALSO ASSUMING ALSO EACH TOILET IS USED 50% OF THE TIME ON AVERAGE. NO KITCHEN GRINDER IS CONNECTED (SOURCE: ANNEX 2 AND ANNEX 4)

2,071	[kg y-1 Exel inhabitants-1] OM (no cellulose) in urine and faeces in vacuum toilet
442	[kg y-1 Exel inhabitants-1] Cellulose OM in vacuum toilet
2,513	[kg y-1 Exel inhabitants-1] total OM in vacuum toilet
186	[p] inhabitants Exel
5.9	[times p-1 d-1] Usage frequency toilet on average in The Netherlands
1.5	[L] Average demand per time for flushing vacuum toilet, litres per flush range from 1 to 2 [L] (De Graaf and Van Hell, 2014)
8.85	[L d-1 p-1] Water use per person per day for flushing vacuum toilet
25	[°C] required minimum temperature UASB[42]
15.97	[°C] black water influent temperature into UASB
35.8	Maximum energy contents biogas [MJ m3-1] assuming it is 100% methane (Biogas-E vzw, 2016)
0.5	[m3 kg-1] biogas production per kg digestible organic matter

To calculate the primary energy required to heat the UASB reactor to 25° Celsius the following formula was used:

$$\Delta Q = m * C * \Delta T$$

where ΔQ is the required energy (J), *m* is the mass of liquid (g), C is the specific heat capacity of water (4.2 J/g°C) and ΔT is the temperature difference between the influent temperature and the operational temperature of the reactor.

m = (8.26 * 1,000 * 186 * 365) = 280,385,700 [g y-1 inhabitants Exel-1]

ΔT = 25 – 15.97 = 9.03° Celsius

ΔQ = 10,633.91 [MJ year-1 inhabitants Exel-1] primary energy needed to heat the UASB reactor for digestion of the black water of the connected vacuum toilets in SST2 of Exel

The biogas production is 2,513 [kg year-1 inhabitants Exel-1] organic matter * 0.5 = 1,256.5 m3 biogas.

The biogas energy available to heat the UASB reactor is 1,256.5 [m3] * 35.8 [MJ m3-1] = 44,982.7 [MJ]

There is a surplus of 44,982.7 – 10,633.91 = 34,348.79 MJ primary energy. Or just over 423% of the primary energy demand is able to be covered by the produced biogas.

[42] Requires larger reactor size, but when other 50% of toilets, that cannot be connected at start-up, are connected the temperature of the UASB can be moved up to 35 [°C] and no new reactor has to be built.

Annex 11: Calculations and explanations on scoring indicators Stepping Stone Technology 2: Vacuum systems for black water, in rural case Exel

The calculations and scoring are only including the part of the SST that is able to be implemented right now. So it does not consider the future connection of second floor toilets to the vacuum system in SST2 for example, and hence recovery percentages are currently lower than their full potential. Moreover, the connection of these second floor toilets to the conventional system is not scored in terms of robustness and recovery of nutrients by such a centralized system.

#2 Phosphorous

TABLE 44: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in vacuum toilet (assuming two toilets per house of which only ground floor toilet is a vacuum toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
100%	Percentage of P in incinerated sludge recovered (Ecophos, 2016).
35.0%	Percentage of total P in SST2 removed in struvite reactor (De Graaf and Van Hell, 2014).
56.0%	Percentage of P in black water + kitchen refuse removed in struvite reactor (De Graaf and Van Hell, 2014).
53.0%	Percentage of total P in SST2 removed by total system (De Graaf and Van Hell, 2014).
41.7%	Percentage of P in greywater removed in AB process.
18.0%	Percentage of P in greywater and struvite reactor effluent removed in AB process.
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

TABLE 45: CALCULATION TO FIND PERCENTAGE P RECOVERED

	Total P (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	54.31	0.245	13.3
In faeces	33.95	0.245	8.3
In greywater	27.16	0.417	11.3
In effluent black water system		0.417	17.1
In kitchen refuse	13.58	0.487	6.6
Total P all streams	129	-	56.7
Percentage of total recovery	-	-	43.9%

Additional assumptions:

- There is probably higher phosphate recovery possible, as the reference project phosphate recovery percentages have been measured in an under loaded system, however as no data of the system with a normal load is available the data of the under loaded system is used (De Graaf and Van Hell, 2014).

#3 Nitrogen

As the focus lies on removal and not on recovery of nitrogen, it is assumed that this decentralized wastewater system removes nitrogen at a higher energy than the embedded energy of the nitrogen recovery from struvite and UASB sludge (N production with the Haber Bosch process) the energy saved by nitrogen recovery is set to zero.

#4 Potassium

Table 46: Information used to make calculation

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in vacuum toilet (assuming two toilets per house of which only ground floor toilet is a vacuum toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
0%	Percentage of K in incinerated sludge recovered.
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
9%	Percentage of N to UASB sludge (remainder to effluent) (De Graaff et al., 2010)

Table 47: Calculation to find percentage K recovered

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	190.09	0.039	7.5
In faeces	61.1	0.039	2.4
In greywater	54.35	0	0
In kitchen refuse	13.58	0.044	0.6
Total K all streams	319.12	0.039	10.5
Percentage of total recovery	-		3.3%

Additional assumptions:

- It is assumed that Potassium behaves the same way as Nitrogen in the UASB reactor; hence the same percentage of K goes to sludge as N.

#6 Organic Matter

Table 48: Information used to make calculation

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in vacuum toilet (assuming two toilets per house of which only ground floor toilet is a vacuum toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
78.0%	Percentage organic matter in black water system of SST to biogas (De Graaf and Van Hell, 2014).
7.0%	Percentage organic matter in black water system of SST to UASB sludge (De Graaf and Van Hell, 2014).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
80%	Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016).

TABLE 49: CALCULATION TO FIND PERCENTAGE OM RECOVERED

	Total OM (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	746.79	0.372	277.7
In faeces + toilet paper	4,278.00	0.372	1,590.9
In greywater	3,530.3	0	0
In kitchen refuse	4,005.51	0.181	725.4
Total OM all streams	12,560.6	0.372	2,594.0
Total OM volatilization in UASB sludge and kitchen refuse composting			390.6
Percentage of total recovery			17.5%

Additional assumption:

- The sludge production of the AB process is minimal so has been assumed to be zero (De Graaf and Van Hell, 2014).
- No organic matter caught in struvite crystals.

#7 Nutrient/resource input[43] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: -

[43] Materials and chemicals (not energy).

The hi tech system is quite material intensive as a large number of technologies are operating at a relatively small scale (De Graaf and Van Hell, 2014).

Chemicals: +

Magnesium is added to recover phosphorous as struvite (De Graaf and Van Hell, 2014).

Overall score: +-

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[44].

Scored ++, +, +-, - or -- [45].

The deposits/effluents from the system are from the AB process and effluent from the entire system. The effluent complies with current Dutch standards and the sludge from the AB process originates party in greywater so is polluted with metals and micropollutants to a high degree and needs to be incinerated. However, it does not enter the ecosystem.

Overall score: +-

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[46].

Scored ++, +, +-, - or --.

There are no unwanted by-products from treatment as no chemicals are added.

Struvite: +

The recovered phosphorous from struvite is to a high degree free of micropollutants and metals (Rondeltrap et al., 2007). The recovered phosphorous from incinerated sludge ash, which was incinerated at a dedicated sludge incineration facility, is free from all harmful substances (Ecophos, 2016).

Biogas and residual heat: ++

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[44] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.

[45] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

[46] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

Biogas and residual heat are resources free of harmful substances.

Sludge from UASB: +-

Metals present in faeces and urine are almost completely traceable to the food consumed. Hence it can be argued that these are safe levels for reuse (Tervahauta, 2014).

Reduction of micropollutants in recovered compost is possible by introduction some lifestyle changes of users. They can avoid using pharmaceuticals and personal care and household products with non-biodegradable components. Moreover, when this is not possible, they can use a urine bag during the time of medicine use which will be disposed with the solid waste and incinerated instead of composted.

Overall score: +

#10 Direct heat recovery

TABLE 50: INFORMATION TO MAKE CALCULATION AND CALCULATION TO FIND PERCENTAGE DIRECT HEAT RECOVERED WITH SHOWER HEAT EXCHANGER

2.5	Average renovations of bathroom per year (lifetime bathroom 25 years according to Huur Commissie (2011)
3	Average number of inhabitants per home in Exel
62	Number of households in Exel
1.9	Savings per person per year by using shower heat exchange [Gj p-1 y-1] (Blom et al., 2010)
14.1	Savings for cluster of Exel per year using shower heat exchange [Gj Excel inhabitants-1 y-1]
33.41	Average energy contents natural gas Dutch situation [MJ m3-1] (Blom et al., 2010)
1,400	Natural gas use average Dutch household [m3 y-1] (Milieu Centraal, 2016b)
2,899,988	Natural gas in MJ use for total Exel [MJ Exel total-1 y-1]
2,900	Gj natural gas for total Exel [Gj Exel total-1 y-1]
0.5%	Savings on total natural gas use by implementing shower heat exchangers.
264	kWh per inhabitant per year electricity costs for the heat pump (De Graaf and Van Hell, 2014).
477	kWh per inhabitant per year electricity gain in the form of heat from greywater (De Graaf and Van Hell, 2014).
213	kWh net per inhabitant per year electricity gain in the form of heat from greywater
186	Number of inhabitants in Exel
39,618	kWh net per total cluster Exel per year electricity gain in the form of heat from greywater
142.62	Gj net per total cluster Exel per year electricity gain in the form of heat from greywater.
4,9%	Savings by implementing greywater indirect heat recovery.
5.4%	Savings by implementing both shower heat exchange and greywater heat recovery

Additional assumptions:

- A heat network is already in place that can efficiently use the recovered heat.

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[47].

Scored ++, +, +-, - or -- [48].

A rough life cycle analysis shows that an optimized version of the reference project Waterschoon in Sneek scores very positive compared the centralized system currently in place when looking at CO_2 emissions and depletion of fossil fuels.

Overall score: ++

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[49].

Scored ++, +, +-, - or --.

The goals of the reference project Waterschoon in Sneek was maximum recovery of energy and phosphorous and minimizing the use of drinking water (De Graaf and Van Hell, 2014). It can be concluded that the trade-off was given consideration.

Overall score: ++

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

This stepping stone technology comprises of several hi tech components that require professionals to run and maintain the system.

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[47] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.
[48] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.
[49] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

Overall score: --

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[50] for recreation or landscape purposes, are allocated and accessible to the communities the waste (water) originates from.

Scored ++, +, +-, - or --.

Direct heat, biogas and UASB sludge need to be reused locally because transporting them will not be energy efficient. Struvite may be transported for longer distances as it does not contain water it is more energy efficient to transport out of the city by truck.

Overall score: +

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

The sustainability evaluation of the reference project Waterschoon in Sneek shows that the system may cause some inconvenience to users. However, besides the adjustment in the deposition of kitchen refuse in the grinder and the operation of the vacuum toilet, not much changes for the users in their daily routine (De Graaf and Van Hell, 2014). Other research on several other comparable projects shows that the inconvenience of noise and the operation of the toilet may be remediated by a better vacuum toilet and piping design (Van den Bulk and Telkamp, 2008).

Overall score: +

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

The sustainability evaluation of the reference project Waterschoon in Sneek shows that the system may cause some noise hindrance and service quality concerns (De Graaf and Van Hell, 2014). Other research on several other comparable projects shows that this inconvenience may be remediated by a better vacuum toilet and piping design (Van den Bulk and Telkamp, 2008).

Overall score: +

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[50] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

The reference project Waterschoon in Sneek is considered fairly robust. In the three monitoring years hardly any failures took place, except for a few malfunctions of the vacuum system and a start up problem with the kitchen grinders.

Overall score: +

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

Users are not in contact with pathogens or harmful substances, as these are transported away from homes by vacuum piping and treated in the hi tech community-on-site treatment facility.

Overall score: ++

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). Organic matter is used to make biogas, which does not increase soil fertility. Struvite can be transported over long distances so does not necessarily end up on local soils. UASB sludge can be used for increasing local soil fertility though, although the quantity of organic matter is reduced by biogas production.

Overall score: +-

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

As the implementation of this stepping stone technology was very new in the realization of the reference project Waterschoon in Sneek, all parties were actively involved in developing and realizing the system (De Graaf and Van Hell, 2014).

Overall score: +

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

The longest lifespan of elements of the stepping stone technology is 30 years, except for the sewage pipes outside, those will last for 50 years. This means that the system is fairly flexible, as there is source separation new innovative techniques for treatment can be implemented in 30 years, instead of the 60 years lifespan of conventional combined wastewater sewage pipes.

Overall score: +-

#22 Investment in flexible platform technology today has a good return on investment[51].

Scored ++, +, +-, - or --.

The economic financial analysis shows that at the current scale of the reference project Waterschoon in Sneek the costs are 11% higher than the conventional centralized wastewater treatment system. However at 2400 inhabitants the costs would be equal. Environmentally, the sustainability evaluation of the reference project shows the decentralized solution scores equal to the centralized solution (De Graaf and Van Hell, 2014).

Overall score: +-

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

The amount of resources needed to make this hi tech system is considerable, although the lifespan is lower than that of the conventional system. It does however score fairly well with the four sustainability principles of TNS.

Overall score: +

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

Scored ++, +, +-, - or --.

Solution is not BAU.

Overall score: ++

[51] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

Annex 12: Calculations and explanations on scoring indicators Stepping Stone Technology 3: Composting dry toilets with urine storage, in rural case Exel

The calculations and scoring are only including the part of the SST that is able to be implemented right now. So it does not consider the future connection of second floor toilets to the compost system in SST3 for example, and hence recovery percentages are currently lower than their full potential. Moreover, the connection of these second floor toilets to the conventional system is not scored in terms of robustness and recovery of nutrients by such a centralized system.

#2 Phosphorous

TABLE 51: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in composting toilet (assuming two toilets per house of which only ground floor toilet is a composting toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
18.5%	Average of P recovery percentage in Willows in vertical flow constructed wetland from two studies, 14% and 23% were found (Otte and Boosten, 2014)

TABLE 52: CALCULATION TO FIND PERCENTAGE P RECOVERED

	Total P (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	54.31	0.438	23.8
In faeces	33.95	0.438	14.9
In greywater	27.16	0.185	5.0
In kitchen refuse	13.58	0.487	6.6
Total P all streams	129	-	50.3
Percentage of total recovery	-	-	39.0%

Additional assumptions:

- The Imhoff tank does not significantly remove nutrients and nutrient removal in the sludge is therefore assumed to be negligible.

#3 Nitrogen

TABLE 53: INFORMATION USED TO MAKE CALCULATION

43	Embedded energy for production N the Haber Bosch process [kJ g-1] (Rittmann, 2013)

970.84	Total N input excluding drinking water N input from MFA baseline nutrients [kg y-1 Exel inhabitants-1]
41,746,120	Energy needed for total input production N [kJ y-1]
362.8	Recovered N of input (total recovery percentage from table 54 multiplied by Total N input from this table) [kg y-1 Exel inhabitants-1]
15,601,802	Energy needed to produce recovered N in Haber Bosch (N recovered multiplied by embedded energy multiplied by 1000) [kJ y-1]
2.4	Maximum energy need of one electric fan for one compost compartment [Watt] (Harrington, 2016)
kJ = W × s / 1000	Conversion formula W to kJ
31,556,926	Number of seconds in one year
75,737	Energy needs of one electric fan [kJ y-1]
62	Number of households in Exel
4,695,671	kJ needed to run all ventilators in Exel 24 hours a day, every day the whole year [kJ y-1]
87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in composting toilet (assuming two toilets per house of which only ground floor toilet is a composting toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
37.5	Average of N recovery percentage in Willows in vertical flow constructed wetland from two studies, 32% and 43% were found (Otte and Boosten, 2014)
55%	Loss N due to volatilization as ammonia (reactive N) in composting process (Anand and Apul, 2014)
0%	Loss N due to volatilization as ammonia (reactive N) in urine storage process

TABLE 54: CALCULATION TO FIND PERCENTAGE KJ SAVED TROUGH N RECOVERY

	Total N (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	611.01	0.438	267.6
In faeces	122.2	0.438	53.5
In greywater	122.22	0.375	45.8
In kitchen refuse	115.41	0.487	56.2
Total N all streams	970.84	-	423.2
Total N volatilization in faeces and kitchen refuse composting			60.4
Percentage of total recovery	-	-	37.4%
Energy saved	-	-	10,906,131 [kJ y-1]
Percentage kJ saved	-	-	26.1%

Additional assumption:

- If the C:N ratio is correct and the composting chamber is operating well, less reactive nitrogen (ammonium gas) should escape through the ventilation pipe (Cornell Waste Management Institute, 2016). However, as some homes may have better operating compost chambers as others, therefore the average number of the range of ammonium gas losses is used to account for this variety (Anand and Apul, 2014)
- The design of the storage tank is optimized for minimized N losses during filling, storage and emptying of the tank when applied as liquid organic fertilizer.
- The Imhoff tank does not significantly remove nutrients and nutrient removal in the sludge is therefore assumed to be negligible.

#4 Potassium

Table 55: Information used to make calculation

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in composting toilet (assuming two toilets per house of which only ground floor toilet is a composting toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
14%	K recovery percentage in Willows in 'no discharge' constructed wetland in one study is 28%, assumed this is too high so took half this number (Otte and Boosten, 2014)

Table 56: Calculation to find percentage K recovered

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	190.09	0.438	83.3
In faeces	61.1	0.438	26.8
In greywater	54.35	0.14	7.6
In kitchen refuse	13.58	0.487	6.6
Total K all streams	319.12	-	124.2
Percentage of total recovery	-	-	38.9%

Additional assumptions:

- The Imhoff tank does not significantly remove nutrients and nutrient removal in the sludge is therefore assumed to be negligible.

#6 Organic Matter

Table 57: Information used to make calculation

87.5%	Houses with crawl space (Harder, 2012)

43.75%	Percentage of total excreted urine and faeces collected in composting toilet (assuming two toilets per house of which only ground floor toilet is a composting toilet and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
80%	Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016)
37.5%	Organic matter to sludge in the Imhoff tank (Stauffer and Spuhler, 2016)

Table 58: Calculation to find percentage OM recovered

	Total OM (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	746.79	0.438	327.1
In faeces + toilet paper	4,278.00	0.438	1,873.8
In greywater	3,530.3	0.000	0.0
In kitchen refuse	4,005.51	0.487	1,950.7
Total OM all streams	12,560.6	-	4,151.5
Total OM volatilization in faeces and kitchen refuse composting			3,059.6
Percentage of total recovery	-	-	8.7%

Additional assumption:

- If the C:N ratio is correct, the composting chamber is operating well and a bulking agent with a low biodegradability, such as sawdust is applied, less mineralization of organic matter will occur than assumed in this calculation (Anand and Apul, 2014)

#7 Nutrient/resource input[52] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: ++

Significantly fewer materials needed to make the system compared to other Stepping Stone Technologies (Otte and Boosten, 2014, SuSanA, 2009b).

Chemicals: ++

[52] Materials and chemicals (not energy).

No chemicals are added to run the processes (Otte and Boosten, 2014, SuSanA, 2009b).

Overall score: ++

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[53].

Scored ++, +, +-, - or -- [54].

Compost toilet and secondary compost heap: +

Closed system: No untreated residual waste exits (SuSanA, 2009b). There are emission of short cycle carbon dioxide, ammonia, volatile compounds and water in the composting process (Anand and Apul, 2014).

Urine storage: +

There is no effluent or residual waste from the urine storage technology, all urine is used as liquid organic fertilizer.

Imhoff tank and willow filter: +-

Effluent willow filter complies with current Dutch standards (Otte and Boosten, 2014), but it does not remove high levels of metals or micropollutants. The small amount of sludge from the Imhoff tank is polluted so it has to be incinerated.

Overall score: +

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[55].

Scored ++, +, +-, - or --.

There are no unwanted by-products from treatment as no chemicals are added.

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[53] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.
[54] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.
[55] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

Metals present in faeces and urine are almost completely traceable to the food consumed. Hence it can be argued that these are safe levels for reuse (Tervahauta, 2014).

Reduction of micropollutants in recovered compost is possible by introduction some lifestyle changes of users. They can avoid using pharmaceuticals and personal care and household products with non-biodegradable components. Moreover, when this is not possible, they can use a urine bag during the time of medicine use which will be disposed with the solid waste and incinerated instead of composted.

Aside from micropollutants and metals that may be present in organic liquid fertilizer from urine it is a clean resource. By current Dutch standards it is probably acceptable, as metal content in urine is very low (Schönning, 2001) and no standards for micropollutants exist yet.

Willow filters are capable of removing metals to a high degree and storing them in the woody biomass. In the soil some biodegradable micropollutants are likely to be converted to less harmful substances, comparable to a constructed wetlands (Otte and Boosten, 2014, Zhang et al., 2013a).

Overall score: +-

#10 Direct heat recovery

TABLE 59: INFORMATION TO MAKE CALCULATION AND CALCULATION TO FIND PERCENTAGE DIRECT HEAT RECOVERED WITH SHOWER HEAT EXCHANGER

2.5	Average renovations of bathroom per year (lifetime bathroom 25 years according to Huur Commissie (2011)
3	Average number of inhabitants per home in Exel
62	Number of households in Exel
1.9	Savings per person per year by using shower heat exchange [Gj p-1 y-1] (Blom et al., 2010)
14.1	Savings for cluster of Exel per year using shower heat exchange [Gj Excel inhabitants-1 y-1]
33.41	Average energy contents natural gas Dutch situation [MJ m3-1] (Blom et al., 2010)
1,400	Natural gas use average Dutch household [m3 y-1] (Milieu Centraal, 2016b)
2,899,988	Natural gas in MJ use for total Exel [MJ Exel total-1 y-1]
2,900	Gj natural gas for total Exel [Gj Exel total-1 y-1]
0.5%	Savings on total natural gas use by implementing shower heat exchangers

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[56].

Scored ++, +, +-, - or -- [57].

[56] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.

There is no renewable energy generation in the human waste treatment; however, there is hardly any energy input either. The willow filter has a positive energy ratio (Otte and Boosten, 2014, SuSanA, 2009b) and the compost toilet uses less energy than the embedded energy in the nitrogen recovered (see criterion #3).

Overall score: +-

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[58].

Scored ++, +, +-, - or --.

In this mid-tech system the focus lies on high resource and energy efficiency, not on energy production. In the case of the reference project in Allermöhe, Germany, this was a conscious decision (SuSanA, 2009b).

Overall score: +

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

Every resident knows how to maintain the compost toilet in their home and provisions will be made for those physically unable to do the labour. House-on-site urine storage and reuse is also managed by residents themselves. The Imhoff tank and willow filter and community-on-site secondary compost heap are operated by experienced residents with sufficient know-how (SuSanA, 2009b).

Overall score: ++

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[59] for recreation or landscape

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[57] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.

[58] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

[59] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

purposes, are allocated and accessible to the communities the waste (water) originates from.

Scored ++, +, +-, - or --.

Organic fertilizer from the secondary compost heap and urine storage is used locally. Savings from direct heat recovery in showers are allocated to the households where they are installed directly by default. The willow filter looks attractive and biomass can be used or sold by the community as they own the constructed wetland.

Overall score: ++

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

The socio-cultural and institutional acceptance of collection and transport, treatment and transport and reuse is strong in the ecological settlement of Allermöhe, Germany (SuSanA, 2009b) and likewise in the Earthships in Olst, The Netherlands (De Waard, 2015). However, this was in eco communities which may not represent the average inhabitant of Exel who may be less receptive to this new technology, hence care should be given to creating sufficient support amongst residents before implementing the technology. Also, the use of harsh chemicals that may interfere with composting should be avoided by residents, which represents a minor lifestyle change.

Overall score: +

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

There can be bad smell from the ventilation pipe from the compost toilet, or from the urine storage container when opened to apply as liquid organic fertilizer. The toilet therefore has to have the exhaust placed high enough not to notice any bad smell on ground level. On the ease of construction, operation and monitoring the entire stepping stone technology, as well as robustness, for collection and transport, treatment and transport and treatment the score in the case of Allermöhe, Germany, is average (SuSanA, 2009b). The score of the effects review of STOWA (2016c) indicated a somewhat negative effect on comfort of the user of a compost toilet. But the effect on comfort for users of the urine storage and reuse as local liquid fertilizer is positive.

Overall score: +-

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

As long as the compost compartment is dimensioned large enough to deal with high loading rates there is flexibility, as under loading is not a problem with composting. Likewise with the urine storage and secondary compost heap are flexible. The willow filter also needs to be dimensioned for low temperatures and thus not too small, but under loading is unlikely to be a problem (Tilley et al., 2008).

As there are no hi tech components, the system has a low malfunction rate and low sensitivity for failure. Knowledge in each household about composting is however important, as well as for the urine storage.

Overall score: +

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

According to STOWA (2016c) the compost toilet provides the same public health security as the conventional centralized sewage system. Likewise for the urine storage and willow filter. In the reference project of Allermöhe, Germany, a somewhat higher risk of exposure to pathogens and hazardous substances in the collection and transport phase was found, however in the treatment and transport and reuse phase no increased risk was found (SuSanA, 2009b).

Overall score: +

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). The intention is to use the organic fertilizer of the secondary compost heap and the urine storage locally to improve soils and to decrease transportation (SuSanA, 2009b).

Overall score: ++

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

The main stakeholders are the users as they also maintain the system. Experience of the producer of the used compost toilets shows that their active involvement in design, installation and improvements is a requirement for satisfactory operation (Berger, 2003). In the original project governments were unfamiliar with constructed wetlands and therefore too involved in the requirements for the design, leading to over dimensions and expensive material use (SuSanA, 2009b). In The Netherlands many projects have been realized and even though involvement of all stakeholders is needed for the somewhat novel implementation of a Willow filter, an overly cautious government is not to be expected due to experience at the Biesbosch museum and solid research on design parameters (Global Wetlands, 2016, Otte and Boosten, 2014).

Overall score: ++

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

The lifetime of compost toilets is at least 5 years, but likely 25 years for the compost chamber, based on warranty by technology providers (Envirolet, 2016, Berger Biotechnik GmbH, 2016). The technical lifetime of a Willow constructed wetland is 20 to 25 years (Otte and Boosten, 2014). This is significantly lower than the conventional technology with sewer pipes of a technical lifetime of 60 years (Oosterom and Hermans, 2013). Therefore the stepping stone technology concept is a flexible platform, it allows for upgrading, innovation or replacement within a relatively short time span (Spiller et al., 2015).

Overall score: ++

#22 Investment in flexible platform technology today has a good return on investment[60].

Scored ++, +, +-, - or --.

Taking into account the benefit from recovered resources as well as the costs for sanitation and the carrying capacity of households for collection and transport, treatment and transport and reuse the stepping stone technology scores strong (SuSanA, 2009b). STOWA (2016c) evaluates the compost toilet and willow filter as cost neutral compared to centralized treatment, urine storage as somewhat more expensive. However all three technologies score very positive on environmental profits.

Overall score: ++

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

This stepping stone technology scores very well with the four sustainability principles of TNS.

Overall score: ++

[60] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

Scored ++, +, +-, - or --.

Solution is not BAU.

Overall score: ++

Annex 13: Calculations and explanations on scoring indicators Stepping Stone Technology 4: Willow filter with ABR, in rural case Exel

The calculations and scoring are only including the part of the SST that is able to be implemented right now. So it does not consider the future connection of second floor in-house sewage system to separate black water and greywater pipes, and hence recovery percentages are currently lower than their full potential. Moreover, the connection of these second floor toilets to the conventional combined black and greywater system is not scored in terms of robustness and recovery of nutrients by such a centralized system.

#2 Phosphorous

TABLE 60: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
18.5%	Average of P recovery percentage in Willows in vertical flow constructed wetland from two studies, 14% and 23% were found (Otte and Boosten, 2014)

TABLE 61: CALCULATION TO FIND PERCENTAGE P RECOVERED

	Total P (source MFA nutrients baseline)	Theoretical recovery	Theoretical recovery
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	54.31	0.438	23.8
In faeces	33.95	0.438	14.9
In greywater	27.16	0.185	5.0
In kitchen refuse	13.58	0.487	6.6
Total P all streams	129	-	50.3
Percentage of total recovery	-	-	39.0%

Additional assumptions:

- The Imhoff tank and ABR do not significantly remove nutrients and nutrient removal in the incinerated sludge is therefore assumed to be negligible.

#3 Nitrogen

TABLE 62: INFORMATION USED TO MAKE CALCULATION

43	Embedded energy for production N the Haber Bosch process [kJ g-1] (Rittmann, 2013)

970.84	Total N input excluding drinking water N input from MFA baseline nutrients [kg y-1 Exel inhabitants-1]
41,746,120	Energy needed for total input production N [kJ y-1]
215.6	Recovered N of input (total recovery percentage from table 63: calculation to find percentage kj saved trough n recovery multiplied by Total N input from this table) [kg y-1 Exel inhabitants-1]
9,272,533	Energy needed to produce recovered N in Haber Bosch (N recovered multiplied by embedded energy multiplied by 1000) [kJ y-1]
0.7	Transport energy conventional wastewater system in The Netherlands [Pj y-1] (Blom et al., 2010)
7,190,543.0	Number of Dutch households in 2007 (Blom et al., 2010)
97,350,1	Transport energy wastewater per Household [kJ.y-1.household]
62	Number of households in Exel
6,035,705.5	Transport energy from collection point to all Technologies in SST4 for all Exel inhabitants [kJ.y-1.Excel inhabitants]
87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
37.5	Average of N recovery percentage in Willows in vertical flow constructed wetland from two studies, 32% and 43% were found (Otte and Boosten, 2014)
55%	Loss N due to volatilization as ammonia (reactive N) in composting process (Anand and Apul, 2014)
9%	Percentage of N to ABR sludge (remainder to effluent) (De Graaff et al., 2010)

TABLE 63: CALCULATION TO FIND PERCENTAGE KJ SAVED TROUGH N RECOVERY

	Total N (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	611.01	0.438	267.6
In faeces	122.2	0.438	53.5
In greywater	122.22	0.375	45.8
In kitchen refuse	115.41	0.487	56.2
Total N all streams	970.84	-	423.2
Total N volatilization in kitchen refuse and ABR sludge composting			45.5
Percentage of total recovery	-	-	38.9%
Energy saved	-	-	10,206,071 [kJ y-1]
Percentage kJ saved	-	-	24.4%

Additional assumptions:

- The transport energy for pumping wastewater, effluent en sludge streams between the collection point and technologies is assumed to be equal to the pumping energy in a centralized wastewater treatment scheme (see SST1).

#4 Potassium

TABLE 64: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
14%	K recovery percentage in Willows in 'no discharge' constructed wetland in one study is 28%, assumed this is too high so took half this number (Otte and Boosten, 2014)

TABLE 65: CALCULATION TO FIND PERCENTAGE K RECOVERED

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	190.09	0.438	83.3
In faeces	61.1	0.438	26.8
In greywater	54.35	0.14	7.6
In kitchen refuse	13.58	0.487	6.6
Total K all streams	319.12	-	124.2
Percentage of total recovery	-	-	38.9%

Additional assumptions:

- The Imhoff tank does not significantly remove nutrients and nutrient removal in the incinerated sludge is therefore assumed to be negligible.

#6 Organic Matter

TABLE 66: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used

	50% of the time).
50%	Removal Organic Matter of ABR to biogas or composted sludge for organic fertilizer (Telkamp, 2016).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
80%	Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016)

TABLE 67: CALCULATION TO FIND PERCENTAGE OM RECOVERED

	Total OM (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	746.79	0.500	373.4
In faeces + toilet paper	4,278	0.500	2,139.0
In greywater	3,532.08	0.000	0.0
In kitchen refuse	4,005.51	0.487	1,950.7
Total OM all streams	11,678.88	-	4,463.1
Total OM volatilization in kitchen refuse composting			1,560.5
Percentage of total recovery	-	-	23.1%

Additional assumption:

- Most of organic matter removed in ABR is biogas and very little organic matter ends up as sludge, as the sludge accumulates very slowly according to Nguyen et al. (2010). Organic matter in sludge is therefore considered negligible, instead organic matter is assumed to go to the effluent of the ABR.

#7 Nutrient/resource input[61] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: +-

Two separate transport systems have to be made: The black water system and the greywater system. However, pipe length is shorter than with conventional sewage as all technologies are community-on-site.

[61] Materials and chemicals (not energy).

Chemicals ++

No chemicals are added to run the biological processes.

Overall score: +

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[62].

Scored ++, +, +-, - or -- [63].

ABR: +

Biogas is a clean product and no other by-products are entering the ecosystem, but instead are led to other technologies to further purify.

Imhoff tank and willow filter: +-

Effluent willow filter complies with current Dutch standards (Otte and Boosten, 2014), but it does not remove high levels of metals or micropollutants. The small amount of sludge from the Imhoff tank is polluted so it has to be incinerated.

Secondary compost heap: +

Closed system: No untreated residual waste exits (SuSanA, 2009b). There are emission of short cycle carbon dioxide, ammonia, volatile compounds and water in the composting process (Anand and Apul, 2014).

Overall score: +

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[64].

Scored ++, +, +-, - or --.

Biogas is free of micropollutants and metals.

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[62] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.

[63] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

[64] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

There are no unwanted by-products from treatment as no chemicals are added.

Metals present in faeces and urine are almost completely traceable to the food consumed. Hence it can be argued that these are safe levels for reuse (Tervahauta, 2014). This means that the compost from the secondary compost heap is safe for agricultural use.

Reduction of micropollutants in recovered compost is possible by introduction some lifestyle changes of users. They can avoid using pharmaceuticals and personal care and household products with non-biodegradable components. Moreover, when this is not possible, they can use a urine bag during the time of medicine use which will be disposed with the solid waste and incinerated instead of composted.

Willow filters are capable of removing metals to a high degree and storing them in the woody biomass. In the soil some biodegradable micropollutants are likely to be converted to less harmful substances, comparable to a constructed wetlands (Otte and Boosten, 2014, Zhang et al., 2013a). However, the willow filter has a somewhat higher load than in SST3, as the effluent from the ABR is also treated.

Overall score: +-

#10 Direct heat recovery

TABLE 68: INFORMATION TO MAKE CALCULATION AND CALCULATION TO FIND PERCENTAGE DIRECT HEAT RECOVERED WITH SHOWER HEAT EXCHANGER

2.5	Average renovations of bathroom per year (lifetime bathroom 25 years according to Huur Commissie (2011)
3	Average number of inhabitants per home in Exel
62	Number of households in Exel
1.9	Savings per person per year by using shower heat exchange [Gj p-1 y-1] (Blom et al., 2010)
14.1	Savings for cluster of Exel per year using shower heat exchange [Gj Excel inhabitants-1 y-1]
33.41	Average energy contents natural gas Dutch situation [MJ m3-1] (Blom et al., 2010)
1,400	Natural gas use average Dutch household [m3 y-1] (Milieu Centraal, 2016b)
2,899,988	Natural gas in MJ use for total Exel [MJ Exel total-1 y-1]
2,900	Gj natural gas for total Exel [Gj Exel total-1 y-1]
0.5%	Savings on total natural gas use by implementing shower heat exchangers

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[65].

Scored ++, +, +-, - or -- [66].

[65] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.

There is renewable energy production (biogas) which can be used locally for cooking or generating heat/electricity (high efficiency electric boiler) in homes, or for powering community lights. The ABR is not heated and does not need electricity. The willow filter has a positive energy ratio (Otte and Boosten, 2014). There is pumping energy needed, but this is lower than the embedded energy in the recovered nitrogen (see criterion #3). There may be energy neutrality, but energy production is unlikely.

Overall score: +

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[67].

Scored ++, +, +-, - or --.

There is focus on recovery of nutrients and of a small amount of biogas energy of one stream (black water). It is a mid-tech system. There seems to be some consideration for the trade-off, as there is a conscious decision not to heat the ABR in the reference project of Drielanden, Groningen (Gemeente Groningen, 2014).

Overall score: +

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

An ABR is simple to build and simple to operate and run by professionals or experienced residents community-on-site (Spuhler, 2016b). Moreover, the Imhoff tank and willow filter and community-on-site secondary compost heap are operated by experienced residents or professionals with sufficient know-how

Overall score: +

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an

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[66] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.
[67] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

attractive treatment facility that mimics nature[68] for recreation or landscape purposes, are allocated and accessible to the communities the waste (water) originates from.

Scored ++, +, +-, - or --.

Biogas is produced in small quantities so can only be efficiently used on site. It can be used by the community to powers local biogas street lights. Savings from direct heat recovery in showers are allocated to the households where they are installed directly by default. The willow filter looks attractive and biomass can be used or sold by the community as they own the constructed wetland. Compost from the secondary compost heap can also most efficiently be used locally.

Overall score: ++

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

There is no extra handling for individual households, however collectively they are responsible for maintaining the system or hiring someone to do this. Also, the use of harsh chemicals that may interfere with composting should be avoided by residents, which represents a minor lifestyle change.

Overall score: ++

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

The technology does not introduce radically different technology, compared to conventional, in the homes of residents. It is also simple to build and operate and has been applied commercially so has been optimized.

Overall score: ++

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

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[68] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

The ABR requires a constant amount of wastewater to operate, which should not be a problem as 62 homes will be connected. It has a high resistance to the variability of several parameters, such as hydraulic and organic shock loading, temperature change, pH or chemical composition of the influent (Spuhler, 2016b, Tilley et al., 2008).

Well designed and maintained willow constructed wetland are robust, however they do have less treatment capacity in winter due to colder temperatures (Tilley et al., 2008).

As there are no hi tech components, the system has a low malfunction rate and low sensitivity for failure.

Overall score: +

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

According to STOWA (2016c) the willow filter and community-on-site secondary compost heap provide the same public health security as the conventional centralized sewage system. Under normal operating conditions users do not come into contact with the influent or effluent of the ABR (Spuhler, 2016b)

The willow constructed wetland is also closed off so no contact with influent is ensured.

Overall score: ++

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). The intention is to use the organic fertilizer of the secondary compost heap locally to improve soils and to decrease transportation. However, the organic matter that has been turned into biogas is not available for soil improvement. Moreover, the nutrients that go to the effluent of the ABR are not available for increasing soil fertility, they are instead used to 'produce' biomass.

Overall score: +

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

In the reference project of Drielanden, Groningen the community, municipality and water board work together to make the pilot a success (Waterschap Noorderzijlvest, 2016). This will be needed because there have been no applications of an ABR anywhere in The Netherlands (Telkamp, 2016).

In The Netherlands many projects have been realized and even though involvement of all stakeholders is needed for the somewhat novel implementation of a Willow filter, an overly cautious government is not to be expected due to experience at the Biesbosch museum and solid research on design parameters (Global Wetlands, 2016, Otte and Boosten, 2014).

As users do need to be cautious with the use of harsh chemicals and micropollutants that may influence the ABR performance or quality of the compost from the secondary composting, they do need to be involved in the project.

Overall score: ++

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

Having a separate greywater and black water sewer already opens up the opportunity for a lot of technological improvements in the future. The economic lifespan of an septic tank, which is comparable to an ABR in construction, is often taken to be 25 years, depending on many variables, but likely to be longer (Verleun et al., 2103). The technical lifetime of a Willow constructed wetland is 20 to 25 years (Otte and Boosten, 2014). Both life spans are lower than the conventional technology with sewer pipes of a technical lifetime of 60 years (Oosterom and Hermans, 2013). Therefore the stepping stone technology concept is a reasonably flexible platform, it allows for upgrading, innovation or replacement within a relatively short time span (Spiller et al., 2015).

Overall score: +

#22 Investment in flexible platform technology today has a good return on investment[69].

Scored ++, +, +-, - or --.

STOWA (2016c) evaluates the secondary compost heap and willow filter as cost neutral compared to centralized treatment, but a regular septic tank (an ABR is not scored) as somewhat more expensive. However all three technologies score very positive on environmental profits, as this ABR does not discharges its effluent on the surface water, but instead on the Imhoff tank and willow filter.

Overall score: +

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

[69] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

This stepping stone technology scores reasonably positive with the four sustainability principles of TNS. However, changing the system before the end of the technical lifespan is possible as it does not take huge amounts of resources to make the system.

Overall score: +-

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

Scored ++, +, +-, - or --.

Solution is not BAU.

Overall score: ++

Annex 14: Calculations and explanations on scoring indicators Stepping Stone Technology 5: Urine separation systems, in rural case Exel

The calculations and scoring are only including the part of the SST that is able to be implemented right now. So it does not consider the future connection of second floor in-house sewage system to separate yellow, brown and greywater pipes, and hence recovery percentages are currently lower than their full potential. Moreover, the connection of these second floor toilets to the conventional combined yellow, brown and greywater system is not scored in terms of robustness and recovery of nutrients by such a centralized system.

#2 Phosphorous

TABLE 69: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
18.5%	Average of P recovery percentage in Willows in vertical flow constructed wetland from two studies, 14% and 23% were found (Otte and Boosten, 2014)

TABLE 70: CALCULATION TO FIND PERCENTAGE P RECOVERED

	Total P (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	54.31	0.438	23.8
In faeces	33.95	0.438	14.9
In greywater	27.16	0.185	5.0
In kitchen refuse	13.58	0.487	6.6
Total P all streams	129	-	50.3
Percentage of total recovery	-	-	39.0%

Additional assumptions:

- The Imhoff tank and septic tank do not significantly remove nutrients and nutrient removal in the incinerated sludge is therefore assumed to be negligible.

#3 Nitrogen

TABLE 71: INFORMATION USED TO MAKE CALCULATION

43	Embedded energy for production N the Haber Bosch process [kJ g-1] (Rittmann, 2013)
970.84	Total N input excluding drinking water N input from MFA baseline nutrients [kg y-1 Exel inhabitants-1]
41,746,120	Energy needed for total input production N [kJ y-1]
362.8	Recovered N of input (total recovery percentage from table 72: calculation to find percentage kj saved trough n recoverymultiplied by Total N input from this table) [kg y-1 Exel inhabitants-1]
15,601,802	Energy needed to produce recovered N in Haber Bosch (N recovered multiplied by embedded energy multiplied by 1000) [kJ y-1]
0.7	Transport energy conventional wastewater system in The Netherlands [Pj y-1] (Blom et al., 2010)
7,190,543.0	Number of Dutch households in 2007 (Blom et al., 2010)
97,350,1	Transport energy wastewater per Household [kJ.y-1.household]
62	Number of households in Exel
6,035,705.5	Transport energy from collection point to all Technologies in SST4 for all Exel inhabitants [kJ.y-1.Excel inhabitants]
87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
37.5	Average of N recovery percentage in Willows in vertical flow constructed wetland from two studies, 32% and 43% were found (Otte and Boosten, 2014)
55%	Loss N due to volatilization as ammonia (reactive N) in composting process (Anand and Apul, 2014)

TABLE 72: CALCULATION TO FIND PERCENTAGE KJ SAVED TROUGH N RECOVERY

	Total N (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	611.01	0.438	267.6
In faeces	122.2	0.438	53.5
In greywater	122.22	0.375	45.8
In kitchen refuse	115.41	0.487	56.2
Total N all streams	970.84	-	423.2
Total N volatilization in faeces and kitchen refuse composting			60.4
Percentage of total recovery	-	-	37.4%
Energy saved	-	-	9,566,096 [kJ y-1]
Percentage kJ saved	-	-	22.9%

Additional assumptions:

- The transport energy for pumping wastewater, effluent en sludge streams between the collection point and technologies is assumed to be equal to the pumping energy in a centralized wastewater treatment scheme (see SST1).

#4 Potassium

TABLE 73: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in separate grey and black water sewage (assuming two toilets per house of which only ground floor toilet is replaced and connected to separate pipes and second floor toilet is conventional. Both toilets are used 50% of the time).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
14%	K recovery percentage in Willows in 'no discharge' constructed wetland in one study is 28%, assumed this is too high so took half this number (Otte and Boosten, 2014)

TABLE 74: CALCULATION TO FIND PERCENTAGE K RECOVERED

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	190.09	0.438	83.3
In faeces	61.1	0.438	26.8
In greywater	54.35	0.14	7.6
In kitchen refuse	13.58	0.487	6.6
Total K all streams	319.12	-	124.2
Percentage of total recovery	-	-	38.9%

Additional assumptions:

- The Imhoff tank and septic tank do not significantly remove nutrients and nutrient removal in the incinerated sludge is therefore assumed to be negligible.

#6 Organic Matter

TABLE 75: INFORMATION USED TO MAKE CALCULATION

87.5%	Houses with crawl space (Harder, 2012)
43.75%	Percentage of total excreted urine and faeces collected in composting toilet (assuming two toilets per house of which only ground floor toilet is a composting toilet and second floor toilet is conventional. Both toilets are used 50% of the time).

48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
80%	Loss OM due to mineralization to CO_2 in composting process or septic tank (Anand and Apul, 2014, Cornell Waste Management Institute, 2016)
37.5%	Organic matter to sludge in the Imhoff tank (Stauffer and Spuhler, 2016)

TABLE 76: CALCULATION TO FIND PERCENTAGE OM RECOVERED

	Total OM (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	746.79	0.438	327.1
In faeces + toilet paper	4,278.00	0.438	1,873.8
In greywater	3,530.3	0.000	0.0
In kitchen refuse	4,005.51	0.487	1,950.7
Total OM all streams	12,560.6	-	4,151.5
Total OM volatilization in faeces and kitchen refuse composting			3,059.6
Percentage of total recovery	-	-	8.7%

Additional assumption:

- If the C:N ratio is correct, the composting chamber is operating well and a bulking agent with a low biodegradability, such as sawdust is applied, less mineralization of organic matter will occur than assumed in this calculation (Anand and Apul, 2014)

#7 Nutrient/resource input[70] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: +-

Fewer materials needed to make the system compared to the centralized system currently in place. However, there is a fair amount o f piping and pumps needed to source separate each stream and to move streams between treatment technologies.

Chemicals: ++

No chemicals are added to run the processes.

[70] Materials and chemicals (not energy).

Overall score: +

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[71].

Scored ++, +, +-, - or -- [72].

Secondary compost heap: +

Closed system: No untreated residual waste exits (SuSanA, 2009b). There are emission of short cycle carbon dioxide, ammonia, volatile compounds and water in the composting process (Anand and Apul, 2014).

Urine storage: +

There is no effluent or residual waste from the urine storage technology, all urine is used as liquid organic fertilizer.

Imhoff tank and willow filter: +-

Effluent willow filter complies with current Dutch standards (Otte and Boosten, 2014), but it does not remove high levels of metals or micropollutants. The small amount of sludge from the Imhoff tank is polluted so it has to be incinerated.

Septic tank: +

No by-products are entering the ecosystem, but instead are led to other technologies to further purify.

Overall score: +

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[73].

Scored ++, +, +-, - or --.

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[71] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.

[72] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

[73] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

There are no unwanted by-products from treatment as no chemicals are added.

Metals present in faeces and urine are almost completely traceable to the food consumed. Hence it can be argued that these are safe levels for reuse (Tervahauta, 2014).

Reduction of micropollutants in recovered compost is possible by introduction some lifestyle changes of users. They can avoid using pharmaceuticals and personal care and household products with non-biodegradable components. Moreover, when this is not possible, they can use a urine bag during the time of medicine use which will be disposed with the solid waste and incinerated instead of composted.

Aside from micropollutants and metals that may be present in organic liquid fertilizer from urine it is a clean resource. By current Dutch standards it is probably acceptable, as metal content in urine is very low (Schönning, 2001) and no standards for micropollutants exist yet.

Willow filters are capable of removing metals to a high degree and storing them in the woody biomass. In the soil some biodegradable micropollutants are likely to be converted to less harmful substances, comparable to a constructed wetlands (Otte and Boosten, 2014, Zhang et al., 2013a).

Overall score: +-

#10 Direct heat recovery

TABLE 77: INFORMATION TO MAKE CALCULATION AND CALCULATION TO FIND PERCENTAGE DIRECT HEAT RECOVERED WITH SHOWER HEAT EXCHANGER

2.5	Average renovations of bathroom per year (lifetime bathroom 25 years according to Huur Commissie (2011)
3	Average number of inhabitants per home in Exel
62	Number of households in Exel
1.9	Savings per person per year by using shower heat exchange [Gj p-1 y-1] (Blom et al., 2010)
14.1	Savings for cluster of Exel per year using shower heat exchange [Gj Excel inhabitants-1 y-1]
33.41	Average energy contents natural gas Dutch situation [MJ m3-1] (Blom et al., 2010)
1,400	Natural gas use average Dutch household [m3 y-1] (Milieu Centraal, 2016b)
2,899,988	Natural gas in MJ use for total Exel [MJ Exel total-1 y-1]
2,900	Gj natural gas for total Exel [Gj Exel total-1 y-1]
0.5%	Savings on total natural gas use by implementing shower heat exchangers

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[74].

[74] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.

Scored ++, +, +-, - or -- [75].

There is no renewable energy generation in the human waste treatment; however, there is hardly any energy input either. The willow filter has a positive energy ratio (Otte and Boosten, 2014, SuSanA, 2009b) and the septic tank, urine storage and secondary compost heap use less energy than the embedded energy in the nitrogen recovered (see criterion #3).

Overall score: +-

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[76].

Scored ++, +, +-, - or --.

In this mid-tech system the focus lies on high resource and energy efficiency, not on energy production. The goal is to keep water clean so it does not have to be purified ('t Natuurlijk Huus, 2016).

Overall score: +

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

House-on-site urine storage and reuse is managed by residents themselves. The septic tanks are managed by a cluster of connected home owners and are simple to operate (Spuhler, 2016c).The Imhoff tank and willow filter and community-on-site secondary compost heap are operated by experienced residents with sufficient know-how

Overall score: ++

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[77] for recreation or landscape

[75] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.

[76] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

[77] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

purposes, are allocated and accessible to the communities the waste (water) originates from.

Scored ++, +, +-, - or --.

Organic fertilizer from the secondary compost heap and urine storage is used locally. Savings from direct heat recovery in showers are allocated to the households where they are installed directly by default. The willow filter looks attractive and biomass can be used or sold by the community as they own the constructed wetland. Compost from the secondary compost heap can also most efficiently be used locally.

Overall score: ++

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

There is education needed to properly use the no-mix toilets. Once users are familiar with the process there should be no problem and high acceptance is to be expected (Lienert and Larsen, 2009).

Overall score: +

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

There is some handling of the urine involved (for use after storage) although this can be outsourced.

There can be bad smell from the urine storage container when opened to apply as liquid organic fertilizer. The score of the effects review of STOWA (2016c) indicated the effect on comfort for users of the urine storage and reuse as local liquid fertilizer is positive and the use of an improved septic tank is neutral compared to the centralized system. Collectively users are responsible for maintaining the system or hiring someone to do this. Lastly, the use of harsh chemicals that may interfere with composting should be avoided by residents, which represents a minor lifestyle change.

Overall score: +

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

The septic tank is proven technology, but the no-mix toilets and urine storage are quite new to The Netherlands so may require some adjustment period and can have higher malfunction than regular toilets.

With the urine storage and secondary compost heap are flexible in dealing with high loading rates and under loading is not a problem. The willow filter needs to be dimensioned for low temperatures and thus not too small, but under loading is unlikely to be a problem (Tilley et al., 2008).

As there are no hi tech components, the system has a low malfunction rate and low sensitivity for failure. Knowledge in each household about urine storage is however important.

Overall score: +

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

According to STOWA (2016c) the improved septic tank, urine storage and willow filter provide the same public health security as the conventional centralized sewage system.

Overall score: +

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). The intention is to use the organic fertilizer locally to improve soils and to decrease transportation. However, the nutrients that go to the effluent of the septic tank are not available for increasing soil fertility, they are instead used to ‘produce’ biomass.

Overall score: +

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

In the reference project of ‘t Natuurlijk Huus in Raalte, the system is copied from a project in Africa and the water board was involved in the project. Moreover, there is active communication to ensure no-mix toilets are used well by visitors and this is not creating problems ('t Natuurlijk Huus, 2016). So now the meeting facility and camping will also be connected (STOWA, 2016c).

Overall score: +

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

Having no-mix toilets with separate sewers already opens up for a lot of technological improvements in the future. The lifespan of a septic tank can be 20 to 40 years, depending on many variables. If it does last 40 years, there is less flexibility to implement improved technology.

Having a source-separated greywater, yellow and brown water sewer already opens up the opportunity for a lot of technological improvements in the future. The economic lifespan of an septic tank, is often taken to be 25 years, depending on many variables, but likely to be longer (Verleun et al., 2103). The technical lifetime of a Willow constructed wetland is 20 to 25 years (Otte and Boosten, 2014). Both life spans are lower than the conventional technology with sewer pipes of a technical lifetime of 60 years (Oosterom and Hermans, 2013). Therefore the stepping stone technology concept is a reasonably flexible platform, it allows for upgrading, innovation or replacement within a relatively short time span (Spiller et al., 2015).

Overall score: +

#22 Investment in flexible platform technology today has a good return on investment[78].

Scored ++, +, +-, - or --.

STOWA (2016c) evaluates the secondary compost heap and willow filter as cost neutral compared to centralized treatment, but a regular septic tank and urine storage as somewhat more expensive. However all three technologies score very positive on environmental profits, as this improved septic tank does not discharges its effluent on the surface water, but instead on the Imhoff tank and willow filter.

Overall score: ++

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

This stepping stone technology fits reasonably well with the four sustainability principles of TNS, however there is some room for improvement. Changing the system before the end of the technical lifespan is possible as it does not take huge amounts of resources to make the system.

Overall score: +-

[78] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

Scored ++, +, +-, - or --.

Solution is not BAU.

Overall score: ++

Annex 15: Calculations and explanations on scoring indicators Stepping Stone Technology 1: Centralized treatment with energy and nutrient reuse, urban case Centrumeiland IJburg

#2 Phosphorous

TABLE 78: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
100%	Percentage of P in incinerated sludge recovered (Ecophos, 2016).
7	Concentration P in influent Dutch wastewater treatment facilities mg/L (CBS, 2016c).
1	Concentration P in effluent Dutch wastewater treatment facilities mg/L (CBS, 2016c).
85.7%	Average treatment efficiency in Dutch wastewater treatment facilities (percentage of P in sewage that is present in sludge).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

TABLE 79: CALCULATION TO FIND PERCENTAGE P RECOVERED

	Total P (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	158.56	0.857	135.9
In faeces	99.1	0.857	84.9
In greywater	79.28	0.857	67.9
In kitchen refuse	39.64	0.487	19.3
Total P all streams	376.58	-	308.1
Percentage of total recovery	-	-	81.8%

Additional assumptions:

- All wastewater treatment sludge is incinerated in dedicated wastewater treatment sludge incinerators and ash is subsequently transported to the Ecophos plant for P recovery.
- No losses of sewage occur in sewage pipes between the house and wastewater treatment facility.

#3 Nitrogen

As the conventional centralized wastewater system removes nitrogen with high energy requirement for aeration and does not recover any nitrogen and only the kitchen refuse is composted with some nitrogen recovery, the energy saved by nitrogen recovery is set to zero.

#4 Potassium

TABLE 80: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
0%	Percentage of K in incinerated sludge recovered.
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

Table 81: Calculation to find percentage K recovered

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	554.95	0.000	0.0
In faeces	178.38	0.000	0.0
In greywater	158.68	0.000	0.0
In kitchen refuse	39.64	0.487	19.3
Total K all streams	931.65	-	19.3
Percentage of total recovery	-	-	2.1%

Additional assumptions:

- No losses of sewage occur in sewage pipes between the house and wastewater treatment facility.

#5 Cellulose

Table 82: Information used to make calculation

100%	Percentage of urine and faeces that flows to SST.
84%	Percentage of organic matter in fine sieve mass (mesh size 350 micro meter) that is cellulose (Ghasimi, 2016).
50%	Percentage removal of suspended solids of influent WWT by 350 micro meter mesh sieve (Ghasimi, 2016).

Table 83: Calculation to find percentage K recovered

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
Total K all streams	2,579.25	0.420	1,083.3
Percentage of total recovery	-	-	42.0%

#6 Organic Matter

TABLE 84: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
16	[pJ.y-1] Organic matter as chemical energy discharged by Dutch households and Industry into centralized sewage system (Blom et al., 2010)
2,4	[pJ.y-1] Organic matter from sludge transformed into biogas (Blom et al., 2010).
15.00%	Percentage of organic matter in Dutch wastewater treatment system influent transformed to biogas.
80%	Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

TABLE 85: CALCULATION TO FIND PERCENTAGE OM RECOVERED

	Total OM (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	2,180.15	0.150	327.0
In faeces + toilet paper not sieved out	11,199.38	0.150	1,679.9
In greywater	10,900.95	0.150	1,635.1
In kitchen refuse	11,693.51	0.487	5,694.7
Total OM all streams	35,973.99	-	9,336.8
Total OM volatilization in kitchen refuse composting			4,555.8
Percentage of total recovery	-	-	13.3%

Additional assumption:

- Recovered cellulose is used to thicken/dry sludge and it not co-digested in the anaerobic sludge digestion to recovery biogas.

#7 Nutrient/resource input[79] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: --

[79] Materials and chemicals (not energy).

The long sewage pipelines from all homes in urban areas to a centralized wastewater treatment plant including pumps and the large treatment capacity needed to treat much diluted wastewater require a lot of materials to construct.

Chemicals: -

There may be chemicals added to remove or recovery phosphorous.

Overall score: --

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[80].

Scored ++, +, +-, - or -- [81].

Kitchen refuse centralized composting: +

Closed system: No untreated residual waste exits (SuSanA, 2009b). There are emission of short cycle carbon dioxide, ammonia, volatile compounds and water in the composting process (Anand and Apul, 2014).

Centralized treatment: +-

In the case of extreme rain fall during storm events, the overflow capacity of centralized wastewater treatment facilities is exceeded and wastewater is discharged untreated onto surface water. During normal operations all effluent of centralized wastewater complies with current Dutch standards (Baltussen, 2015).

Overall score: +-

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[82].

Scored ++, +, +-, - or --.

Chemical by-products: -

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[80] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.

[81] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

[82] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

There may be unwanted by-products from treatment from the added chemicals for phosphorous removal or recovery.

Struvite: +

The recovered phosphorous from struvite is to a high degree free of micropollutants and metals (Rondeltrap et al., 2007). The recovered phosphorous from incinerated sludge ash, which was incinerated at a dedicated sludge incineration facility, is free from all harmful substances (Ecophos, 2016).

Biogas: ++

Biogas is free or harmful substances.

Cellulose: not scored

Recovered cellulose is applied to thicken sludge and hence is incinerated together with the remaining sludge. As cellulose is therefore not the end product and metals and micropollutants do not come into contact with the natural environment or humans, they are not scored in this criterion.

Overall score: +-

#10 Direct heat recovery

No heat recovery technologies are implemented.

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[83].

Scored ++, +, +-, - or -- [84].

Energy input is high. Biogas is produced, but it is less than the energy needed for the sewage system (Blom et al., 2010).

Overall score: +-

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[85].

Scored ++, +, +-, - or --.

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[83] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.
[84] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.
[85] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

In this hi-tech system the focus lies on nutrient and organic matter removal and not on energy production. There is a trade-off between struvite production and phosphorous recovery from incinerated sludge. Incinerating sludge generates energy and makes it possible to recovery phosphorous from ashes, which means a preceding treatment step of struvite recovery is redundant.

Overall score: -

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

The centralized wastewater transport and treatment system is hi-tech and needs to be built and run by professionals (Spuhler, 2016a).

Overall score: --

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[86] for recreation or landscape purposes, are allocated and accessible to the communities the waste (water) originates from.

Scored ++, +, +-, - or --.

Centralized treatment in wastewater treatment facilities and sludge incineration in a specialized and dedicated sludge incineration plant and phosphorous recovery in an even more specialized sludge ash recovery facility means the distances between the location where nutrients are recovered and the location where the nutrients originate (the households) are very large. SST1 is not adapted for use in small communities (Spuhler, 2016a).

Overall score: --

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

Nothing changes for the user compared to the current system which requires no handling or monitoring by the user.

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[86] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

Overall score: ++

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

Nothing changes for the user compared to the current system which is perceived to have high convenience.

Overall score: ++

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

The treatment technology can handle high organic and hydraulic shock loads (Spuhler, 2016a). The sewage system is mostly gravity driven so no hi tech components can cause malfunction. The wastewater treatment facility relies upon hi tech components and monitoring which can fail temporarily (Spuhler, 2016a).

Overall score: ++

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

The current centralized wastewater treatment and collection system has been designed to optimize public health.

Overall score: ++

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). However, organic matter is used for biological treatment of wastewater and the organic matter remaining is mostly caught in sludge which may be used to generate biogas or is incinerated directly (Spuhler, 2016a). Therefore there is no organic matter available to increase soil fertility, especially not at the point where the human waste is produced.

Overall score: --

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

The centralized wastewater system is flush-and-forget (Harder, 2012) and is run by professionals (Spuhler, 2016a). Hence there is no involvement of stakeholders.

Overall score: --

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

The transportation system, the gravity sewage pipes, has an average lifetime of 60 years (Oosterom and Hermans, 2013). Hence it is not a flexible platform.

Overall score: --

#22 Investment in flexible platform technology today has a good return on investment[87].

Scored ++, +, +-, - or --.

The centralized wastewater treatment and collection system has high construction and maintenance costs, as well as high energy requirements (Spuhler, 2016a) and low environmental benefits in terms of resources recovered.

Overall score: -

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

There is considerable doubt that the investment in this system is complying with the four sustainability principles of TNS (Harder, 2012) and the system requires large amounts of resources (Spuhler, 2016a).

Overall score: -

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

[87] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

Scored ++, +, +-, - or --.

Solution is a variation on BAU.

Overall score: -

Annex 16: Calculations and explanations on scoring indicators Stepping Stone Technology 2: Vacuum system for black water, urban case Centrumeiland IJburg

#2 Phosphorous

TABLE 86: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
100%	Percentage of P in incinerated sludge recovered (Ecophos, 2016).
53.0%	Percentage of total P in SST2 (underloaded) recovered by total system (De Graaf and Van Hell, 2014).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
1.7	[mg L-1] effluent concentration possible in fully loaded system (De Graaf and Van Hell, 2014).
13.51	[mg L-1] effluent concentration measured in underloaded system (De Graaf and Van Hell, 2014).
93.3%	Percentage of total P in SST2 (fully loaded) recovered by total system.

TABLE 87: CALCULATION TO FIND PERCENTAGE P RECOVERED

	Total P (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	158.56	93.3%	148.0
In faeces	99.1	93.3%	92.5
In greywater	79.28	93.3%	74.0
In kitchen refuse	39.64	45.5%	18.0
Total P all streams	376.58	-	332.5
Percentage of total recovery	-	-	88.3%

Additional assumptions:

- There is probably higher phosphate recovery possible, as the reference project phosphate recovery percentages have been measured in an under loaded system, however as no data of the system with a normal load is available the data of the under loaded system is used (De Graaf and Van Hell, 2014).

#3 Nitrogen

As the focus lies on removal and not on recovery of nitrogen, it is assumed that this decentralized wastewater system removes nitrogen at a higher energy than the embedded energy of the nitrogen *recovery from struvite and UASB sludge (N production with the Haber Bosch process) the energy saved by nitrogen recovery is set to zero.*

#4 Potassium

TABLE 88: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
0%	Percentage of K in incinerated sludge recovered.
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
9%	Percentage of N to UASB sludge (remainder to effluent) (De Graaff et al., 2010)

TABLE 89: CALCULATION TO FIND PERCENTAGE K RECOVERED

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	554.95	0.09	49.9
In faeces	178.38	0.09	16.1
In greywater	158.68	0.0	0.0
In kitchen refuse	39.64	0.044	1.7
Total K all streams	931.65	-	67.7
Percentage of total recovery	-	-	7.3%

Additional assumptions:

- It is assumed that Potassium behaves the same way as Nitrogen in the UASB reactor; hence the same percentage of K goes to sludge as N.

#6 Organic Matter

TABLE 90: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
78.0%	Percentage organic matter in black water system of SST to biogas (De Graaf and Van Hell, 2014).
7.0%	Percentage organic matter in black water system of SST to UASB sludge (De Graaf and Van Hell, 2014).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).
80%	Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016).

TABLE 91: CALCULATION TO FIND PERCENTAGE OM RECOVERED

	Total OM (source MFA nutrients baseline)	Theoretical recovery	Theoretical recovery
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	2,180.15	0.850	1,853.1
In faeces + toilet paper	9,909.75	0.850	10,615.7
In greywater	10,900.95	0.000	0.0
In kitchen refuse	11,693.51	0.414	4,840.5
Total OM all streams	34,684.36	-	17,309.3
Total OM volatilization in UASB sludge and kitchen refuse composting			1,140.4
Percentage of total recovery	-	-	43.4%

Additional assumption:

- The sludge production of the AB process is minimal so has been assumed to be zero (De Graaf and Van Hell, 2014).
- No organic matter caught in struvite crystals.

#7 Nutrient/resource input[88] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: -

The hi tech system is quite material intensive as a large number of technologies are operating at a relatively small scale (De Graaf and Van Hell, 2014).

Chemicals: +

Magnesium is added to recover phosphorous as struvite (De Graaf and Van Hell, 2014).

Overall score: +-

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[89].

[88] Materials and chemicals (not energy).

Scored ++, +, +-, - or -- [90].

The deposits/effluents from the system are from the AB process and effluent from the entire system. The effluent complies with current Dutch standards and the sludge from the AB process originates party in greywater so is polluted with metals and micropollutants to a high degree and needs to be incinerated. However, it does not enter the ecosystem.

Overall score: +-

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[91].

Scored ++, +, +-, - or --.

There are no unwanted by-products from treatment as no chemicals are added.

Struvite: +

The recovered phosphorous from struvite is to a high degree free of micropollutants and metals (Rondeltrap et al., 2007). The recovered phosphorous from incinerated sludge ash, which was incinerated at a dedicated sludge incineration facility, is free from all harmful substances (Ecophos, 2016).

Biogas and residual heat: ++

Biogas and residual heat are resources free of harmful substances.

Sludge from UASB: +-

Metals present in faeces and urine are almost completely traceable to the food consumed. Hence it can be argued that these are safe levels for reuse (Tervahauta, 2014).

Reduction of micropollutants in recovered compost is possible by introduction some lifestyle changes of users. They can avoid using pharmaceuticals and personal care and household products with non-biodegradable components. Moreover, when this is not possible, they can use a urine bag during the time of medicine use which will be disposed with the solid waste and incinerated instead of composted.

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[89] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.

[90] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

[91] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

Overall score: +

#10 Direct heat recovery

TABLE 92: INFORMATION TO MAKE CALCULATION AND CALCULATION TO FIND PERCENTAGE DIRECT HEAT RECOVERED WITH SHOWER HEAT EXCHANGER

12.0	Average renovations of bathroom per year (lifetime bathroom 25 years according to Huur Commissie (2011)
1.81	Average number of inhabitants per home in Centrumeiland IJburg
300	Number of households in Centrumeiland IJburg
1.9	Savings per person per year by using shower heat exchange [Gj p-1 y-1] (Blom et al., 2010)
41.3	Savings for apartment complex Centrumeiland IJburg per year using shower heat exchange [Gj Excel inhabitants-1 y-1]
33.41	Average energy contents natural gas Dutch situation [MJ m3-1] (Blom et al., 2010)
1,400	Natural gas use average Dutch household [m3 y-1] (Milieu Centraal, 2016b)
14,032,200	Natural gas in MJ use for total Centrumeiland IJburg [MJ Exel total-1 y-1]
14,032	Gj natural gas for total Centrumeiland IJburg [Gj Exel total-1 y-1]
0.3%	Savings on total natural gas use by implementing shower heat exchangers.
264	kWh per inhabitant per year electricity costs for the heat pump (De Graaf and Van Hell, 2014).
477	kWh per inhabitant per year electricity gain in the form of heat from greywater (De Graaf and Van Hell, 2014).
213	kWh net per inhabitant per year electricity gain in the form of heat from greywater
543	Number of inhabitants in Centrumeiland IJburg.
115,659	kWh net per total apartment complex per year electricity gain in the form of heat from greywater.
416.37	Gj net per total apartment complex per year electricity gain in the form of heat from greywater.
3.0%	Savings by implementing greywater indirect heat recovery.
3.3%	Savings by implementing both shower heat exchange and greywater heat recovery

Additional assumptions:

- A heat network is already in place that can efficiently use the recovered heat.

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[92].

[92] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.

Scored ++, +, +-, - or -- [93].

A rough life cycle analysis shows that an optimized version of the reference project Waterschoon in Sneek scores very positive compared the centralized system currently in place when looking at CO_2 emissions and depletion of fossil fuels.

Overall score: ++

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[94].

Scored ++, +, +-, - or --.

The goals of the reference project Waterschoon in Sneek was maximum recovery of energy and phosphorous and minimizing the use of drinking water (De Graaf and Van Hell, 2014). It can be concluded that the trade-off was given consideration.

Overall score: ++

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

This stepping stone technology comprises of several hi tech components that require professionals to run and maintain the system.

Overall score: --

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[95] for recreation or landscape purposes, are allocated and accessible to the communities the waste (water) originates from.

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[93] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.

[94] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

[95] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

Scored ++, +, +-, - or --.

Direct heat, biogas and UASB sludge need to be reused locally because transporting them will not be energy efficient. Struvite may be transported for longer distances as it does not contain water it is more energy efficient to transport out of the city by truck.

Overall score: +

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

The sustainability evaluation of the reference project Waterschoon in Sneek shows that the system may cause some inconvenience to users. However, besides the adjustment in the deposition of kitchen refuse in the grinder and the operation of the vacuum toilet, not much changes for the users in their daily routine (De Graaf and Van Hell, 2014). Other research on several other comparable projects shows that this inconvenience may be remediated by a better vacuum toilet and piping design (Van den Bulk and Telkamp, 2008).

Overall score: +

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

The sustainability evaluation of the reference project Waterschoon in Sneek shows that the system may cause some noise hindrance and service quality concerns (De Graaf and Van Hell, 2014). Other research on several other comparable projects shows that this inconvenience may be remediated by a better vacuum toilet and piping design (Van den Bulk and Telkamp, 2008).

Overall score: +

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

The reference project Waterschoon in Sneek is considered fairly robust. In the three monitoring years hardly any failures took place, except for a few malfunctions of the vacuum system and a start up problem with the kitchen grinders.

Overall score: +

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

Users are not in contact with pathogens or harmful substances, as these are transported away from homes by vacuum piping and treated in the hi tech community-on-site treatment facility.

Overall score: ++

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). Organic matter is used to make biogas, which does not increase soil fertility. Struvite can be transported over long distances so does not necessarily end up on local soils. UASB sludge can be used for increasing local soil fertility though, although the quantity of organic matter is reduced by biogas production.

Overall score: +-

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

As the implementation of this stepping stone technology was very new in the realization of the reference project Waterschoon in Sneek, all parties were actively involved in developing and realizing the system (De Graaf and Van Hell, 2014).

Overall score: +

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

The longest lifespan of elements of the stepping stone technology is 30 years, except for the sewage pipes outside, those will last for 50 years. This means that the system is fairly flexible, as there is source separation new innovative techniques for treatment can be implemented in 30 years, instead of the 60 years lifespan of conventional combined wastewater sewage pipes.

Overall score: +-

#22 Investment in flexible platform technology today has a good return on investment[96].

Scored ++, +, +-, - or --.

The economic financial analysis shows that at the current scale of the reference project Waterschoon in Sneek the costs are 11% higher than the conventional centralized wastewater treatment system. However at 2400 inhabitants the costs would be equal. Environmentally, the sustainability evaluation of the reference project shows the decentralized solution scores equal to the centralized solution (De Graaf and Van Hell, 2014).

Overall score: +-

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

The amount of resources needed to make this hi tech system is considerable, although the lifespan is lower than that of the conventional system. It does however score fairly well with the four sustainability principles of TNS.

Overall score: +

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

Scored ++, +, +-, - or --.

Solution is not BAU.

Overall score: ++

[96] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

Annex 17: Calculations and explanations on scoring indicators Stepping Stone Technology 5: Urine separation systems, urban case Centrumeiland IJburg

#2 Phosphorous

Table 93: Information used to make calculation

100%	Percentage of urine and faeces that flows to SST.
100%	Percentage of P in incinerated sludge recovered (Ecophos, 2016).
95%	Percentage of total P in urine removed in struvite reactor (Kabdasli et al., 2013).
7	Concentration P in influent Dutch wastewater treatment facilities mg/L (CBS, 2016c).
1	Concentration P in effluent Dutch wastewater treatment facilities mg/L (CBS, 2016c).
85.7%	Average treatment efficiency in Dutch wastewater treatment facilities (percentage of P in sewage that is present in sludge).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

Table 94: Calculation to find percentage P recovered

	Total P (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Exel inhabitants-1]	*[fraction]*	*[kg y-1 Exel inhabitants-1]*
In urine	158.56	0,950	150.6
In faeces	99.1	0.857	84.9
In greywater	79.28	0.857	67.9
In kitchen refuse	13.58	0.487	19.3
Total P all streams	350.52	-	322.8
Percentage of total recovery	-	-	85.7%

Additional assumptions:

- All wastewater treatment sludge is incinerated in dedicated wastewater treatment sludge incinerators and ash is subsequently transported to the Ecophos plant for P recovery.
- No losses of sewage occur in sewage pipes between the house and wastewater treatment facility.

#3 Nitrogen

As the conventional centralized wastewater system removes nitrogen with high energy requirement for aeration and does not recover any nitrogen and recovery of N is only accomplished through the composting of kitchen refuse and air stripping of urine with a relatively high energy demand *compared to centralized treatment (Siegrist et al., 2013), the energy saved by nitrogen recovery is set to zero .*

#4 Potassium

TABLE 95: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
0%	Percentage of K in incinerated sludge recovered.
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

TABLE 96: CALCULATION TO FIND PERCENTAGE K RECOVERED

	Total K (source MFA nutrients baseline)	**Theoretical recovery**	**Theoretical recovery**
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	554.95	0.000	0.0
In faeces	178.38	0.000	0.0
In greywater	158.68	0.000	0.0
In kitchen refuse	39.64	0.487	19.3
Total K all streams	931.65	-	19.3
Percentage of total recovery	-	-	2,1%

Additional assumptions:

- Capture of potassium in struvite crystals is not significant and therefore not calculated. Ammonia air stripping does not remove potassium. So all potassium present in urine will be discharged into the conventional sewage system in the effluent of the community-on-site ammonium air stripping reactor.
- No losses of sewage occur in sewage pipes between the house and wastewater treatment facility.

#5 Cellulose

TABLE 97: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
84%	Percentage of organic matter in fine sieve mass (mesh size 350 micro meter) that is cellulose (Ghasimi, 2016).
50%	Percentage removal of suspended solids of influent WWT by 350 micro meter mesh sieve (Ghasimi, 2016).

TABLE 98: CALCULATION TO FIND PERCENTAGE K RECOVERED

	Total K	**Theoretical recovery**	**Theoretical recovery**

	(source MFA nutrients baseline)		
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
Total K all streams	2,579.25	0.420	1,083.3
Percentage of total recovery	-	-	42.0%

#6 Organic Matter

TABLE 99: INFORMATION USED TO MAKE CALCULATION

100%	Percentage of urine and faeces that flows to SST.
16	[pJ.y-1] Organic matter as chemical energy discharged by Dutch households and Industry into centralized sewage system (Blom et al., 2010)
2,4	[pJ.y-1] Organic matter from sludge transformed into biogas (Blom et al., 2010).
15.00%	Percentage of organic matter in Dutch wastewater treatment system influent transformed to biogas.
80%	Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016).
48.7%	Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)).

TABLE 100: CALCULATION TO FIND PERCENTAGE OM RECOVERED

	Total OM (source MFA nutrients baseline)	Theoretical recovery	Theoretical recovery
	[kg y-1 Excel inhabitants-1]	*[fraction]*	*[kg y-1 Excel inhabitants-1]*
In urine	2,180.15	0.150	327.0
In faeces + toilet paper not sieved out	11,199.38	0.150	1,679.9
In greywater	10,900.95	0.150	1,635.1
In kitchen refuse	11,693.51	0.487	5,694.7
Total OM all streams	35,973.99	-	9,336.8
Total OM volatilization in kitchen refuse composting			4,555.8
Percentage of total recovery	-	-	13.3%

Additional assumption:

- Capture of organic matter in struvite crystals is not significant and therefore not calculated. Ammonia air stripping does not remove organic matter. So all organic matter present in urine will be discharged into the conventional sewage system in the effluent of the community-on-site ammonium air stripping reactor.

#7 Nutrient/resource input[97] needed to operate the stepping stone technology/process for production of recovered nutrients/resources complies with four sustainability principles of TNS.

Scored ++, +, +-, - or --.

Materials: -

The long sewage pipelines from all homes in urban areas to a centralized wastewater treatment plant including pumps and the large treatment capacity needed to treat much diluted wastewater require a lot of materials to construct.

The struvite reactor and ammonium air stripper are additional technologies requiring additional materials to construct.

Chemicals: +

Magnesium is added to recover phosphorous as struvite (Kabdasli et al., 2013).

Overall score: +-

#8 Quality of effluent or residual waste from dry sanitation entering the watershed or (atmospheric/groundwater) ecosystem, by applicable governmental standards[98].

Scored ++, +, +-, - or -- [99].

Kitchen refuse centralized composting: +

Closed system: No untreated residual waste exits (SuSanA, 2009b). There are emission of short cycle carbon dioxide, ammonia, volatile compounds and water in the composting process (Anand and Apul, 2014).

Centralized treatment: +-

In the case of extreme rain fall during storm events, the overflow capacity of centralized wastewater treatment facilities is exceeded and wastewater is discharged untreated onto surface water. During normal operations all effluent of centralized wastewater complies with current Dutch standards (Baltussen, 2015).

Overall score: +-

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[97] Materials and chemicals (not energy).

[98] Please note, as micropollutants currently are not regulated in The Netherlands, their presence effluent or residual waste does not influence this indicator.

[99] Scored +- if it complies with (international) standards for such deposits on **all** pollution sources. The challenge is to score ++ which is a deposit that enhances the ecosystem due to its superior quality.

#9 Recovered nutrient is free of unnatural and persistent substances such as micropollutants (from pharmaceuticals, hormones and personal care and household products (Butkovskyi, 2015)) or unnatural amounts and types of metals (Tervahauta, 2014) or other unwanted by-products from treatment[100].

Scored ++, +, +-, - or --.

Chemical by-products: -

There may be unwanted by-products from treatment from the added chemicals for phosphorous removal or recovery.

Struvite: +

The recovered phosphorous from struvite is to a high degree free of micropollutants and metals (Rondeltrap et al., 2007). The recovered phosphorous from incinerated sludge ash, which was incinerated at a dedicated sludge incineration facility, is free from all harmful substances (Ecophos, 2016).

Biogas: ++

Biogas is free or harmful substances.

Cellulose: not scored

Recovered cellulose is applied to thicken sludge and hence is incinerated together with the remaining sludge. As cellulose is therefore not the end product and metals and micropollutants do not come into contact with the natural environment or humans, they are not scored in this criterion.

Overall score: +-

#10 Direct heat recovery

TABLE 101: INFORMATION TO MAKE CALCULATION AND CALCULATION TO FIND PERCENTAGE DIRECT HEAT RECOVERED WITH SHOWER HEAT EXCHANGER

12.0	Average renovations of bathroom per year (lifetime bathroom 25 years according to Huur Commissie (2011)
1.81	Average number of inhabitants per home in Centrumeiland IJburg
300	Number of households in Centrumeiland IJburg
1.9	Savings per person per year by using shower heat exchange [Gj p-1 y-1] (Blom et al., 2010)
41.3	Savings for apartment complex Centrumeiland IJburg per year using

[100] This is excluding recovery of micro pollutants and metals for reuse in a technical cycle because a recovery technology does not currently exist and the incentive for research and innovation in this field is very low due to very low quantities, especially on household or community scale.
High purity and low toxicity can be reached by avoiding the entering of micro pollutants and metals into the waste (water) stream by cultural and lifestyle changes. Such as the use of more ecological pharmaceuticals or cosmetics for example. See chapter 3 for information on lifestyle changes.

	shower heat exchange [Gj Excel inhabitants-1 y-1]
33.41	Average energy contents natural gas Dutch situation [MJ m3-1] (Blom et al., 2010)
1,400	Natural gas use average Dutch household [m3 y-1] (Milieu Centraal, 2016b)
14,032,200	Natural gas in MJ use for total Centrumeiland IJburg [MJ Exel total-1 y-1]
14,032	Gj natural gas for total Centrumeiland IJburg [Gj Exel total-1 y-1]
0.3%	Savings on total natural gas use by implementing shower heat exchangers.

#11 Energy generated (or lost) by collection, transport, treatment and recovery of the combined sanitation & kitchen waste (water) stream[101].

Scored ++, +, +-, - or -- [102].

Energy input is high. Biogas is produced, but it is less than the energy needed for the sewage system (Blom et al., 2010).

Energy use of ammonium air stripping with adsorption in acid is relatively high as smaller reactors are generally less energy efficient. However, it is now extensively tested lab scale technology so can be optimized (Siegrist et al., 2013).

As urine contains most of the nitrogen that is excreted by humans, this means the nitrogen load to the centralized wastewater treatment plans is reduced due to the community-on-site ammonia air stripping and adsorption in acid. Therefore the energy input for aeration of the centralized wastewater treatment plans is reduced (Wilsenach, 2006).

Overall score: +

#12 The trade-off between energy production and production of recovered nutrients has been given consideration with regard to optimizing positive environmental impact[103].

Scored ++, +, +-, - or --.

In this hi-tech system the focus lies on nutrient recovery and not on energy production. There is a trade-off between struvite production and phosphorous recovery from incinerated sludge.

[101] More local reuse is better as this saves transport energy. Moreover, the water content of the reuse product is important, as more water means higher CO_2 emissions from transport as more weight is transported.
[102] When there is more energy used for collection, transport, treatment and reuse than there is energy generated the score is – or --. Energy neutral is +- and energy generation gives a positive score of +, whereas a stepping stone technology that hardly uses energy but generates a lot will score ++.
[103] For example, does energy recovery from incinerating sludge means fossil, mined phosphorous becomes difficult or impossible or very energy intensive to recover? This would be conflicting with TNS sustainability principle 1.

Incinerating sludge generates energy and makes it possible to recovery phosphorous from ashes, which means a preceding treatment step of struvite recovery is redundant.

Overall score: +-

#13 Technical knowhow to control and maintain the stepping stone technology/process is systematically available to the connected community on the chosen scale of the technology/process for the technical lifetime of the design.

Scored ++, +, +-, - or --.

The centralized wastewater transport and treatment system is hi-tech and needs to be built and run by professionals (Spuhler, 2016a). The struvite reactor and ammonia air stripping likewise are hi tech and will require professionals to run them on site.

Overall score: --

#14 Benefits from the stepping stone technology/process, such as natural fertilizer for (urban) agriculture, profits from reused nutrients/resources or an attractive treatment facility that mimics nature[104] for recreation or landscape purposes, are allocated and accessible to the communities the waste (water) originates from.

Scored ++, +, +-, - or --.

Centralized treatment in wastewater treatment facilities and sludge incineration in a specialized and dedicated sludge incineration plant and phosphorous recovery in an even more specialized sludge ash recovery facility means the distances between the location where nutrients are recovered and the location where the nutrients originate (the households) are very large (Spuhler, 2016a). Struvite may be transported for longer distances as it does not contain water it is more energy efficient to transport out of the city by truck. The recovered ammonia solutions should be reused locally, as it is a liquid that cannot be transported long distances energy efficiently.

Overall score: +-

#15 Users accept the system, the possible extra handling/monitoring weight against the benefits it gives the users and the community.

Scored ++, +, +-, - or --.

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[104] Such as the Organica Greenhouse for wastewater treatment and water reuse ORGANICA WATER INC. 2016a. *Organica enables water reuse with cost-effective treatment near point of use* [Online]. Available: http://www.organicawater.com/learn/resource/organica-for-reuse [Accessed 11 February 2016].

There is education needed to properly use the no-mix toilets. Once users are familiar with the process there should be no problem and high acceptance is to be expected (Lienert and Larsen, 2009).

Overall score: +

#16 The stepping stone technology/process has high convenience in terms of nuisance (no bad smell, no additional vermin, weather proof) and service quality (effects of malfunctions are quickly and easily resolved).

Scored ++, +, +-, - or --.

When no-mix toilets are designed properly and urine pipes are laid out properly and are cleaned regularly, there should be no blockages and bad smell from no-mix toilets (Lienert and Larsen, 2009). Otherwise there is no handling of human waste by users.

Overall score: +

#17 The chosen system/process is robust: it can deal with reasonable future higher and lower loading rates, it has low malfunction and sensitivity for failure, it is not vulnerable and it is resilient in recovery from malfunction.

Scored ++, +, +-, - or --.

The three technologies (struvite reactor, ammonium air stripping and adsorption in acid and centralized wastewater treatment) in the SST5 concept are proven. The no-mix toilets are the most susceptible to malfunction and require some attention in diligent design to avoid failure.

Overall score: +

#18 (In)direct contact of humans with pathogens and harmful substances in the waste (water) infrastructure is minimized due to good management practices and technology application, hence public health is optimized.

Scored ++, +, +-, - or --.

Users are not in contact with pathogens or harmful substances, as these are transported away from homes by source-separated piping and treated in the hi tech community-on-site and centralized wastewater treatment facilities.

Overall score: ++

#19 If locally there is poor, infertile soil, the waste (water) effluent is used to increase local soil fertility.

Scored ++, +, +-, - or --.

There is no poor, infertile soil in The Netherlands currently; although farmers worry it may become an issue in the future (Reijneveld, 2013). However, organic matter is used for biological treatment of wastewater and the organic matter remaining is mostly caught in sludge which may be used to generate biogas or is incinerated directly (Spuhler, 2016a). Therefore there is no organic matter available to increase soil fertility, especially not at the point where the human waste is produced. Struvite can be transported over long distances so does not necessarily end up on local soils.

Overall score: -

#20 Relevant stakeholders are actively involved in the design process.

Scored ++, +, +-, - or --.

The centralized wastewater system is flush-and-forget (Harder, 2012) and is run by professionals (Spuhler, 2016a). Hence there is no involvement of stakeholders.

The no-mix toilets require involvement of users as well as producers and installers to make sure the system well designed and optimized for use and maintenance.

Overall score: +-

#21 Investment in technology today does not block the future proof technical design implementation, so only investment in flexible platforms.

Scored ++, +, +-, - or --.

Having no-mix toilets with separate sewers already opens up for a lot of technological improvements in the future. However, the transportation system, the gravity sewage pipes, has an average lifetime of 60 years (Oosterom and Hermans, 2013). Hence it is not a flexible platform.

Overall score: +-

#22 Investment in flexible platform technology today has a good return on investment[105].

Scored ++, +, +-, - or --.

The centralized wastewater treatment and collection system has high construction and maintenance costs, as well as high energy requirements (Spuhler, 2016a) and low environmental benefits in terms of resources recovered. The struvite and ammonia stripping solution do have environmental and economical benefits. Moreover, ammonia air stripping means the energy requirement for aeration in the centralized wastewater treatment plant is substantially lower (Wilsenach, 2006).

Overall score: +-

[105] Refers to all types of value, including financial and investment in future technology development, but also prosperity in broader sense than just financial profit.

#23 Investment in flexible platform technology today that requires large amounts of resources is only undertaken when there is no doubt it complies with the four sustainability principles of TNS, so taking precaution.

Scored ++, +, +-, - or --.

There is considerable doubt that the investment in the centralized wastewater treatment system is complying with the four sustainability principles of TNS (Harder, 2012) and the system requires large amounts of resources (Spuhler, 2016a). Struvite precipitation and ammonium air stripping with adsorption in acid do fit better with the four sustainability principles of TNS.

Overall score:+ -

#24 Inaction or business as usual (BAU) is not undertaken without conscious consideration of the consequences of inaction.

Scored ++, +, +-, - or --.

Solution is partially BAU.

Overall score: ++

Annex 18: Sources and calculations for MFA SST3 water and nutrients Exel and MFA SST2 water and nutrients Centrumeiland IJburg

In this annex the additional assumptions and sources of information for the adjusted baseline MFAs for the water and nutrient streams in the rural case of Exel and urban case of Centrumeiland IJburg are given. The baseline information can be found in the following annexes:

- Annex 2: Sources and calculations for MFA baseline water Exel
- Annex 3: Sources and calculations for MFA baseline water Centrumeiland IJburg
- Annex 4: Sources and calculations for MFA baseline nutrients Exel
- Annex 5: Sources and calculations for MFA baseline nutrients Centrumeiland

MFA water SST3 Composting dry toilets with urine storage in Exel

Assumptions:

- Water content of sludge from the Imhoff tank is not significant compared to the effluent water content, due to the long retention time (months or years) of sludge (Stauffer and Spuhler, 2016).
- Based on literature of willow filter evaporation in other countries the lowest possible evaporation could be 1,8 [mm d-1], which means a flow of 3,320 [m³ ha-1 y-1] (Otte and Boosten, 2014). As the willow filter will be dimensioned for discharge a willow filter of one hectare is assumed. If a higher evaporation and flow are possible, then the willow filter will not be over dimensioned. This means 58% of water in the willow filter will be evaporated (5663 influent / 3320 flow evaporated).
- Compost moisture should be between 35% and 65% (Cornell Waste Management Institute, 2016). This means that a maximum of 30% (65% - 35%) water content is allowed to evaporate, assuming the compost is not too wet at the start.

MFA nutrients SST3 Composting dry toilets with urine storage in Exel

Assumptions:

- The evaporation of N and OM from storage urine is assumed to be zero.
- Loss N due to volatilization as ammonia (reactive N) in composting process (Anand and Apul, 2014) is 55%.
- Faeces N volatilization from no-mix compost toilet 122.2 * 0,55 = 67.21 [kg y-1].
- Loss OM due to mineralization to CO_2 in composting process (Anand and Apul, 2014, Cornell Waste Management Institute, 2016) is 80%.
- Faeces organic matter volatilization from no-mix compost toilet (883.5 + 3,394.50) * 0,80 = 3,422.4 [kg y-1]
- Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)) is 48.7%.
- Kitchen refuse to secondary compost heap:

	Baseline components kitchen refuse	**SST3 kitchen refuse to secondary compost heap**
P	13.58	6.61

N	115.41	56.20
K	13.58	6.61
OM	4,005.51	1,950.68
Total	**4,148.08**	**2,020.10**

- Kitchen refuse N volatilization from secondary compost heap 56.20 * 0,55 = 30.91 [kg y-1].
- Kitchen refuse organic matter volatilization from secondary compost heap 1,950.68 * 0,80 = 1,560.54 [kg y-1].
- The Imhoff tank does not significantly remove nutrients and nutrient removal in the sludge is therefore assumed to be negligible.
- There is very little nitrification in the soil, as outside temperatures are not very high in The Netherlands (Otte and Boosten, 2014). Therefore nitrification is assumed to be negligible.
- Assumed is K behaves like N where no information is found.
- Organic matter is not taken up by willows.
- N uptake by willows is between 18 and 100, average 59 [kg ha-1 y-1] (Otte and Boosten, 2014).
- Removal in willow filters of N is between 75 and 630, average 352.5 [kg ha-1 y-1] (Otte and Boosten, 2014).
- Average of N recovery percentage in Willows in vertical flow constructed wetland from two studies, 32% and 43% were found (Otte and Boosten, 2014) is 37%.
- Assumed is that (59/352.5) * 37% = 6.2% removal of N goes to biomass.
- P uptake by willows is between 3 and 13, average 8 [kg ha-1 y-1] (Otte and Boosten, 2014).
- Removal in willow filters of P is between 5 and 50, average 27.5 [kg ha-1 y-1] (Otte and Boosten, 2014).
- Average of P recovery percentage in Willows in vertical flow constructed wetland from two studies, 14% and 23% were found (Otte and Boosten, 2014) is 18.5%.
- Assumed is that (8/27.5) * 18.5% = 5.4% removal of P goes to biomass.
- K recovery percentage in Willows in ‘no discharge’ constructed wetland in one study is 28%, assumed this is too high so took half this number (Otte and Boosten, 2014) is 14%.
- Assumed is that (59/352.5) * 14% = 2.3% removal of K goes to biomass.
- Average of OM removal percentage in Willows in vertical flow constructed wetland from two studies, 87% and 75% were found (Otte and Boosten, 2014) is 81%.

MFA water SST2 Vacuum system for black water in Centrumeiland IJburg

Assumptions:

- The drinking water usage is decreased by 30% overall compared to conventional (De Graaf and Van Hell, 2014).
- Vacuum toilets use one to two litres water per flush (De Graaf and Van Hell, 2014), with an average usage frequency of 5.9 [times p-1 d-1] (Van Thiel, 2014) this amounts to 8.85 litres (5.9 * 1.5). For the total apartment complex of Centrumeiland IJburg this is 1,754.03 [m3 p-1 y-1].

- 13.7 [l p-1 d-1] water is used for total black water (De Graaf and Van Hell, 2014) which means 4.85 [l p-1 d-1] (13.7 – 8.85) is used for the kitchen grinder. For the total apartment complex of Centrumeiland IJburg this is 961.25 [m3 p-1 y-1].
- Drinking water used for water drinking and making coffee and tea stays the same as in the baseline MFA for water for Centrumeiland IJburg.
- Calculation other greywater use streams besides vacuum toilet and kitchen grinder:
    - Total drinking water use in baseline Centrumeiland IJburg MFA: 23,625 [m3 y-1 Centrumeiland IJburg-1].
    - 30% water savings new total drinking water use with SST2 Centrumeiland IJburg: 16,537.5 [m3 y-1 Centrumeiland IJburg-1].
    - Water use for 'other drinking water use' besides vacuum toilet and kitchen grinder, drinking water and coffee and tea making (16,537.5 - 1,754.03 - 961.25 – 119 - 79) = 13,624.22 [m3 y-1 Centrumeiland IJburg-1].
    - 1 – (13,624.22 / 16,728) = 18.55% water savings on 'other drinking water use'.

Type of drinking water use	**Old drinking water use** *[m3 y-1 Centrumeiland IJburg-1]*	**New drinking water use 81.45% of 'old drinking water use'** *[m3 y-1 Centrumeiland IJburg-1]*
Watering plants/garden	198	161.27
Shower + bath	10,544	8,588.09
Bathroom sink	1,031	839.75
Dishwashing machine	396	322.54
Laundry machine/hand	3,112	2,534.72
Other kitchen tap use (excluding kitchen grinder, water drinking and coffee and tea making)	1,447	1,178.58
Total	**16,728**	**13,624.95**

- Average water vapour content in biogas is 3 vol% (Biogas-E vzw, 2016). Biogas production is 1,256.5 m3 biogas per year, see annex 10. So on average 37.7 m3 water vapour per year (0.03 * 1,256.5)
- 7% organic matter in black water system of SST2 to UASB sludge (De Graaf and Van Hell, 2014). Assumed the same percentage applies to the water in the sludge.
- 5% estimated sludge production in the OLAND reactor based on the mass balance COD graph of (2014, p78). Assumed the same percentage applies to the water in the sludge.
- The sludge production of the AB process is minimal so has been assumed to be zero (De Graaf and Van Hell, 2014).

MFA nutrients SST2 Vacuum system for black water in Centrumeiland IJburg

Assumptions:

- The drinking water usage is decreased by 30% overall compared to conventional (De Graaf and Van Hell, 2014). So the nutrients in drinking water decrease by that same percentage.
- Recovery kitchen refuse (assuming this is equal to kitchen and garden waste recovery of average Dutch households according to Milieu Centraal (2012)) is 48.7%.

	Baseline components kitchen refuse	SST3 kitchen refuse to kitchen grinder
P	39.64	19.30
N	336.93	164.08
K	39.64	19.30
OM	11,693.51	5,694.74
Total	**12,109.72**	**5,897.42**

- 7% organic matter in black water system of SST2 to UASB sludge (De Graaf and Van Hell, 2014).
- 5% estimated sludge production in the OLAND reactor based on the mass balance COD graph of (2014, p78).
- The sludge production of N and P in the AB process is minimal so has been assumed to be zero (De Graaf and Van Hell, 2014).
- Percentage of P in black water + kitchen refuse removed in struvite reactor (De Graaf and Van Hell, 2014) is 56%.
- Percentage of P to UASB sludge (remainder to effluent) (De Graaf and Van Hell, 2014) is 10%.
- Percentage of N to UASB sludge (remainder to effluent) (De Graaff et al., 2010)is 9%.
- Percentage of N to N2 gas in OLAND process (remainder to effluent) (De Graaff et al., 2010)is 70%.
- Assumed is K behaves like N where no information is found.
- Percentage organic matter in black water system of SST to UASB sludge (De Graaf and Van Hell, 2014) is 9%.
- Percentage organic matter in black water system of SST to biogas (De Graaf and Van Hell, 2014)s 78%.
- Percentage organic matter in black water system of SST to struvite based on the mass balance COD graph of (De Graaf and Van Hell, 2014) is 8.32%.
- Percentage N in black water system of SST to struvite based on the mass balance N graph of (De Graaf and Van Hell, 2014) is 1.1%.
- N2 gas and N2O gas are not produced in significant quantities in the UASB with concentrate black water (De Graaff et al., 2010, Biogas-E vzw, 2016). Hence this value is assumed to be zero.
- Percentage N removal to N2 gas in the AB process (De Graaf and Van Hell, 2014) is 62.8%.
- Percentage OM removal to CO_2 in the AB process (De Graaf and Van Hell, 2014) is 90.65%.

Annex 19: Questionnaire setup

Enquête voor stakeholders van nieuwe sanitatie

Invoering

Deze enquête is onderdeel van het MSc afstudeeronderzoek van Carolien van Merksteijn aan de Wageningen Universiteit (Urban Systems Engineering) naar toekomstbestendige nieuwe sanitatie[1] in een landelijke en stedelijke renovatie casus. Het onderzoek is gedaan onder supervisie van Grietje Zeeman van de Wageningen Universiteit en met medewerking van Paul Telkamp van Tauw.

Met deze enquête wil ik feedback krijgen van stakeholders in nieuwe sanitatie en afvalwater op de conclusies van mijn onderzoek. Deze conclusie bestaat uit een ontwerp voor nieuwe sanitatie voor een gedeeltelijk fictieve landelijke en fictieve stedelijke casus voor renovatie van gebouwen en/of riolering. Het criterium voor de selectie van de technologieën is de toekomstbestendigheid[2] van het concept. Deze toekomstbestendigheid is bepaald door een combinatie van twee duurzaamheidmethodieken (The Natural Step en Cradle to Cradle).

Hieronder volgen de twee casus omschrijvingen met over elk 11 korte vragen. Alvast hartelijk dank voor uw medewerking aan deze enquête!

[1] Gehanteerde definitie van "nieuwe sanitatie": Sanitatie met als doel het volledig herwinnen van grondstoffen van afval (water) stromen en het lokaal sluiten van nutriënten en water cyclussen onder energie neutrale condities en bij voorkeur met productie van een overschot aan energie.
[2] Gehanteerde definitie van "toekomstbestendig": Een ontwerp dat de tand des tijds kan weerstaan terwijl het voorziet in de behoeften van de huidige en toekomstige generaties.

Enquête voor stakeholders van nieuwe sanitatie

Case 1

Landelijk gelegen dorpskern Exel in de gemeente Lochem, Gelderland

Deze casus is gedeeltelijk fictief omdat regenwater (nog) niet volledig is afgekoppeld van de riolering en de drukriolering (nog) niet toe is aan vervanging.

Omschrijving casus

In Exel wonen 186 mensen in 62 bestaande grondgebonden huizen met tuin met een gemiddeld woonoppervlak van 149 m2. De dorpskern is omringd door platteland en bos, in individueel particulier bezit. De bevolkingsdichtheid is laag en er wonen relatief weinig 20ers en 30ers, maar relatief veel 50 plussers, vergeleken met de stedelijke casus. Momenteel is Exel via drukriolering aangesloten op de relatief kleine rioolwaterzuiveringsinstallatie van Zutphen. Regenwater is volledig afgekoppeld van de riolering. De zandgrond is geschikt voor regen en/of afvalwater effluent infiltratie in de bodem. De drukriolering is aan vervanging toe. Voor een nieuwe sanitatie oplossing is gedeeltelijke aanpassing/renovatie van bestaande huizen nodig, wat zoveel mogelijk zal aansluiten op een natuurlijk vervangmoment[1]. Het nieuwe sanitatie ontwerp zal dus stapsgewijs worden geïmplementeerd.

Toekomst visie voor sanitatie in Exel over 60 jaar [2]

Gebaseerd op het afstudeeronderzoek is droge sanitatie met een maximale water besparing door middel van technologie en gedragsverandering de meest duurzame en praktisch haalbare toekomstbestendige sanitatie oplossing voor Exel. Het doel is volledige scheiding van nutriënten en (afval)water en maximaal hergebruik van beide stromen. In de praktijk wordt dit bereikt door (no-mix) composttoiletten voor urine en fecaliën. Nutriënten worden ingezet voor het verbeteren van (landbouw)grond. Daarnaast wordt gestreefd naar een minimale hoeveelheid grijs water[3]. Uitdagingen zijn gedragsverandering, risico's van pathogenen en microverontreinigingen in nutriënten/meststoffen en grijs water en waarborging van de volksgezondheid.

Opstaptechnologieën voor implementatie visie in Exel **nu**

Om over 60 jaar de toekomstvisie voor Exel mogelijk te maken, moeten er vandaag toekomstbestendige technologieën geselecteerd worden voor de sanitatie oplossing in Exel. Na een uitgebreide analyse is de conclusie van het onderzoek dat de volgende opstaptechnologieën het beste voldoen aan de eisen van duurzaamheid, evenals aan praktische voorwaarden voorgeschreven door relevante stakeholders[4]:

Voor fecaliën, urine en keukenafval wordt een no-mix composttoilet ingezet in plaats van het huidige conventionele toilet op de begane grond van de huizen. Droge compost van fecaliën en keukenafval en vloeibare meststof van urine wordt na verwijdering van pathogenen door compostering/opslag in tuinen gebruikt. Douche water gaat door een warmtewisselaar om rechtstreeks warmte terug te winnen. Grijs water wordt gezuiverd in een wilgenfilter waarvan effluent in de bodem wordt geïnfiltreerd en biomassa wordt gewonnen. Regenwater van daken wordt opgevangen en gebruikt voor de tuin of wasmachines. Zie figuur 1. Dit technische concept is gebaseerd op de sanitatie oplossing van de ecologische wijk in Allermöhe, Duitsland.

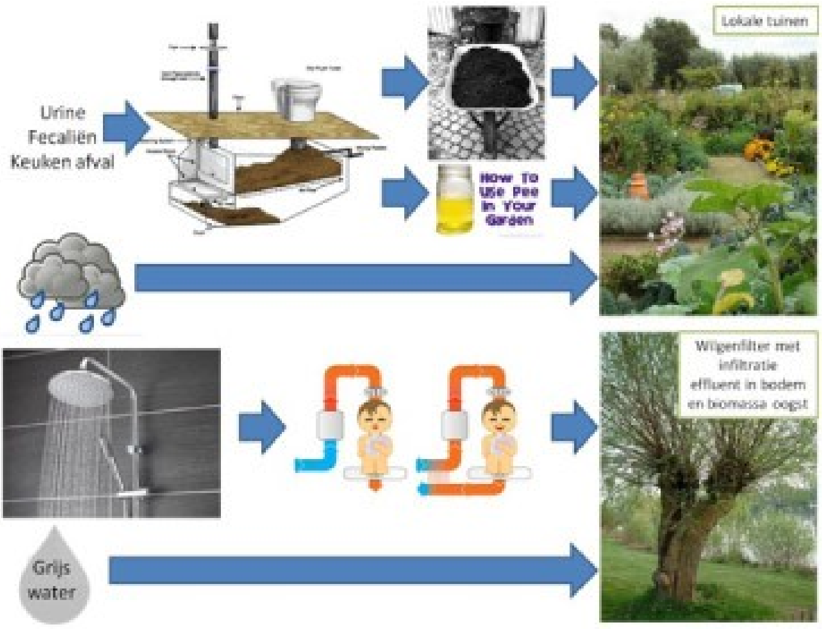
[1] Wanneer woningeigenaren besluiten tot renovatie van toilet of badkamer.

[2] Zestig jaar is de gemiddelde levensduur van riolering. Dit is het onderdeel van de huidige (centrale) sanitatie oplossing die het langste mee gaat.

[3] Definitie "grijs water": al het afvalwater in een huishouden behalve het spoelwater van de wc, dus onder andere douche water en keukengootsteen water.

[4] Economische/financiële voorwaarden zijn niet meegenomen in dit onderzoek om twee redenen: 1. De Circle Economy met vernieuwende verdienmodellen maakt een stevige opmars. 2. Er zijn signalen dat vergroening van het belastingstelsel een serieuze kans maakt geïmplementeerd te worden. Beide trends zullen de komende 60 jaar waarschijnlijk doorzetten en alternatieve sanitatie opties financieel aantrekkelijk maken t.o.v. het huidige systeem.

Figuur 1: Schematische weergave opstaptechnologieën landelijke casus Exel



Vragen over landelijk gelegen dorpskern Exel, gemeente Lochem, Gelderland:

* 1. Past deze visie bij de casus volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

2. Waarom wel/niet?

3. Zo niet, wat is volgens u een alternatieve visie en waarom is deze meer toekomstbestendig denkt u?

[ ]

* 4. Is de visie binnen 60 jaar haalbaar volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

* 5. Passen de opstaptechnologieën, zie figuur 1, bij de gekozen visie volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

6. Waarom wel/niet?

[ ]

7. Zo niet, wat is een alternatieve oplossing en waarom past deze beter bij de visie denkt u?

[ ]

* 8. Is implementatie van de opstaptechnologieën haalbaar volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

* 9. Ziet u belangenconflicten en heeft u tips om deze op te lossen?

- ◯ Ja
- ◯ Nee

10. Tips:

11. Heeft u nog praktische tips of verbeterpunten of andere opmerkingen?

Enquête voor stakeholders van nieuwe sanitatie

Case 2

Stedelijk gelegen appartementencomplex op Centrumeiland IJburg in de gemeente Amsterdam

Deze casus is gedeeltelijk fictief omdat er geen projecten zijn in Nederland waarbij renovatie van een appartementencomplex wordt gecombineerd met renovatie van het rioolstelsel.

Omschrijving casus

In een appartementencomplex op Centrumeiland IJburg met bouwjaar 1960 wonen na grootschalige renovatie 543 inwoners. Het complex wordt tot het betonskelet gestript en gerenoveerd, waarbij 292 nieuwe appartementen worden gerealiseerd met verschillende indelingen van gemiddeld 75 m2 woonoppervlakte. Het complex is omringd door bebouwd gebied en gemeenschappelijke groenzones en Centrumeiland IJburg is omringd door oppervlaktewater. De bevolkingsdichtheid is hoog en er wonen relatief veel 20ers en 30ers, maar relatief weinig 50 plussers, vergeleken met de landelijke casus. De riolering voor het hele eiland wordt nieuw aangelegd[1]. Regenwater is volledig afgekoppeld van de riolering. De opgespoten zandgrond van het eiland is geschikt voor regen en/of afvalwater effluent infiltratie in de bodem. Het nieuwe sanitatie concept zal in één keer worden geïmplementeerd.

Toekomst visie voor sanitatie in Centrumeiland IJburg over 60 jaar [2]

Gebaseerd op het afstudeeronderzoek is een infrastructuur, in combinatie met gedragsverandering, die water en nutriënten ontkoppelt en nutriënten terugwint de meest duurzame en praktisch haalbare toekomstbestendige sanitatie oplossing voor Centrumeiland IJburg. Het doel is bronscheiding van afvalwaterfracties en het maximaliseren van de nutriëntenconcentratie door eco-efficiënt watergebruik. Teruggewonnen nutriënten/(kunst)meststoffen worden ingezet voor het verbeteren van (landbouw)grond. In de praktijk variëren technische concepten op type bronscheiding (geel[3], bruin[4], grijs en regenwater) en complexiteit. Afhankelijk van het type concept zijn de uitdagingen gedragsverandering en risico's van pathogenen en microverontreinigingen in nutriënten/meststoffen en grijs water.

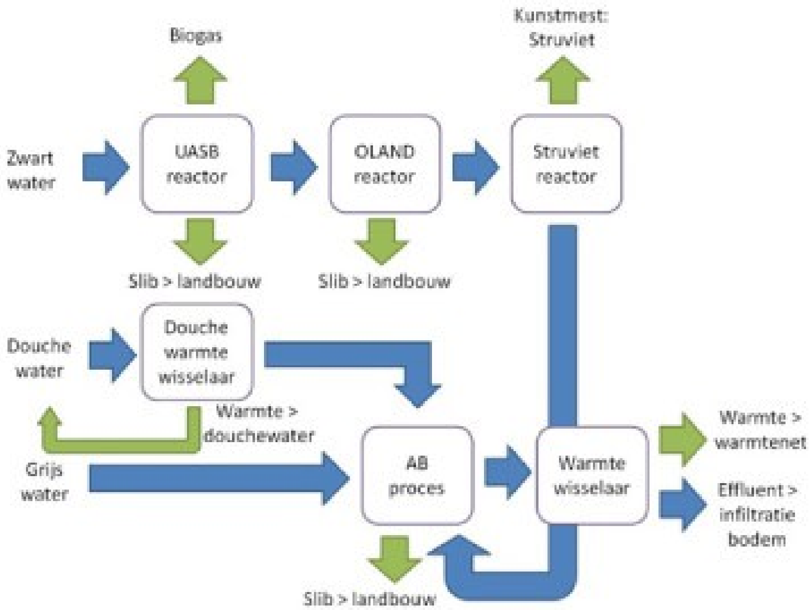
Opstaptechnologieën voor implementatie visie in Centrumeiland IJburg **nu**

Om over 60 jaar de toekomstvisie voor Centrumeiland IJburg mogelijk te maken, moeten er vandaag toekomst bestendige technologieën geselecteerd worden voor de sanitatie oplossing in Centrumeiland IJburg. Na een uitgebreide analyse is de conclusie van het onderzoek dat de volgende opstaptechnologieën het beste voldoen aan de eisen van duurzaamheid evenals aan praktische voorwaarden voorgeschreven door relevante stakeholders[5]:

Zwart water[6] en GFT worden gezamenlijk in één vacuüm leiding en grijs water in een aparte leiding ingezameld en lokaal behandeld. Vacuüm technologie maximaliseert de concentratie nutriënten in afvalwater door minimaal waterverbruik. Douchewater gaat door een warmtewisselaar om rechtstreeks warmte terug te winnen. De afvalwaterbehandeling bestaat uit het winnen van biogas uit zwart water (UASB reactor), energiearme stikstof verwijdering (OLAND), fosfaat terugwinning als kunstmest (struviet reactor), aerobe zuivering van grijs water en effluent zwart water (AB proces) en warmte terugwinning uit het effluent van het AB proces. Slib uit de zuivering wordt als meststof ingezet op (landbouw)grond. Gezuiverd effluent zal worden geïnfiltreerd in de bodem. Zie figuur 2. Dit technische concept is gebaseerd op de sanitatie oplossing van het project Waterschoon in Sneek.

[1] Indien gekozen wordt voor conventionele riolering zou deze worden aangesloten op een grote Amsterdamse rioolwaterzuiveringsinstallatie.
[2] Zestig jaar is de gemiddelde levensduur van riolering. Dit is het onderdeel van de huidige (centrale) sanitatie oplossing die het langste mee gaat.
[3] Definitie geel water: Urine met spoelwater.
[4] Definitie bruin water: Fecaliën met spoelwater.
[5] Economische/financiële voorwaarden zijn niet meegenomen in dit onderzoek om twee redenen: 1. De Circle Economy met vernieuwende verdienmodellen maakt een stevige opmars. 2. Er zijn signalen dat vergroening van het belastingstelsel een serieuze kans maakt geïmplementeerd te worden. Beide trends zullen de komende 60 jaar waarschijnlijk doorzetten en alternatieve sanitatie opties financieel aantrekkelijk maken t.o.v. het huidige systeem.
[6] Definitie zwart water: Urine en fecaliën en spoelwater (ofwel toiletwater).

Figuur 2: Schematische weergave opstaptechnologieën stedelijke casus Centrumeiland IJburg



Vragen over stedelijk appartementencomplex in Centrumeiland IJburg, Amsterdam:

* 12. Past deze visie bij de casus volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

13. Waarom wel/niet?

14. Zo niet, wat is volgens u een alternatieve visie en waarom is deze meer toekomstbestendig denkt u?

* 15. Is de visie binnen 60 jaar haalbaar volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

* 16. Passen de opstaptechnologieën, zie figuur 2, bij de gekozen visie volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

17. Waarom wel/niet?

18. Zo niet, wat is een alternatieve oplossing en waarom past deze beter bij de visie denkt u?

* 19. Is implementatie van de opstaptechnologieën haalbaar volgens u?

- ◯ Helemaal
- ◯ Wel aardig
- ◯ Neutraal
- ◯ Niet echt
- ◯ Helemaal niet

* 20. Ziet u belangenconflicten en heeft u tips om deze op te lossen?

- ◯ Ja
- ◯ Nee

21. Tips:

[ ]

22. Heeft u nog praktische tips of verbeterpunten of andere opmerkingen?

[ ]

Enquête voor stakeholders van nieuwe sanitatie

Algemene Vragen

* 23. Welk type stakeholder bent u:

- ◯ Waterschap
- ◯ Gemeente
- ◯ Wetenschap
- ◯ Adviesbureau
- ◯ Anders, namelijk ...

24. Indien u meer informatie wilt ontvangen vul uw email adres in (u krijgt maximaal twee emails in 2016):

Literatuur

Voor gebruikte literatuur verwijs ik naar het eind 2016 beschikbare afstudeerrapport.

Annex 20: Summary feedback stakeholders on conclusions research

A questionnaire was sent out by email to 88 stakeholders in The Netherlands of new sanitation projects to receive feedback on the conclusions of this research. Most stakeholders approached are experts that attended the New Sanitation Platform meeting of STOWA in April 2016. In total 33 people responded of which 29 fully completed the survey. Most of these 29 stakeholders work at a water board, municipality or consultancy. A minority comes from the scientific community, other governments or is inhabitant (see figure 33).

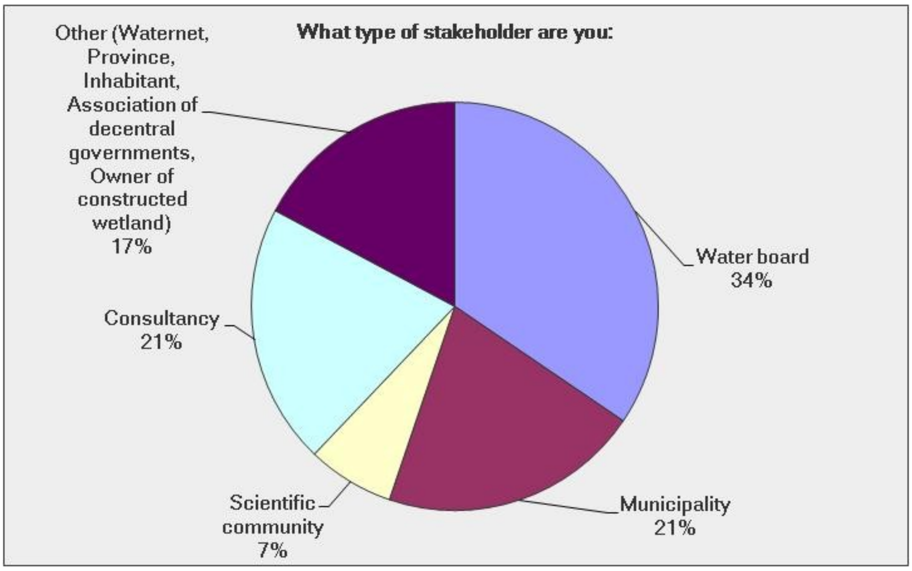


FIGURE 33: TYPE OF STAKEHOLDERS THAT ANSWERED FULL SURVEY (N=29)

Rural case Exel, municipality Lochem

Almost 61% or respondents think the vision presented for rural Exel fully or reasonably fits the case description. However, 21% doe not really see a fit (see figure 34). Positive remarks about the vision are that autonomy, maximum reuse and source separation sound good and that this ambitious vision as a dot on the horizon can really create sustainability and future proof solutions. On the downside, respondents believe that inhabitants may not be motivated for significant lifestyle change because of lesser ease of use and comfort and the perception that they take ‘a step back in time’. Application may be difficult in existing homes and the perceived quality of life will be lower which impairs the replacement of old inhabitants with new ones. This means inhabitants will not support the technologies. Dual systems in the transition period and metals and soap residues in greywater are also of concern. Lastly, the population is relatively old, which means they are not physically able to maintain the compost toilet and will excrete relative high amounts of medicines which are difficult to degrade.

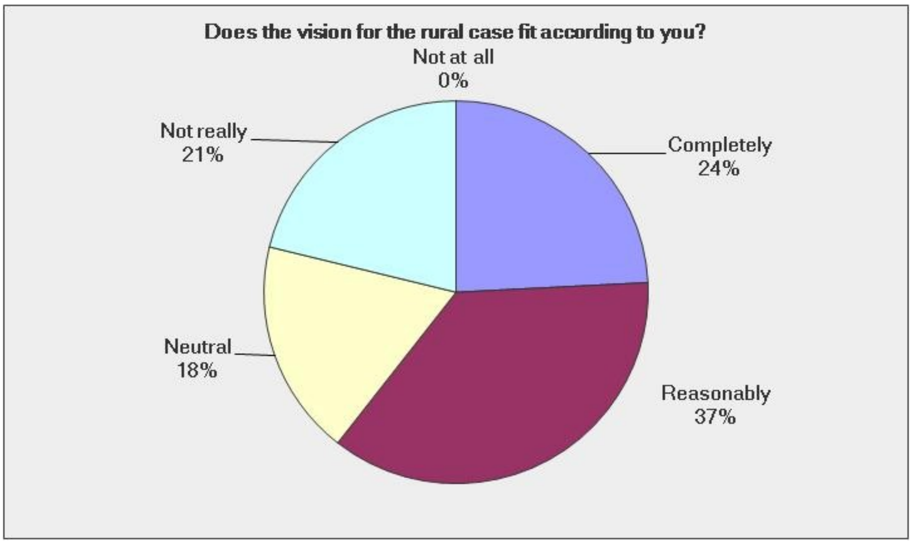


FIGURE 34: DOES THE VISION FOR THE RURAL CASE FIT ACCORDING TO YOU?

About 67% of stakeholders believe the vision for Exel is achievable within 60 years, although 21% believe it is not really possible to attain (see figure 35). Alternative visions proposed include a wet sanitation system with water-saving and local treatment that reuses fertiliser, produces high quality drinking water and energy. A botanical green house, or paperless 'clean with water' toilet may be an option. Several other respondents are of the opinion that the pressure sewer should be kept either with local storage of fertiliser or with separate streams or with discharge to the river Ijssel due to relatively lenient effluent requirements for discharge. Lastly, it is advised that more attention should be given to the experience of inhabitants and lifestyle change.

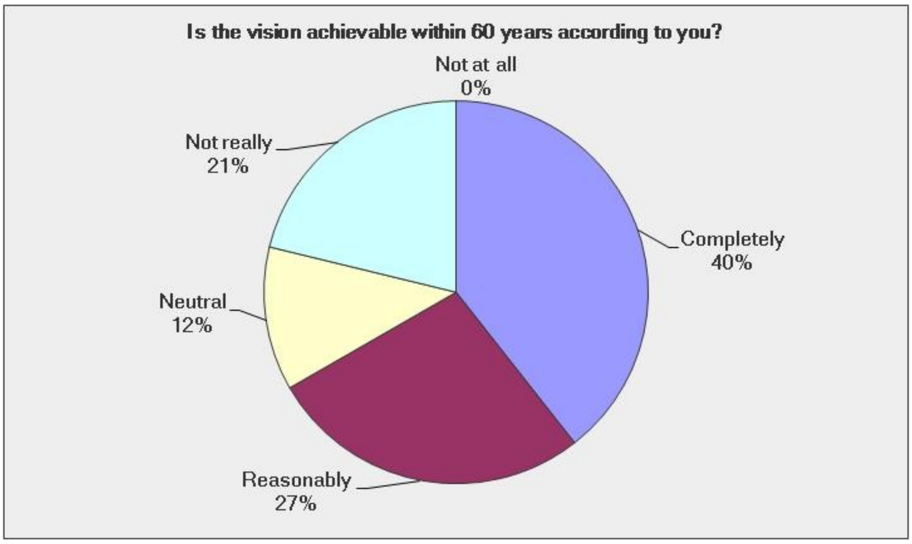


FIGURE 35: IS THE VISION FOR THE RURAL CASE ACHIEVABLE WITHIN 60 YEARS ACCORDING TO YOU?

Fewer stakeholders see a fit between the stepping stone technology that has been selected on sustainability grounds and the chosen vision. A slim majority of 55% see a complete or partial fit, but over 30% do not really see a fit (see figure 36). On the positive side remarks are that a new approach to "waste" is necessary for a sustainable liveable climate and this is indeed the most sustainable as it gives the highest chance for closing cycles. Also, besides the introduction of the compost toilet there is no big difference in technologies that are already applied and the solution is simple and could have low malfunction. On the downside, the proposed stepping stone technology will have to deal with low acceptance of compost toilets and cultural and institutional resistance against dealing with faeces and urine. The societal context and ownership of technology also needs to be addressed. Other remarks indicate that maintenance and management needs to be professional and pathogen removal and micro pollutant prevention are important for the SST to succeed. Stakeholders also mention that due to urbanisation of rural areas a system that is easy to scale up and is less dependent on green space may be more appropriate, perhaps only producing synthetic fertiliser, and this may only work in new developments.

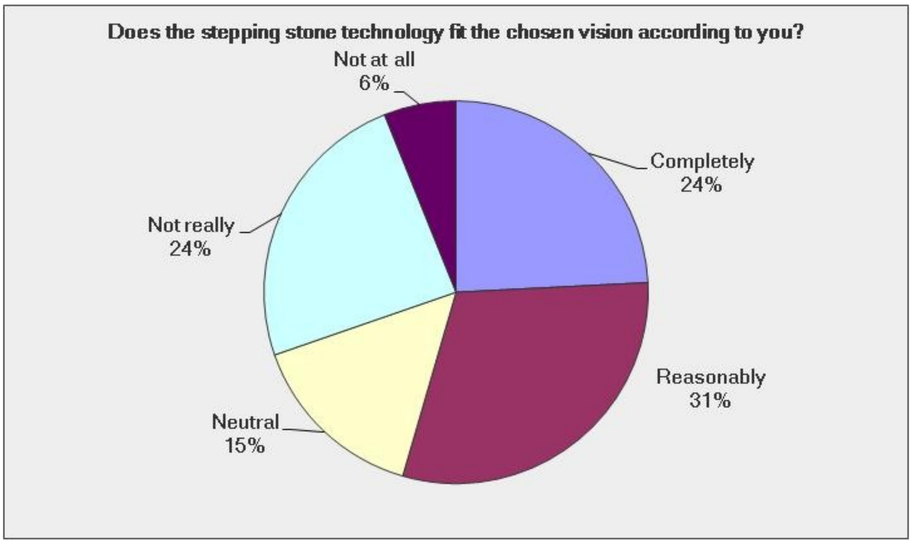


FIGURE 36: DOES THE STEPPING STONE TECHNOLOGY FOR THE RURAL CASE FIT THE CHOSEN VISION ACCORDING TO YOU?

An alternative stepping stone technology mentioned by stakeholders is to minimize water use (vacuum or low flush) and avoid lifestyle change. A shorter term vision of 2025 for use of existing technology was also mentioned. Treatment technology selection based on the most promising customer for the end product is also advised.

Almost 40% of stakeholders think the implementation of the stepping stone technology for the rural case is feasible, whereas over 30% do not really see this happening (see figure 37). Almost 70% of respondents think there is a conflict of interest, the remainder does not. Tips to solve potential conflicts are foremost to pay a lot of attention to creating acceptance of compost toilets such as a financial stimulus, peer pressure by making it desirable through publicity and avoiding (perceived) value decrease of homes trough publicity of value of sustainable technology. Starting with pilots and showing positive results of comfort, cost reduction and emission reduction will help to create acceptance as well. Moreover, it is important to take advantage of the replacement of old residents with new residents when properties change ownership. Stakeholders also mention that it is important to map the interests of stakeholders in general, plan well who is the owner of techniques inside of homes and make sure responsibilities of water boards and municipalities are shared and it is understood that these will change in the future. Resistance of water boards can arise when central becomes decentralized and they may ask for financial compensation for fast depreciation of assets due to uncoupling of wastewater of central treatment. Lastly, stakeholders' advice to avoid public health and environmental risks and one respondent believes that a collective solution works better than the individual solution proposed.

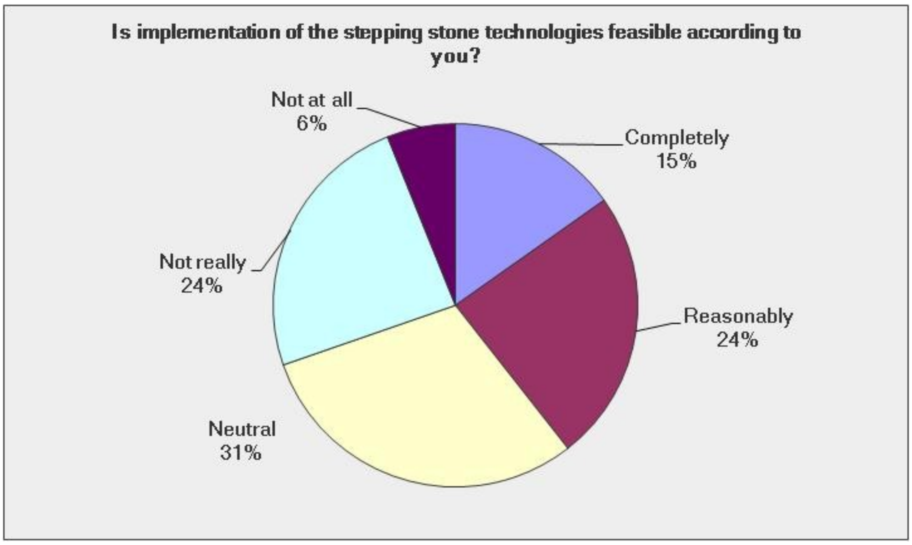


FIGURE 37: IS IMPLEMENTATION OF THE RURAL STEPPING STONE TECHNOLOGY FEASIBLE ACCORDING TO YOU?

Lastly, some practical tips, improvement suggestions and general remarks from stakeholders are that it is very important to include the social context in addition to the technical one. The 'human' should not be forgotten. It is also of utmost importance to be aware who the target group is and what their expectations are. An appealing sales story that takes users along in the ideas and allows them to take initiative will help make the vision and proposed stepping stone technology reality. It is important to facilitate enthusiasts with guarantees, financing and material. This will seduce on the short term instead and will avoid having to force on the long term. One respondent stresses that only proven technology should be applied.

Urban case Centrumeiland IJburg, municipality Amsterdam

69% or respondents think the vision presented for urban Centrumeiland IJburg fully or reasonably fits the case description. However, almost 14% doe not really see a fit (see figure 38). Positive remarks about the vision are that this source separation is the only way to efficiently recover back nutrients and heat. Also, the vision unburdens and has a low threshold due to more technical solutions that take less space. Vacuum technology works best in apartments where the caretaker can fix malfunctions. The scale of an apartment complex is also fitting to the technology. Lastly it is mentioned that because extensive renovation is planned, it can almost be considered a new development which fits well. On the downside stakeholders mention that a central solution would give a better economy of scale because of the urban character of the case. Moreover, a decentralized solution with less involvement of inhabitants increases the chance for failure and seems inflexible. One respondent points out a technology for micro pollutant removal is missing and another states that lifestyle change is a risk. It seems to one stakeholder that finding a customer for the recovered products inside the city is preferably so the city can profit directly.

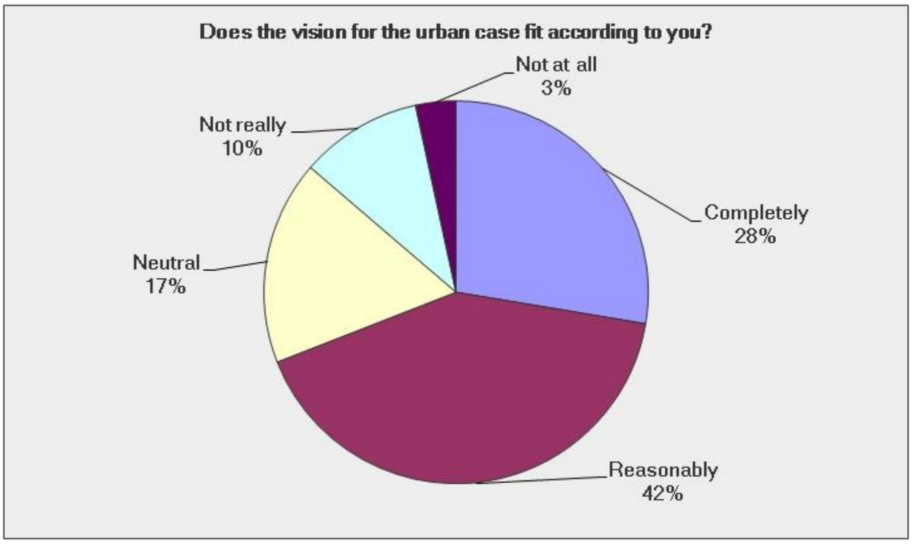


FIGURE 38: DOES THE VISION FOR THE URBAN CASE FIT ACCORDING TO YOU?

Almost 73% of stakeholders believe the vision for the urban case is fully or somewhat achievable within 60 years, whereas over 10% of respondents do not really find it achievable (see figure 39). Alternatives to the vision proposed are source separation of clean and dirty water streams. Clean water is reused close by and more concentrated wastewater is treated centrally with sustainable techniques such as an UASB. This creates more efficiency, reliability and continuity. Also mentioned is that techniques that produce less noise hindrance and are less sensitive to malfunction should be implemented, and only for a homogeneous user group that is committed to this change. Lastly it is stated that more flexible techniques should be chosen that are depreciated in less than 30 years, preferably within 10 years so adaptation is possible quickly when new techniques become available.

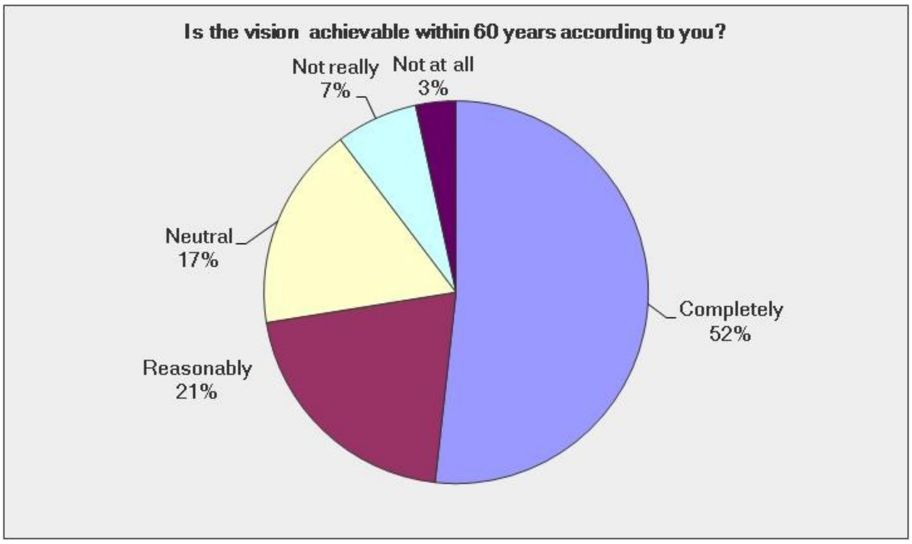


FIGURE 39: IS THE VISION FOR THE URBAN CASE ACHIEVABLE WITHIN 60 YEARS ACCORDING TO YOU?

Almost an equal percentage of stakeholders see a fit between the stepping stone technology that has been selected on sustainability grounds and the chosen vision for the urban case. A majority of 69% see a complete or partial fit and just over 10% do not really see a fit (see figure 40). On the positive side respondents think the system fits because it is a local case and application will help optimize the technology. Also, vacuum pipes are flexible and flexibility is needed to be able to take advantage of new developments in treatment technology. Lastly, this stepping stone technology does not require much lifestyle change. On the downside the stepping stone technology is not considered innovative and does not take advantage of economies of scale while it has high space requirements which might collide in a highly urbanized area such as Centrumeiland IJburg. Heat recovery is only useful when heat and cold storage (aquifer thermal energy storage) is available. It is also mentioned tertiary treatment of effluent from the AB stage is missing. Lastly, one respondent believes some parts of the system do not fit, notably Greywater in the AB stage process and the OLAND and struvite reactors.

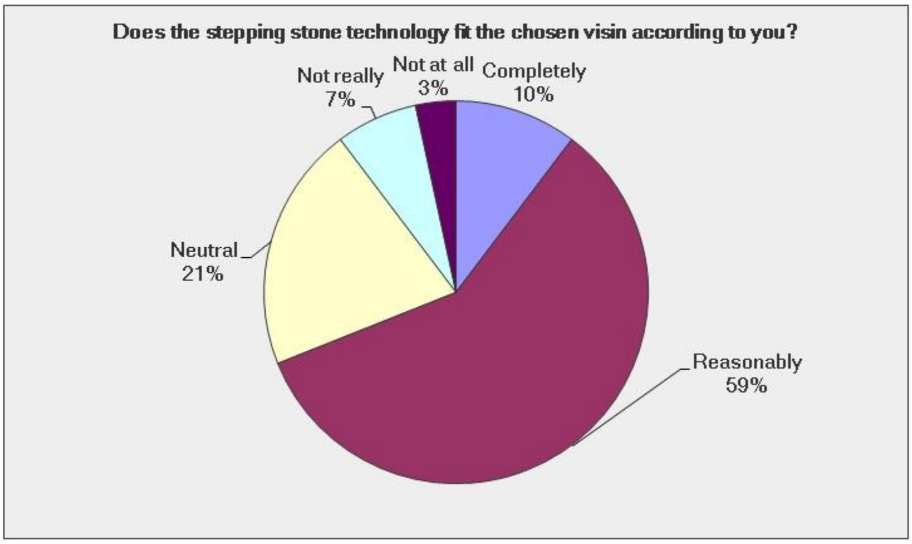


FIGURE 40: DOES THE STEPPING STONE TECHNOLOGY FOR THE URBAN CASE FIT THE CHOSEN VISION ACCORDING TO YOU?

An alternative stepping stone technology proposed by stakeholders is transportation of concentrated black water to centralized treatment, thus with water-saving techniques applied in homes. Clean water streams can be reused locally. Another idea is the application of a cold network instead of a heat network. Research of the respondent shows this may be a crucial argument for inhabitants to vote for a decentralized sanitation concept. Lastly stakeholders believe more robustness is needed in the concept and a more short term solution is preferable.

Almost 66% of stakeholders think the implementation of the stepping stone technology for the rural case is feasible to a degree, whereas almost 14% do not really see this happening (see figure 41). 69% of respondents think there is a conflict of interest, the remainder does not. Tips to solve potential conflicts are to create a master plan that describes all ins and outs, and includes all sectors that are connected (by the green arrows) early on in the planning stage. Notably energy providers can feel threatened and there will also be competition with the existing wastewater treatment plant and city heat network. It needs to be clear who will maintain the system, water board, municipality or third party, and the new streams of sludge to agriculture need to be closely monitored to ensure good quality. Conflicts of interests between inhabitants can be a real challenge, like the use of chemical disinfectant for example. Heat networks also invoke resistance due to inflexibility and forced purchase for connected homes. Often mentioned is the challenge of the lifestyle change required. Support can be created by building on experiences from the similar project Waterschoon in Sneek, appointing a local ambassador, provide clear information, let profits of the system flow back to inhabitants and making connection to the system part of the sale of homes. The users need to take initiative and their ideas should be included in the master plan. Lastly, one respondent suggests using rain water for toilet flushing if all is to be renovated anyway.

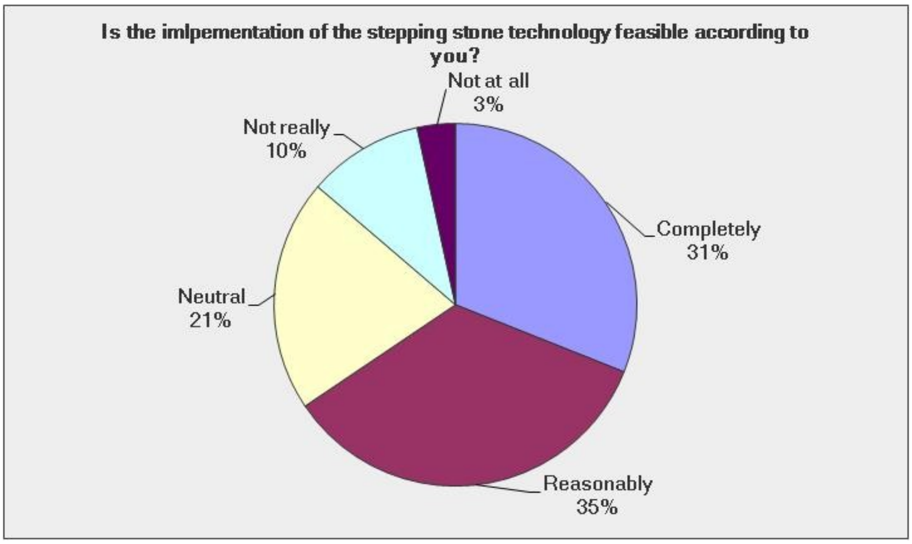


Figure 41: Is the implementation of the stepping stone technology for the urban case feasible according to you?

Lastly, some practical tips, improvement suggestions and general remarks from stakeholders are to include the social-economical chain. Between input and output is no black box, but people with routines. It also has to be clear what to do with potentially missed tax income for water boards and faster than usual decapitalization of assets due to reduced loading of centralized wastewater plants. Further it was noted that garden waste should be composted, not fermented. So only vegetable and fruit waste (kitchen refuse) should be included. Lastly, one stakeholder proposes to avoid changes behind the front door because one does not have the authority there. An optimal output has to produce benefits for the user, with other words "what is in it for me".

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