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Global Change and Ecosystems

D 4.1.10 Best practice and a decision-support system for ecosan systems

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SWITCH Briefing Note

SWITCH Document 4.1.10 entitled **Best practice and a decision-support system for ecosan systems**
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Audience This document is targeted mainly at engineers, scientists and policy makers.
Purpose This deliverable, 4.1.10 provides a summary of current best practice in urban ecosan systems, mainly based on Deliverable 4.1.1, and presents an approach for technology selection based on a multi criteria approach. It also provided inputs for technology selection of the urban settlements Ma'awa El Sayadeen in Alexandria, that was conducted as one of the SWITCH pilot projects.
Main outcomes The developed approach uses a set of seven scores describe system performance: contextual independence, public health, impact on environment, resources use, system robustness, invisibility and cost. To facilitate comparison the scores are normalized in a scale from 0 to 100; low and high performance respectively; and the results are shown in a radar plot. In the second part of the deliverable the framework was tested by evaluating 5 systems. Another test was done in the framework of the technology selection of the urban settlements Ma'awa El Sayadeen in Alexandria.
Potential Impact The developed approach shows promising potential for use in negotiations between stakeholders because of its visual, multi-dimensional approach that is understandable for involved parties without deep knowledge on the evaluated technologies.
Issues An important prerequisite for proper system evaluation is availability of data. The evaluation performed within the context of the methodology development showed that the main data gaps relate to contextual independence, impact on environment and resource use
Recommendations Further piloting and development of the developed methodology is recommended, preferably in a real life setting with involved stakeholders.

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Abstract

We live in an era of rapid urbanization. Cities are rapidly developing and are in need of good infrastructure and resources like water, energy and food. At the same time they produce large quantities of wastes. Overall, the rapid urbanization requires new approaches in order to remain within the carrying capacity of our global ecosystem.

One of the issues is the implementation of appropriate sanitation systems which also value the 'resource value' of wastes and wastewater. The standard approach to manage wastewater is the construction of sewerage and wastewater treatment plants. After treatment, the wastewater is disposed off to surface water. Alternative options called ecological sanitation, promoting flows separation at household level and wastewater management in decentralized systems, receive increasing attention in the last decades and are experimented with in various pilot projects (see also Deliverable 4.1.1). A proper evaluation to assess the potential of these new sanitation systems for their potential to improve the sustainability of cities is however lacking. Different methodologies and approaches have been piloted for the selection of sanitation options, some complex, others with high data requirements or complex weighing factors.

Chapter 2 provides an overview of urban ecosan systems and also summarizes the findings of Deliverable 4.1 Adoption, operation and performance of urban ecosan systems.

In the second part of this report (chapters 3-6), a literature review into multi-criteria methodologies and existing frameworks was done to gain insight into decision making process and assessment methodologies regarding sanitation systems. Based on that, the existing framework "Global Sanitation Assessment", developed for the Urban Environmental Group of Wageningen University, was evaluated and some suggestion for improvements were defined.

From the literature review, it was found that 42 different multi-criteria methodologies are applicable for water management; selection of a specific methodology depends on the objective, boundaries, data availability and time allocation of the specific case. Based on some of those methodologies, 18 frameworks for water management assessment have been developed the last 12 years; an inventory of indicators was done finding in total 77 indicators.

The framework is a tool for system's performance evaluation, the optimization of the framework was done by defining a specific objective per criteria and selecting a set of 21 indicators that describe system's performance, and this selection was based on literature review, data availability, relevance and measurability. In order to facilitate and standardize the calculations, and trace raw data, six extra tables were designed. The main shortcoming of the existing framework was the lack of an aggregation method for criteria evaluation; to overcome that problem several methodologies were tested; finally a different approach was defined per criterion; for public health was used the approach of Quantitative Microbial Risk Assessment (QMRA), for impact on the environment was used the approach of Life Cycle Assessment (LCA), and for contextual independence, system robustness and invisibility some check list were designed, based on literature review and interviews with some experts; for cost evaluation it was used the existing approach to calculate annual cost.

As a result, a set of seven scores describe system performance: contextual independence, public health, impact on environment, resources use, system robustness, invisibility and cost. To facilitate comparison those scores are normalized in a scale from 0 to 100; low and high performance respectively; and the results are shown in a radar plot. In the second part of the deliverable the framework was tested by evaluating 5 systems, from the test it was possible to identify that the main data gaps are regarding contextual independence, impact on environment and resource use, also it was found, as expected, that none of the technologies can be define as the best one, each one has different performance score per criteria.

Key words: *Multi-criteria assessment, sanitation, performance, sustainability.*

1. Introduction

Sanitation systems are important for protection of public health and transport of excess water out of urban areas. The conventional sanitation system in Europe collects the different types of wastewater (black, grey and sometimes storm water) to be discharged into the sewer, and transported to the wastewater treatment plant where it is treated and finally discharged into a receiving water body.

This solution has been successful, and over the years it has been replicated all over the world. Nowadays, even though this system has a positive acceptance, its sustainability is questioned due to the combination of drinking water with other components like urine, faeces, soaps, etc.; that complex fluid has to be treated with multifaceted steps making the systems technologically complex and highly expensive. "The conventional model was designed and built on the premise that human excreta is a waste suitable only for disposal, and that the natural environment is capable of assimilating this waste", (Esrey, 2001). However, with accelerated urbanization, the situation has changed and new approaches are under development aiming for improvements in wastewater management.

As a response to pressures increased by rapid urbanization, objectives of wastewater management have changed over time from hygienic concerns to environmental protection and from environmental protection to sustainability. "Originally it has been oriented towards protection only, asking e.g. for a reduction of the maximal acceptable levels of pollution. During the 1970s its scope has become widened to include a principle of provision, aiming at minimizing the environmental impacts. Typical for this principle are demands for further reduction of the emissions. As with modern technology an improvement often involves a trade-off with impairments elsewhere, in the last decade the principle of an integrated assessment of all environmental impacts has been emerging, the typical example being the integrated pollution prevention and control regulation by the EU". (Starkl, 2004).

During the last decades, novel technologies called "non conventional" or "ecological sanitation" have been developed and implemented in pilot projects. The basic principle of ecological sanitation is that urine, faeces and wastewater are resources in the ecological loop. These new technologies promote and courage resource use minimization, and reuse and recycling activities. At this moment, "Technology offers a wide range of alternative solutions, for instance rainwater infiltration, usage of rainwater for toilet flushing, vacuum toilets, urine separation, anaerobic digestion, etc. (Balkema, 2003). The aim is the implementation of "customized sanitation systems" based on local conditions. Nesstaff[1] describes this goal as "Sustainable sanitation" and it refers to sanitation systems that protect and promote human health, do not contribute to environmental degradation or depletion of the resource base, are technically and institutionally appropriate, economically viable and socially acceptable, being the issue of reuse and recycling an optional feature.

[1] Network for the development of Sustainable approaches for large scale implementation in Africa.

2. Urban ecosan systems

2.1. Urban Sanitation Systems

During the 19th century, European cities faced different problems, like epidemics, lack of adequate drinking water supply and lack of sanitation infrastructure to manage human waste and rain flows. Sewers were designed and constructed to improve livability. This solution has been replicated from city to city until now, becoming a conventional sanitation system, with high levels of acceptance.

Nowadays, developing countries are facing a similar situation to the experienced by Europe in the 19th century, water demands and sanitation of a growing human population, combining rapid urbanization and industrialization. For this reason, providing housing, health care, social services, and access to basic human needs infrastructure, such as clean water and the disposal of effluent, presents major challenges to engineers, planners and politicians (Black, 1994; Giles and Brown, 1997). There are strong interactions between the urbanization process, the resulting discharges of wastewater due to individual, industrial, and collective water consumption, the transfer of pollutants in storm water runoff, and their impacts on natural surface and ground waters. Some of these numerous interactions are shown on Fig. 3, (Bertrand-Krajewski, 2000). But contrary to European situation, developing countries can not afford expensive systems and run complex systems that require high levels of expertise.

This is a crucial point in Europe for system renovations and for new housing developments, and in developing countries to implement sustainable systems. Decision makers have a big challenge to find optimal solutions according to local conditions with a long-term perspective.

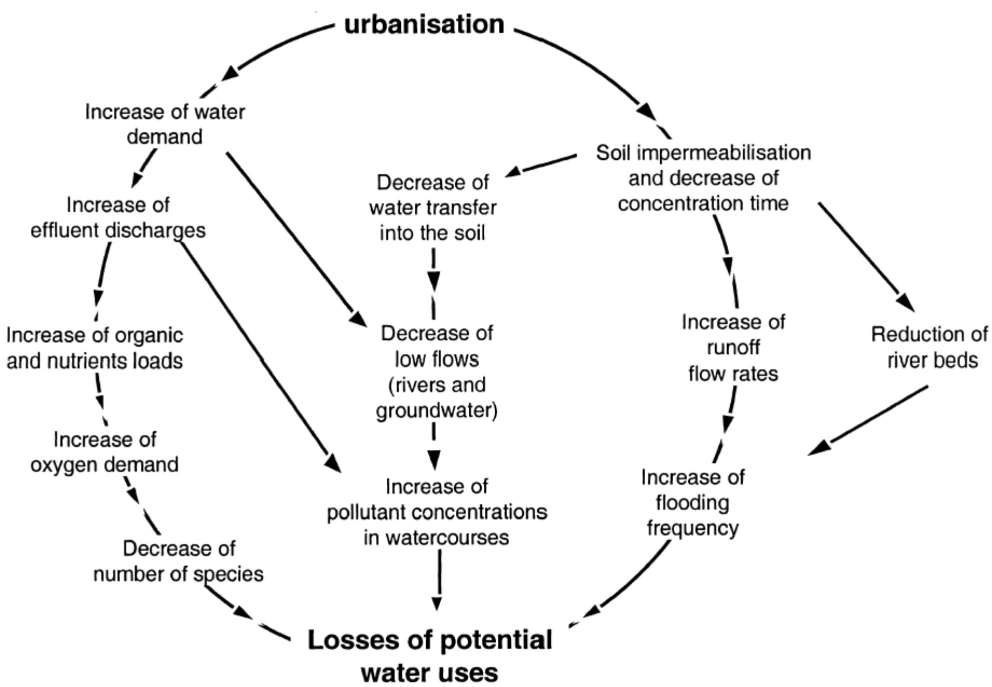

Figure 1. Impacts of urbanization on aquatic environments

Source: Bertrand-Krajewski, 2000

The main objectives of the sanitation system are the protection of public health and transport of excess water out of urban areas; moreover further requirements have been included over time. “From about 1900 to the early 1970s treatment objectives were concerned primarily with (1) removal of colloidal, suspended, and floatable material, (2) the treatment of biodegradable organics, and (3) the elimination of pathogenic organisms. From the early 1970s to about 1980, waste water treatment objectives were based primarily on aesthetic and environmental concerns. The earlier objectives involving the reduction biological oxygen demand (BOD), total suspended solids (TSS), and pathogenic organisms continued but a higher levels. Removal of nutrients, such as nitrogen and phosphorus, also began to be addressed. Also improvements to achieve and widespread treatment of waste water to improve the quality the quality of the surface waters.” (Tchobanoglous, 2003).

Nowadays, ambitious goals have to be achieved in order to accomplish with sustainable standards, and unless we change our traditional approach to solve urban problems, we will not be able to realize them. GTZ agency states that “Only a change in the basic paradigm from linear flow streams and disposal towards a cycle oriented management of renewable resources has the potential to deliver the kind and degree of change which the millennium development goals demand.” (GTZ, 2006).

However, to achieve sustainable development in sanitation is not an easy task. On the one hand the definition of “sustainable development” is ambiguous, while on the other hand sanitation has different aspects and implications at different levels. E.g, at neighborhood level costs and environmental protection are really important factors but at household level parameters like comfort and invisibility become more relevant. For some authors some social and behavioral changes are seen as unsustainable and so on. Supporters and critics of these new technologies are in conflict during decision making processes, making the implementation of novel technologies a big challenge.

2.2. Conventional Sanitation Systems

The conventional[2] sanitation system as usually applied in Europe is illustrated in the figure 4. One of the main characteristics of this system is that different types of wastewater (black, grey and also some storm water) are collected and discharged into the sewer, and transported to the wastewater treatment plant to be treated and finally discharged into a receiving water body.

As a reference system, the conventional system in the Netherlands will be used.
One of the main criticisms to the conventional system is the use of drinking water, for some activities that do not require such high quality. Around 30 percent of the drinking water is mixed with faeces and urine and flushed in the toilet, as shown in figure 5; where it is illustrated the average water consumption in the Netherlands, per household per day.

[2] The word “conventional” can create ambiguity; for the purpose of this study it makes reference to the conventional sanitation system in Europe.

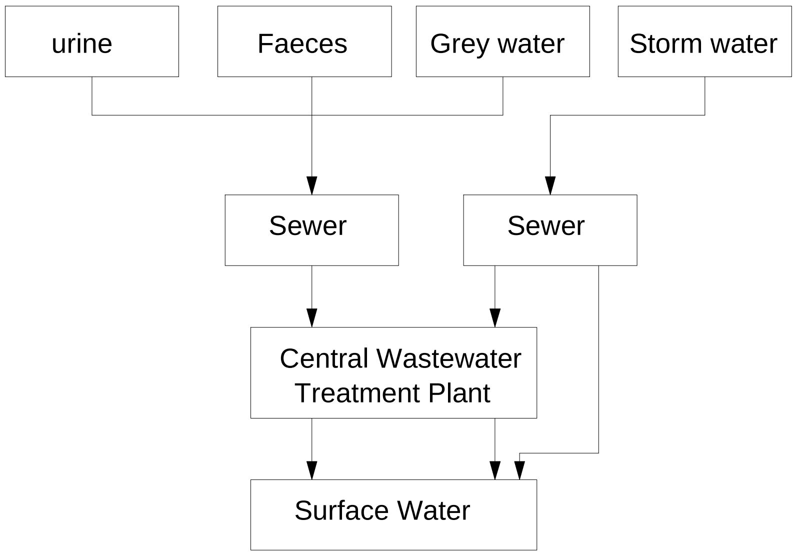

Figure 2. Mixed collection of household wastewater flows in the conventional sanitation system in Europe

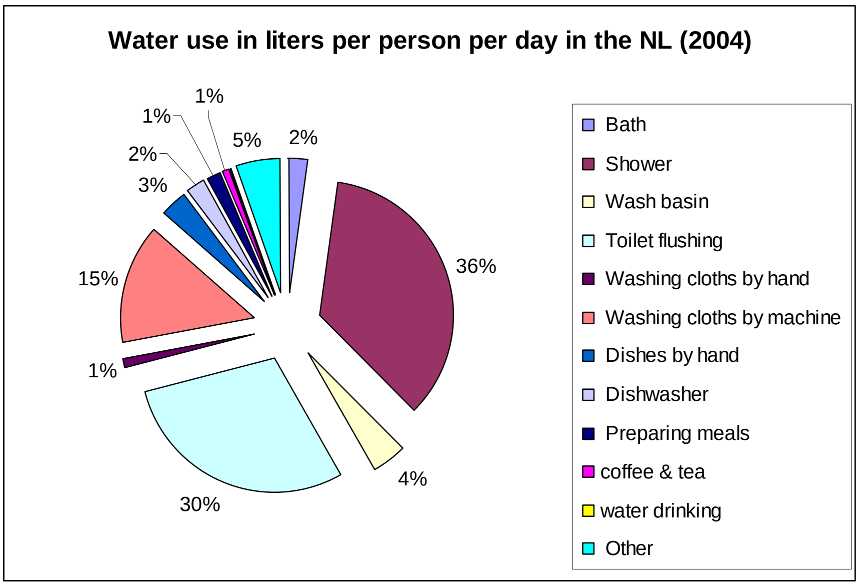

Figure 3. Daily water consumption in the Netherlands - 2004
Source: Betuw, 2005

Figure 6, presents a scheme of a conventional WTP in the Netherlands. In most WMS the combined sewage is treated by several steps: screening, sedimentation, biological treatment, sedimentation, and sludge treatment. Sewage treatment, or domestic wastewater treatment, is the process of removing contaminants from wastewater, both runoff and domestic. It includes physical, chemical and biological processes to remove physical, chemical and biological contaminants. Its objective is to produce a waste stream (or treated effluent) and a solid waste or sludge also suitable for discharge or reuse back into the environment. Typically, sewage treatment involves three stages, called primary, secondary and tertiary treatment. First, the solids are separated from the wastewater stream. Then dissolved biological matter is progressively converted into a solid mass by using indigenous, water-borne bacteria. Finally, the biological solids are neutralized then disposed of or re-used, and the treated water may be disinfected chemically or physically (for example by lagoons and micro-filtration). The final effluent can be discharged into a stream, river, bay, lagoon or wetland, or it can be used for the irrigation of a golf course, green way or park. If it is sufficiently clean, it can also be used for groundwater recharge

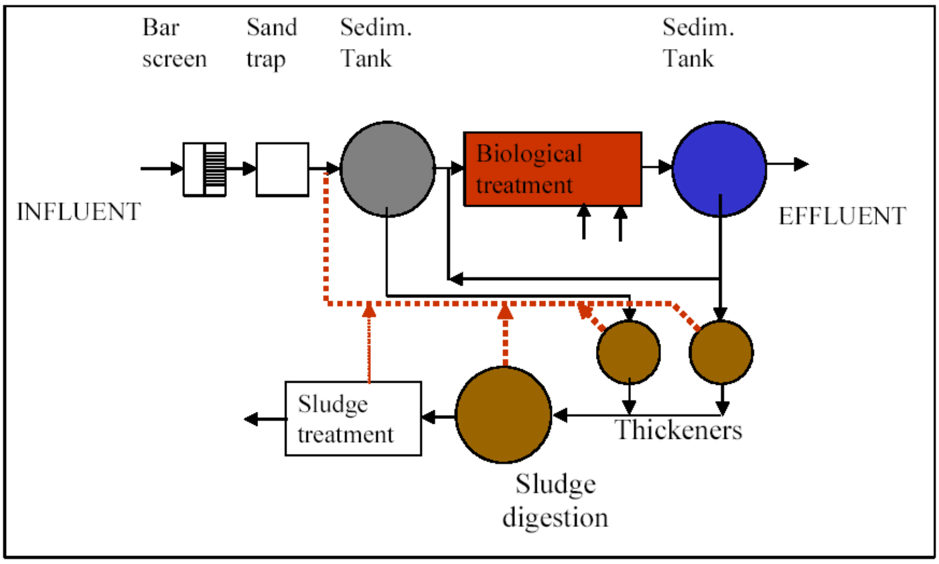

Figure 4. Conventional WWTP
Source: Van Buuren, 2004 in Betuw, 2005

2.3. Ecological Sanitation Technologies

Ecological sanitation promotes separation at source obtaining different flows that can be treated by decentralized systems using less complex processes, reusing or recycling some substances and minimizing discharges in the environment. The different flows, possible treatments and uses are shown in the figure 7.

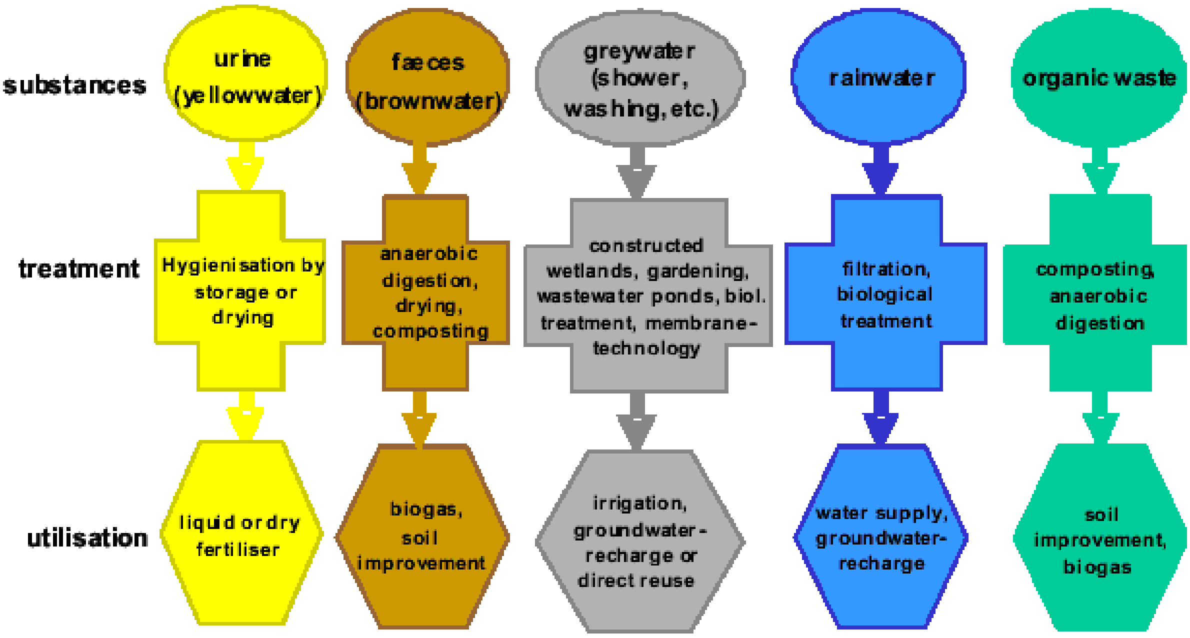

Figure 5. Separation of substances and options for treatment and utilization
Source: GTZ, 2006

“The basic principle of ecological sanitation is that urine, faeces and wastewater are resources in the ecological loop. Ideally ecological sanitation refers to ‘dry toilets’; approaches to manage undiluted urine and faeces separately and reuse or recycle them. Important characteristics of ecological sanitation are: efficient destruction of pathogenic organisms; separation at source and thus no mixing of water, urine and faeces; recycling of urine, faeces and grey water; no drinking water, or very little drinking water, is used”, (Bijleveld, 2003). With these new technologies, and due to the separation of faeces and urine, fertilizers can be produced adding value to the system, at the same time; less water is used to flush the toilets generating a reduction in the water bills and resulting also in less complex waste water treatments.

As a result, there are different undiluted flows with specific characteristics that can be reused or recycled, for instance, most pathogens are contained in brown water, while most nutrients are contained in yellow water. With ecological sanitation the black water is separated and low diluted or undiluted, keeping the pathogens in a relatively small volume, and urine separation toilets collect urine separately, which leaves the nutrients uncontaminated, (Balkema,2003). In conclusion, ecological sanitation aims reduction in wastewater production and water pollution and promotes efficient use of the resources by diminishing the water consumption and recycling resources. Many and diverse non-conventional systems have been developed. Table 2 describes different alternatives within the different stages of the system (generation and separation, collection and storage, transfer and transport, treatment, reuse or recycling, disposal). When new systems are used, it should be taking into account that choices in one stage may create restrictions in other stages. Different combinations can be designed but not all the combinations are feasible.

Table 1: Summary of different types of sanitation systems

		Conven-tional	Com-posting	Vacuum	Dry urine diverting	Low flush urine diverting	Vacuum urine diverting	Inci-neration toilet
Generation & separation	Water use	X	-	X	-	X	X	-
	Separation	-	-	-	X	X	X	X
Collection	Central	X	-	(X)	-	(X)	(X)	-
	Semi-central	-	-	X	-	X	X	(X)
	Decentralised	-	X	-	X	(X)	-	X
Transfer & transport	Sewer	X	-	X	-	X	X	-
	Truck	-	(X)	-	X	X	X	X
Treatment	WWTP	X	-	(X)	-	X	(X)	(X)
	Composting	-	X	-	X	-	-	-
	Anaerobic digestion	-	-	X	-	(X)	X	-
	Incineration	-	-	-	-	-	-	X
	Separate Grey water treatment	-	X	(X)	X	(X)	(X)	X
Reuse or recycling	Urine	-	X	(X)	X	X	X	X
	Faeces	-	X	(X)	X	X	X	-
Disposal	Residual Waste	X	(X)	X	-	(X)	X	X
- = No X = Yes (X) = Possible								

Source: Bijleveld, 2003

2.4. Assessing the adoption and operational performance of urban ecosan systems

The practical implementation of source-separating sanitation systems in urban and rural settings has shown to be rather complex due to the involvement of many actors, such as project developers or housing corporations, future inhabitants, the local municipality, water authorities and water utility companies. Another important barrier in implementing new sanitation systems is that in most cities, sewer systems already exist and investments in assets have already been made. Development of new sanitation options in most western countries therefore requires a long-term vision. Despite the complexity, a number of demonstration projects based on source-separation have been realized inside and outside the European Union in the past 15 years. In order to assess the potential of source-separating sanitation systems for wide-scale application in the long run, it is important to learn from these practical experiences. One of the outputs of Theme 4 is an investigation into practical experiences with source-separation in urban settings. The investigations include:

Short description	**Location and number of investigated cases**	**Location and implemented technologies**
Grey water separation in The Netherlands and urine separation in Sweden (Del. 4.1.1, chapter 2)	Netherlands (2), Sweden (3)	The Netherlands: local grey water treatment in constructed wetland followed by reuse for toilet flush. The black water is discharged to the municipal sewerage. Sweden: urine separation and use in agriculture. In 2 cases grey and brown water is discharged to the municipal sewerage. In one case feces are collected in a dry toilet and locally composted, while the grey water is discharged to the municipal sewerage.
Source separated grey wastewater treatment and agricultural reuse in Palestine (Del. 4.1.1, chapter 3)	Palestine (47)	West Bank - Qebia, located in the western parts of Ramallah district. House onsite- source separated – grey wastewater treatment and reuse. Grey water treated in septic tank- Up-flow gravel filter household grey wastewater treatment plant
Decentralised wastewater reclamation systems in Beijing (Del. 4.1.1, chapter 4)	China (5)	Beijing: decentralized treatment of grey and mixed wastewater with Activated sludge systems, Aerated Ceramic Filter and Contact oxidation systems; frequently combined with disinfection
Constructed wetlands for decentralized treatment of grey water in the Netherlands, Germany and Norway (Del. 4.1.1, chapter 5)	Netherlands (4), Norway (2), Germany (1)	Various modifications of constructed wetlands
User acceptance of vacuum toilets and grey water systems in The Netherlands, Norway and Germany (Del. 4.1.1, chapter 6)	The Netherlands (1), Norway (2) and Germany (2)	Vacuum toilets, in one case combined with local digestion. Constructed wetlands.
Drivers and barriers for scaling up on-site ecosan toilets	Over 100 systemsin various countries, including Philippines, Nepal, India, Burkina Faso, Kenya, Malawi, Mexico, Peru, Costa Rico	On-site ecosan toilets with urine and feces separation. Urine is meant for reuse as fertilizer; while feces are first dried or composted and used as fertilizer

The research into the various cases has focused on:

1. Technology selection - the drivers and barriers that led to establishment of a non-conventional system in a neighbourhood. For this purpose interviews were made with the important stakeholders in these projects in order to gain insight into their main drivers and barriers.
2. Performance - the comparative performance of the source separation systems after they have been established.
3. Operations management - the support systems that make the technologies function.

The main outcomes of the investigation are shown below:

Grey water separation in The Netherlands and urine separation in Sweden
The investigations showed that there were different drivers for the establishment of source-separating sanitation systems in the Swedish and Dutch cases. For the Swedish cases the main drivers of the involved actors were nutrient recycling, reductions of emissions and an active policy of the local government. In the Netherlands the main drivers were the reduction of water use, reduction of sewer overflows and reduction of emissions. The main barriers in all cases were high investment costs and the limited experience with new sanitation approaches systems compared to the conventional system (sewers and off-site treatment). All cases were operational and well-functioning after 8 – 12 years of operation and most people using the systems are satisfied about the performance and use of the systems.

The three Swedish cases show that urine separation systems have a high potential in reducing emissions and in recovering resources (nutrients). The dominant failure reason for the urine separation systems in Sweden was pipe clogging. Pipe clogging can be controlled by extra maintenance activities of the tenants / house owners. For future cases recommendations for improvement have been made by Swedish experts. One of these sites had frequent problems with flies and a high O&M requirement by the tenants.

The two Dutch cases with local grey water treatment illustrate that decentralised grey water treatment systems have a large potential to reduce water consumption (upto 40%). Both systems lack an effluent monitoring system which in the used performance assessment is considered as a risk to public health. Some (partial) system failures have been encountered due to lack of operation and maintenance by inhabitants.

All five cases were characterised by relatively higher investment costs compared to the conventional sanitation system. The yearly costs (capital and operation expenditures) of two cases in Sweden were lower than the conventional system.

Constructed wetlands for decentralized treatment of grey water in the Netherlands, Germany and Norway
This study has investigated four of these systems in the Netherlands, two in Norway, and one in Germany built between 1993 and 2000. The investigated constructed wetlands include various designs. These cases showed that the implementation of on-site grey water treatment systems combined with reuse of reclaimed water may lead up to 57% less drinking water consumption.

The treatment performance of the wetlands was generally satisfactory, although a number of the studied systems did not monitor properly the systems due to high costs this imply and some operational difficulties with clogging because of inadequate maintenance. People perception of constructed wetlands is positive, health risk is inexistent and different schemes of management and operation can be implemented. Nowadays, there is a big potential for the implementation of these type of systems due to the increasing need to diminish discharges of pollutants into environment, source separation trends and sustainability goals. In addition, constructed wetlands in neighbourhood areas may form an attractive element in urban landscaping, especially in water-scarce areas.

Source separated grey wastewater treatment and reuse in Palestine
The approach of house onsite treatment of grey wastewater and reuse of treated effluent for irrigating crops has a high acceptance in the investigated Palestinian peri-urban and rural settlements. The application of this non conventional sanitation systems so far been initiated by local NGOs which have constructed so far more than 600 units all over the West Bank with co funding of various donors. The main driver for application is water scarcity in the West Bank.

The results of interviews with owners of 47 house onsite sanitation systems in Qebia village showed that the implemented grey water and reuse systems have a high acceptance and commitment of users. The operational and maintenance requirements of the system are limited to routine work like cleaning and desludging, and the system proves to be robust. The biggest incentive for applying this system is the reuse of treated grey wastewater for irrigation purpose which is socially accepted. Another driver was the availability of external funds. The main worries people have over the constructing of those house onsite systems are health risks, flood concerns, and odour emission. Those issues should be given special attention when implementing other projects. The results show that the systems prove to be efficient in wastewater treatment and food production. Further technological improvements should focus on reducing odour emissions and further improvement of the system to handle the black wastewater (currently separately disposed off in cess pits) in order to reduce the desludging frequency and its potential risk of groundwater pollution. The researchers also recommend to do some results in the effluent quality of the systems in order to test compliance with local effluent disposal requirements.

Decentralised wastewater reclamation systems in Beijing
To alleviate water-scarcity, Beijing has an integrated strategy on water-recycling involving a mixture of off-site and on-site wastewater reclamation systems. It is estimated that approximately 300 decentralised wastewater reclamation systems (DWRSs) are in operation, producing 50,000 – 60,000 m^3 / day of second quality water that is used for toilet flushing, landscape irrigation, street cleaning, car washing, etc. The objective of the research was to analyze the adoption and technical performance of these systems based on a number of case studies. The main conclusions of this research are:

- Various techniques are in use for decentralized wastewater reclamation (contact oxidation, activated sludge systems, SBR systems). According to our assessment the investigated systems function well without any processing, safety and health

problem. However, effluent monitoring is done on voluntary basis and real quality control by an independent party is lacking.
- There is a strong financial driver to implement DWRSs, because of the relatively short pay back times, especially for the private sector. Other drivers are related to the regulations and to awareness on water scarcity issues.
- The implementation of the regulation on DWRSs is frustrated by the absence of real penalties. In addition the monitoring of the systems is virtually absent.

User acceptance of vacuum toilets and grey water systems in The Netherlands, Norway and Germany
User acceptance is a key issue in implementing new forms of sanitation, because users are confronted with new types of toilets and equipment in their homes and neighbourhood. This paper reports research on the user acceptance of vacuum toilets and grey water systems in 5 neighbourhoods in The Netherlands, Norway and Germany. Interviews with households in the various cases showed a high appreciation of grey water treatment systems (marks between 7.1 and 8.0) and an average lower satisfaction level for vacuum toilets compared to conventional water flush toilets. Despite of the lower satisfaction, the appreciation of vacuum toilets was generally high, due to the water saving aspect of vacuum toilets (marks between 7.1 and 8.0 for the cases without operational problems compared to 7.1 for the conventional toilets). The flushing sound of vacuum toilets was considered to be unpleasant by 40-65% of the respondents compared to 25% of a control group with conventional water flush toilets. Subsequent sound level measurements showed that the maximal sound level of an average vacuum toilet is 12 dB higher than an average conventional toilet. The measurements indicated that there are various options for sound reduction, such as optimisation of the pipe diameters, sound reducing backplates and silencers.

Drivers and barriers for scaling up on-site ecosan toilets
This study has focused on on-site toilets that combine urine diversion and dehydration or composting of organic matter. The key research question that has been analyzed in the study is what prevents ecological sanitation from going to scale? The paper reports on two questionnaire surveys undertaken between August 2007 and March 2008 with experts in the North and South who have been strongly involved in ecological sanitation. Respondents ranged from field workers testing pilot ecological sanitation schemes to researchers working full-time on understanding specific aspects of ecological sanitation.

In response to the first questionnaire, champions of ecological sanitation mentioned various reasons why ecological sanitation did or did not work. Responses to the second questionnaire, gave further information on the important factors for scaling up ecological sanitation from:
- The user perspective: Driving forces and barriers for implementing and using ecological sanitation
- The Government perspective - creating an enabling environment
- The product user perspective - the end users of excreta and/or urine in agriculture

From a user perspective, there remains a reluctance to accept ecological sanitation as a possible option, mainly because of reluctance to handle the by-products (urine and faeces). Although a number of the experts in ecosan would argue that these social barriers are being overcome (or will be shortly), the overall results from the two questionnaires are more pessimistic. In order to find acceptable solutions, it is of critical importance that stakeholders ranging from government personnel to households are more aware of the potential benefits for ecosan. Promoting ecosan requires advocacy for the benefits and also requires people's concerns to be directly addressed. In particular, it needs to be made clear that the end product is no longer faeces, but a nutrient rich derivative that is no longer unsafe or impure.

There is a general lack of support and co-ordination at all governmental levels, national, intermediate and municipal. Several countries lack any general policies and/or regulation focusing on sanitation, let alone consider ecological sanitation as one of a range of options. Consequently, ecosan is often not taken seriously or takes place only in small scale pilot schemes which are not converted into large-scale sustainable projects.

One of the other constraints is that the initial investment costs tend to be slightly higher for ecological sanitation than for other on-site sanitation options such as VIPs. Some ecosan governmental programmes place strong reliance on government subsidies or external donors to make access affordable. Such programmes however prove not to be sustainable in the long run. Governments will need a long term vision to invest in ecosan to stimulate a range of services which include funds for capacity development and the actually implementation of ecosan facilities.

Ecological sanitation clearly has a niche because it provides the final users with nutrient rich products from urine and faeces for agriculture use. Ecological sanitation can also be useful in certain difficult geographical circumstances (high ground water table, rocky ground). These niches should be developed further and can provide the key to making ecological sanitation successful.

3. Development of a Multi Criteria Framework

3.1. Problem description

Worldwide but also in Europe, the recycling approach called ecological sanitation gets more and more attention. However, despite these novel developments, nowadays there is not clear and precise information available regarding the performance of existing and new urban sanitation systems.

The development of novel technologies causes changes as well in decision making processes, existing evaluation methodologies need changes to include new parameters that before were not relevant for conventional like invisibility or user acceptance. As was mentioned before, sanitation objectives became more complex. At the same time, new technologies offer a wide range of alternatives, decision makers must be aware of the trade-offs since the alternative systems have disadvantages as well. This requires multi-objective optimization and consequently, multiple criteria analysis has become an indispensable tool for dealing with this complex assessment.

Currently, the lack of knowledge about novel systems is a barrier for scaling up the implementation of ecological sanitation systems. In general, urban planners and decision makers are afraid to be innovators and they prefer to continue using the conventional methods to avoid risks. According to Saywell, (2006), “The conventional approach to sanitation planning creates an artificial barrier between technical decision making and institutional analysis in its broadest sense. This result in technically “appropriate” systems which don’t work, or which don’t achieve the objectives that some people value highly, crucial to changing this paradigm is to acknowledge in a more effective way that many of the “objectives” of urban sanitation systems may actually be in conflict; a real discussion about the payoffs is needed.” This statement agrees with the GTZ agency that affirms that: “Knowledge management in the urban environment needs to be updated”. (GTZ, 2006).

One of the main challenges is to stop the inertia of decision making process, to include ecological sanitation systems in the discussions for further urban implementations. In fact, different communities have different needs and for some of them conventional system is the best option while for others is not. The need for reliable information about the performance of conventional and new technologies is clear, for that reason the assessment of the different technologies in a multiple criteria framework can help providing concise and comparable information on different aspects.

The first step is to understand the dynamics of the decision making process; during this process different stakeholders diverge and each one will try to defend their own interests. Bijleveld, (2003) describes the emerging controversy about the sustainability of alternative concepts in urban water management. And he describes as well the limits of the wide-ranging problem, one group that emphasizes in environmental benefits (nutrient recycling, keeping the water cycle clean), whereas the opponents stress on social and cultural criteria (arguing that such concepts are not compatible with the peoples attitudes to wastewater and cannot be integrated into the existing system), environmental risks of the system and other drawbacks. This discussion is also addressed by Starkl et al, (2004), they raise the discussion “feasibility versus sustainability in sanitation”, and also analyze different stakeholders’ usual interests during decision making processes, see table 1,

Table 2: The actors and their usual interests in the DMP in Austria

	Environment	Costs	Social/cultural	Technical
Financer	Low	Minimize subsidies	Low	Low
Authority (provincial)	Enforce BAT	Minimize overall costs to society	Low	Consider interests of other stakeholders
Developer	Avoid excessive damage	Minimize user fees, avoid excessive cost	Minimize local complaints	Low (delegate to planner)
Planner, Consultant	Consider BAT	Select cheapest project, consider consultant fees	Low	High
Users	Mainly low	Minimize user fees	Avoid changes in behavior	Low
Companies	Low	Low	Low	Sell own product
Other stakeholders	Depends on business(e.g. water bottling)	Low	Low	Minimize damages to own property

Source Starkl et al. 2004

3.2. Multiple Criteria Framework for Urban Sanitation Systems

The Multiple Criteria Framework to be developed will be a tool for assessment of sanitation systems’ performance. The main step to achieve this is to define a set of indicators that clearly describe system’s performance, and a methodology to evaluate this multidimensional information. The framework should facilitate comparison among technologies and can be helpful during decision making processes providing valuable information for discussion.

The object of study is urban sanitation systems; however it is necessary to set up boundaries in order to narrow the scope of the assessment. The starting point of the system is the drinking water supply at household level, followed by the different discharges of wastewater, urine and feces, the collection at source (if applicable), the treatment processes, and the final discharges into the ecosystem. The purification treatment required for piped water, and rainwater systems will not be taken into account,

In the decision making process, different criteria are involved when choosing a sanitation technology and the importance of those criteria can differ according to the stakeholders’ interests. Usually, big flows of information (raw data) are available but that information can be analyzed and discussed by policy makers and managers just if they are expressed as indicators and indices that describe the performance of each technology. That ranking of ideas is showed in the Figure 1.

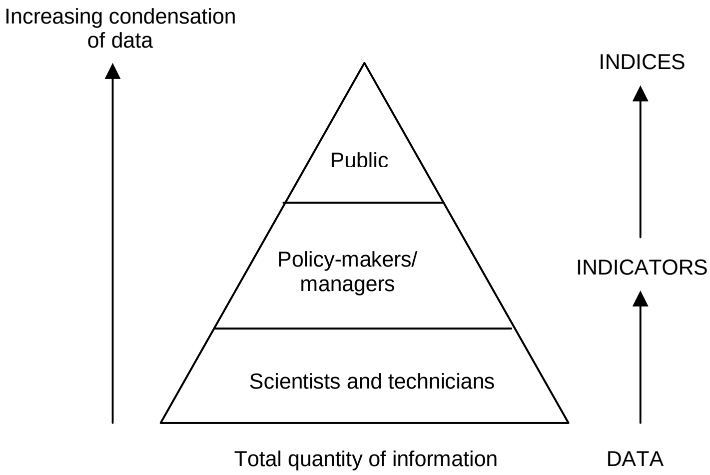

Figure 6. The OECD "pyramid of indicator sets"
Source: (Lohani, 1997)

One of the requirements for the framework is transparency and traceability; it means that the process to transform raw data into indicators and the final calculation of the indices must be clear and understandable for the different stakeholders. Also information should be easily retrieved to know why one technology is better than other in a specific criterion.

Most of the multiple criteria methodologies aims to achieve a final score per alternative to identify the best performer; but is it feasible, sufficient and reliable to come up with a unique performance score per technology? Based on experiences with benchmarking of water supply companies, the different criteria should preferably remain separate. This, because it provides insights for interpretation, avoids comparison and weighting among different criteria. The latter usually leads to sub estimation, overestimation or bias. The multi criteria approach is also helpful for matching local needs with strongest score per criterion to find the most suitable option. Moreover, it promotes the transparency of the assessment and thus increases stakeholders' trust.

The scope of the framework is technological assessment looking for objective data that are preferably quantitative. Subjective, qualitative aspects like cultural acceptance, institutional requirements and perceptions of sanitation are preconditions that should be assessed at the beginning of the decision making process, previous to technical selection. The framework gives a general idea about the technology performance in the different criteria, and more detailed methodologies should be applied per criteria in order to obtain more precise results, being aware that more detailed methodologies have higher data requirements.

In conclusion, the framework is not designed to find the "optimal technology" but to provide an overview on different aspects, that helps decision makers and others stakeholders during decision making processes. It will be also helpful to handle data from research projects that follow the same methodology (apply similar questionnaires) and to create a database of the performance assessment of the different urban sanitation systems.

3.3. Research objective

The main objective is the improvement of the existing framework for the assessment of urban sanitation systems that is currently used in the Global Sanitation Assessment. With this framework, it will be possible to evaluate the performance of conventional and non-conventional urban sanitation technologies.

Main Research Questions

How can the actual framework be improved to perform a proper technical assessment of urban sanitation systems?

Specific Research Questions

1. What are the drawbacks of the existing framework?
2. What methodologies and frameworks are used for decision-making about and assessment of sanitation systems?
3. Which set of criteria and indicators have been used in these methodologies and frameworks?
4. What set of criteria and indicators describe the technical performance of a given sanitation technology?
5. What methodologies can be used for the criteria evaluation and aggregation of indicators to obtain a criteria score?
6. What lessons can be learned from previous assessments?
7. How can the knowledge derived from these decision support tools be used or adapted to improve the existing framework?

After testing the optimized framework:

8. What recommendations can be given for further development of the framework?
9. Where are the main gaps data in the current data sets on conventional and non-conventional sanitation systems, and what recommendations can be given for improvement of data collection?

3.4. Methodology

This approach taken in this research was divided in three parts. The first part was the literature review; the second part was the optimization of the existing framework and the third part was the testing of the optimized framework. An overview of the methodology is shown in the figure 2.

The first part was a literature review into multiple criteria methodologies and assessment of sanitation technologies, and frameworks used to assess urban water management. An inventory of indicators used for urban water management[3] was done based on 18 existing frameworks developed in the last 12 years. After that, sets of indicators per criterion and the “popularity” of each indicator was reviewed.

During the second part, the optimization of the existing framework was done. Due to the aim of the framework, “technology assessment”, criteria closely related with this aspect where selected and specific objectives were set. After that a set of representative indicators per criteria was defined based on the popularity inventory, framework requirements, data availability, and indicators reliability and measurability. After having defined a set of indicators, each criterion was evaluated separately. For that, at least two different aggregation methods were tested, per criterion and the one that fitted better with the objective was selected. With the list of indicators and the chosen methodologies, auxiliary tables were developed in order to allow data traceability and also to facilitate and record intermediate calculations.

The third part of the report was the testing of the framework by using data of the conventional sanitation system in the Netherlands and a number of case studies of non-conventional systems implemented in Europe. The framework was preliminary tested with information from eight studies done in the Netherlands, Sweden and Norway, and the conventional sanitation system in the Netherlands. Afterwards, data gaps were identified and only five system where chosen for the final test. For this final test due to data limitations, some assumptions were made in order to test the framework. Data were aggregated and standardized into a scale from 0-100, low and high performance respectively. Finally, the standardized scores were represented in a radar plot.

[3] Some of the methodologies studied included in their scope drinking water, wastewater and storm water systems

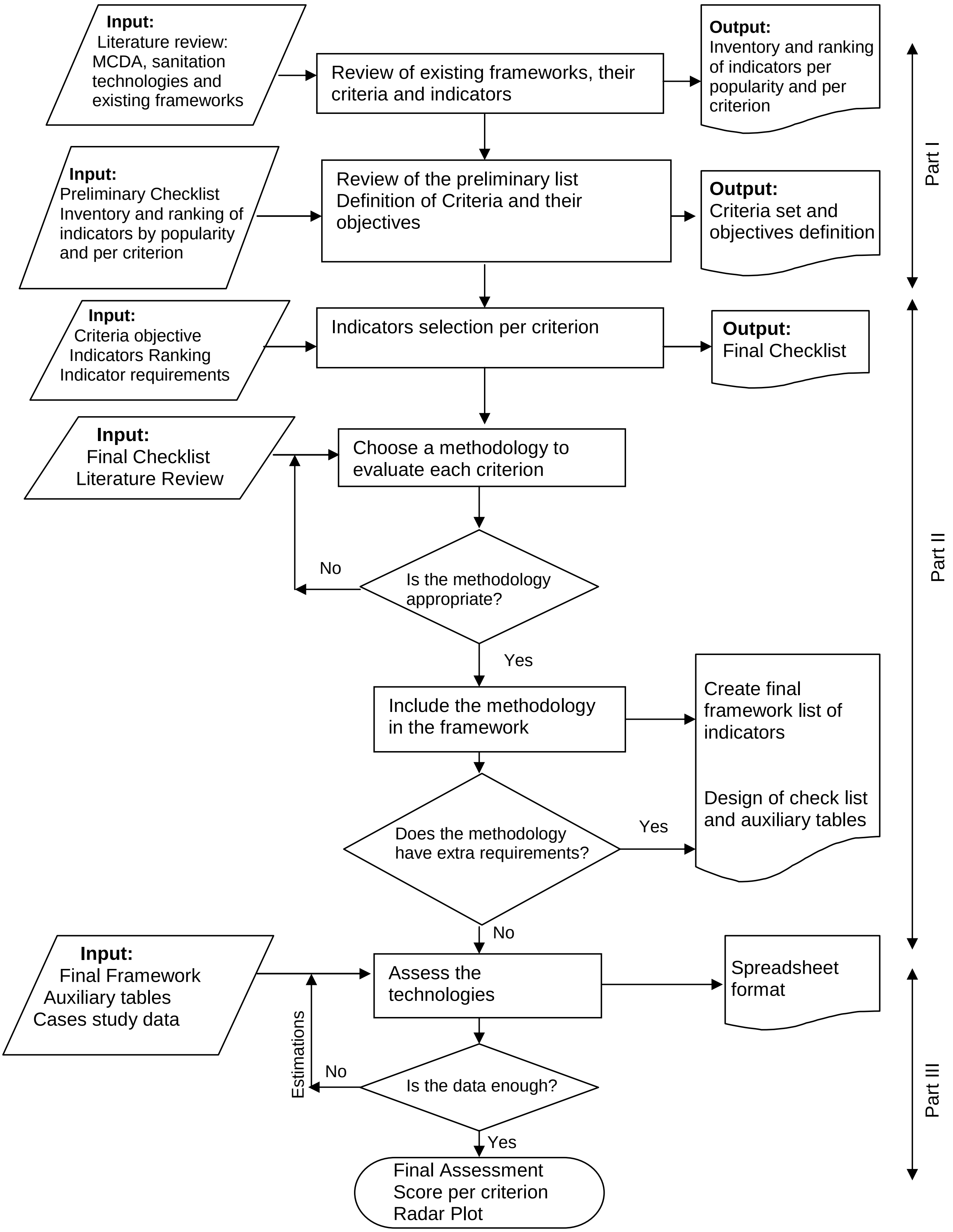

Figure 7. Research Methodology

4. Multi-criteria Methodologies for Urban Sanitation Systems Assessment

The objective of this chapter is to gain insight about multiple criteria methodologies and existing “assessment frameworks” used in urban water management[4]. A review of 18 different methodologies was done to elaborate a detailed list of indicators, also to identify sets of indicators per criterion with their respective occurrence.

4.1. Multiple criteria analysis for selecting sanitation systems

The conventional sewer system, the solution from the 19th century, is still the approach towards sanitation in the Netherlands and in many other countries over the world. Technologies for wastewater reclamation and purification have developed to the point where it is technically feasible to produce water of almost any quality and advances continue to be made.

Nowadays, lifestyles, environmental conditions, drivers and barriers have changed over the years and different technologies have been developed during the last decades to approach in different ways the management of wastewater not only in cities but also in rural areas. And now, it is needed to test pilot projects and to measure their performance in order to create knowledge about non-conventional systems. “*Knowledge management in the urban environment needs to be updated”.* (GTZ, 2006).

Saywell describes the actual conflict and the challenge for overcoming it, “The conventional approach to sanitation planning creates an artificial barrier between technical decision making and institutional analysis in its broadest sense. This result in technically “appropriate” systems which don’t work, or which don’t achieve the objectives that some people value highly. Crucial to changing this paradigm is to acknowledge in a more effective way that many of the “objectives” of urban sanitation systems may actually be in conflict; a real discussion about the payoffs is needed. The first step is to learn to understand what these objectives are and what external factors drive decision making across all the domains of the city. The second step is to build in flexibility and begin to anticipate how these objectives and the urban context itself may change over time.” (Saywell, 2006)

Urban planners have the task to decide between improve actual systems, or shift to new ones; and the limited information about novel technologies slows down its further implementation. Nowadays, there are different systems with a variety of options that can be suitable for different conditions making more complex decision making because there is no “a best system or technology”, each case should be analyzed according the needs and local conditions to find the most favorable option.

But not only, is the technology selection an additional duty for decision makers, but also the selection of the methodology for the assessment. “There are a great number of MCDA methods, a situation that may be seen either as strength or as a weakness”

[4] Some of the methodologies studied included in their scope drinking water, wastewater and storm water systems.

(Bouyssou et al, 1993). Moeffaert, (2003), explains that on the one hand the great variety of multi-criteria methods makes it possible for the decision-maker to choose the appropriate method for a certain decision-making situation and on the other the weakness lays in the fact that not one model is strong enough for all different kinds of decision-making situations. – The decision maker may even choose the MCM that fits best with the wanted decision.

Decision making in sanitation involves different stakeholders with different background, interests and points of view that can be in conflict. Decision making objectives in sanitation have been changing over the years; in the past, decisions were mainly made based on economic assessment, using the relation cost-benefit, a traditional tool based on single criteria. This approach estimates an economic value for all the criteria involved, and the best alternative is the one with the lower total cost. Lately the need to incorporate social and environmental criteria changed the methodologies used in the decision making.

Nowadays, when "the question of the sustainability of urban water systems and of their management is becoming very important, and needs new research actions to get a better knowledge and understanding from scientific, technical, ecological, and socio-economic points of view. This knowledge is absolutely necessary for any methodology aiming at assessing the sustainability of urban water systems by means of indicators and criteria, which should be based on reliable field data", (Bertrand-Krajewski, 2000). As a response, more complex methodologies have been developed to cope with decision making process were conflicting and multiple objective are involved. Those multiple criteria decision assessments (MCDAs) provide a better understanding and are meant to facilitate collective decisions.

The necessity of an integrated and sustainable management of urban water systems led researchers to develop two complementary approaches and methodologies: modeling and decision making tools. Due to the lack of sufficient and validated experimental data (because of technical and financial reasons given in the next section), these models cannot be really calibrated, tested, and verified. To calibrate them, large amounts of data are required that could sometimes be sufficient to make decisions without using the models but simply by analyzing the data. Sustainable water management is a challenge for the future, as is the question what role technology may play in this. (Bertrand-Krajewski, 2000).

4.2. Multiple Criteria Methodologies Review

Multi-criteria Decision Analysis has become an indispensable tool for dealing with complex decision problems in different fields which involve a number of conflicting objectives and a variety of stakeholders. According to Mysiak, (2005), "Multi-criteria decision analysis (MCA), constitutes both a framework for structuring decision problems which encompass multiple decision criteria and alternatives, and a set of methods to generate or elicit and aggregate preferences regarding the performance of these alternatives. Consequently, MCA represents added value to both the decision process first by helping the decision maker learn about the decision problem and explore the alternatives available and the decision outcome and second by helping elicit value judgments about trade-offs between conflicting objectives."

There is a variety of methodologies that can be used for water management assessment; in the table 3 are shown different methodologies with their respective applications, the selection of a given technology depends on the objectives of the assessment, data availability and time allocation. A description of the methodologies with their main characteristics is included in the annex, table 42. However, “Because of the variety of methods, choosing the most appropriate for a particular decision situation is a decision problem in itself.” (Mysiak, 2005) The existence of this large number of methodologies shows that none of them is able to make a broad spectrum of assessments, with satisfactory results.

Several multi-criteria methodologies have been developed, and there is not a unique classification for them. Some of the most used methodologies are included in the table 4 and can be grouped in six categories. According to Starkl et al. (2005), the different MCDA methodologies can be classified as follows:

1. *Simple methods (SM):* These methods are mainly based on intuitive approaches, such as negotiation or simple ecological risk analysis.

2. *Economic evaluations (EV):* This group encompasses basic cost comparisons such as whole life costing, the well known cost-benefit analysis and more advanced single objective optimization tools (where the single objective is cost minimization).

Table 3: Different MCDA methodologies and their applications

		Public Health	Impact on Environment	Resources Use	System Robustness	Invisibility	Cost
1	Cost-Benefit Analysis (CBA)	✓	✓	✓	✓	✓	✓
2	Cost-Effectiveness Analysis (CEA)	✓	✓	✓	✓	✓	✓
3	Life Cycle Assessment (LCA)			✓			
4	Life Cycle Impact Assessment (LCIA)	✓	✓	✓	✓	✓	✓
5	Geography information System (GIS)	✓	✓	✓			✓
6	Analytical Hierarchy Process (AHP)	✓	✓	✓	✓	✓	✓
7	Mathematical Programming	✓	✓	✓	✓	✓	✓
8	Risk Assessment	✓	✓	✓	✓	✓	✓
9	Dollar value appraisal	✓	✓	✓	✓	✓	✓
10	Classical utility analysis (UA)	✓	✓	✓	✓	✓	✓
11	Ecological Risk Analysis	✓	✓	✓			
12	Cost Comparison (based on net present value, annuity)	✓	✓	✓	✓	✓	✓
13	ORWARE	✓	✓	✓	✓	✓	✓
14	ELECTRE I - II(Outranking)	✓	✓	✓	✓	✓	✓
15	PROMETHE II (Index of outranking)	✓	✓	✓	✓	✓	✓
16	Multi-attribute Utility Theory (MAUT)	✓	✓	✓	✓	✓	✓
17	Simple Multiple Attribute Rating Technique (SMART)	✓	✓	✓	✓	✓	✓
18	Absolute veto rule	✓	✓				✓
19	BPEO index (example of a LCA)	✓	✓	✓	✓	✓	✓
20	Compromise Programming	✓	✓	✓	✓	✓	✓
21	Eigenvector Method	✓	✓	✓	✓	✓	✓
22	Individual Veto Rule	✓	✓	✓	✓	✓	✓
23	Majority Election (Intuitive outranking)	✓	✓	✓	✓	✓	✓
24	Majority Vote (Intuitive Contingent index)	✓	✓	✓	✓	✓	✓

25	NAIADE (Novel Approach to Imprecise Assessment and Decision Environments)		✓	✓			✓
26	Random Dictatorial Rule	✓	✓	✓	✓	✓	✓
27	Seniority Rule (used e.g. in ORESTE)	✓	✓	✓	✓	✓	✓
28	Simulated Arbitration (Example of DEA)	✓	✓	✓	✓	✓	✓
29	SMART (Example of MAUT)	✓	✓	✓	✓	✓	✓
30	Strong Dictatorial Rule	✓	✓	✓	✓	✓	✓
31	Environmental Impact Assessment (EIA)	✓	✓	✓			
32	Material Input per Unit of service (MIPS)		✓	✓			
33	Environmental Risk Assessment (ERA)		✓	✓			
34	Material Flow Accounting (MFA)		✓	✓			
35	Cumulative Energy Requirements Analysis (CERA)		✓	✓			
36	Environmental Input-Output Analysis (Env.IOA)		✓	✓			✓
37	Analytical Tools for Eco-design (Eco-design tools)		✓	✓			
38	Life Cycle Costing (LCC)		✓	✓			✓
39	Total cost Accounting (TCA)		✓	✓			✓
40	Social Impact Assessment (SIA)					✓	
41	Social Capital Assessment Tool (SOCAT)					✓	
42	Agent-based modeling (ABM)					✓	

Sources: Munier, 2004; Starkl, 2005; Brunner, 2004; IWA, 2004, Belton, 2002; Jeppsson, 2002; Moeffaert, 2003; Pierini, 2005.

3. *Life cycle analysis based methods (LCA):* This group encompasses several LCA based methodologies.

4. *Multi attributive methods using utility functions (MAM):* e.g. MAUT and its offspring, such as SMART.

5. *Outranking methods (ORa):* Examples are ELECTREE and PROMETHEE, recommended for situations where there is finite number of discrete alternatives to be chosen among.

6. *Special methodologies (SpM):* This group encompasses all methods which can not be clearly assigned to one of the other groups. The most prominent method is the cost-effectiveness analysis which is a hybrid of group 2 and 4, further NAIADE and AHP, which both use ideas of 4 and 5 in a non-standard way.

Table 4: Classification of MCDA methodologies

Group 1 Simple methods	Group 2 Economic evaluations	Group 3 Etc.	Group 4	Group 5	Group 6
Brainstorming	Cost comparison	Critical volumes	MAUT	Election methods	Cost-effectiveness
Negotiation	CBA	Ecological scarcity	SMART, SWING,etc.	ELECTRE I, IS	AHP
Simple ecological risk analysis	Linear system optimization	MIps	Classical utility analysis	ELECTRE II, III, IV	NAIADE
	RWSP	SPI	Compromise programming	ELECTRE TRI	REGIME
	VAROPT	URWARE	Composite Programming	PROMETHEE I, II	Weighting methods
			Expanded utility analysis	Method of interpretation	

Source: Starkl et al, 2005

4.3. Existing Multi-Criteria Frameworks for the Assessment of Urban Water Management

Based on multi-criteria methodologies, different frameworks have been developed for the Assessment of Urban Water Management in the last years, they differ on objectives, boundaries and evaluation methodology. "Approaches vary depending on the author's underlying view of sustainability. Economists tend to use models with roots in economics, while natural scientists use models with roots in the environmental sciences (e.g. the Pressure-State-Response model); others have focused on the relation between society and the environment. Some (often politicians) aspire to use balanced lists, which include social, economic and environmental dimensions", (Oman, 2004).

Criteria Review

Different methodologies have been developed aiming to help in the decision making process, different criteria and different approach has been followed. Starkl et al, 2004, summarize the approach of different methodologies used in water management, see table 5. It is also shown how the same criteria can be assessed based on different sets of indicators, with the possibility of influencing the results.

Table 5: Survey of criteria of different projects

Source	Health	Environment	Economy	Social/cultural	Technology
UWP	Hygiene	Eutrophication	Total costs: investment, O and M	Organizational Capacity	Effectiveness, efficiency
	Chemicals	Pollution (water, soil) Resource utilization		Context adaptability Sector adaptability	Reliability Adaptability, flexibility
SWARD	Risks	Environmental impact Resource utilization	Life cycle cost Willingness to pay	Public awareness Acceptability, public understanding	Performance: system Reliability, durability
		Service provision	Affordability	Participation, social inclusion	Flexibility, adaptability
			Financial risk	Responsibility	
ATV-DVWK	Indirect as pollution	Pollution	Direct and indirect costs (technology)	Communal aesthetics	Risk: failure/accident
		Use of natural resources	Transfer to abroad	Incentive compatibility	Adaptability, flexibility, openness
		Effort/Input for O and M	Labor market		
DMF, Austria	Indirect as impact	Impact (water)	Costs: construction, maintenance	Acceptability	State of the art, BAT
DMF Romania	Indirect as impact	Simplified EIA: Air, water, soil	Costs (construction, maintenance)	Affordability	State of the art

Source: Starkl et al, 2004

Indicators Review

The indicators review was done by comparison with previous frameworks for water management sustainability. The inventory was adapted from Balkema (2003), and included 7 more studies, to have a total of 18 frameworks, in the last 12 years. This comparison is summarized in table 6.

Table 6: Review of indicators from previous studies

List of Indicators		1995	1995	1996	1996	1996	1996	1997	1997	1997	1997	1998	1999	1999	2000	2003	2003	2004	2005
		Em	O/	A	E	F	J	B	Bu	I	O	K	L	M	H	Ba	Br	S	Dl
	Economical indicators:																		
1	Costs		x		x	x	x					x		x	x	x		x	
2	Labor														x				
3	Affordability																x	x	x
4	Use of surface area											x							
5	Financial risk exposure																	x	
	Environmental indicators																		
6	Accumulation			x						x									
7	Biodiversity / land fertility			x	x	x					x	x					x	x	
8	Desiccation										x								
9	Export of problems in time & space						x			x	x								
10	Extraction			x															
11	Integration in natural cycles				x						x								
12	Land area required / space								x			x		x	x	x	x	x	x
13	Odor / noise / insects / visual											x					x		
14	Optimal resource utilization /			x	x	x	x			x	x								
15	Resources reuse				x	x			x	x	x		x		x			x	
16	Water reuse				x	x		x	x	x	x	x	x		x	x			x
17	Nutrients reuse		x		x	x		x	x	x	x	x	x	x	x	x			x
18	Energy reuse				x	x		x		x	x				x		x	x	x
19	Raw materials									x									
20	Pathogen removal / health				x	x			x						x				
21	Pollution prevention				x	x			x		x								
22	BOD / COD Emissions		x		x			x					x	x	x	x	x	x	x
23	Emissions of nutrients		x		x			x					x	x	x	x	x	x	x
24	Emissions of Heavy metals				x										x	x	x		x
25	Others emissions				x			x							x				x
26	Sludge / waste production		x		x			x					x	x				x	x
27	Use of chemicals				x			x					x	x			x	x	
28	CSO															x			
29	Discharge															x		x	
30	Energy use															x		x	
31	Gas produced															x			
32	Soil conditioner															x			
33	Contribution to eutrophication											x					x		
34	Contribution to acidification											x							
35	Contribution to global warming											x					x		
36	Drinking water															x	x	x	
37	Household water															x		x	
38	Construction materials																x	x	
39	Micropollutants																x		
40	Impact on air																	x	
41	**Technical indicators:**																		
	Durability				x				x								x	x	
42	Ease of construction / low tech																x	x	
43	Endure shock loads/seasonal effects										x				x		x	x	x
44	Flexibility / adaptability				x				x						x	x	x		x
45	Maintenance										x					x			
46	Reliability / security				x	x										x		x	
47	Small scale / onsite / local solution						x		x										
48	Robustness															x	x		
49	waste															x			
50	Abuse of system																x		
51	Possibility to use local competence for construction and O&M																x		
52	Ease of system monitoring																x		
53	Compatibility with existing systems																x		
54	Quality of supplied water																	x	
55	**Health and Hygiene**																		
56	Protection of water resources											x							x

57	Direct transmission of infection											x					x	x	
58	Indirect transmission of infection											x					x	x	
59	Reliability / security											x							
60	Spreading of toxic compounds											x							
61	Risk of exposure to hazardous substances																x	x	
	Social-cultural indicators:																		
62	Awareness / participation				X		x					x			x	x	x	x	
63	Competence / information requirements				X	x						x				x		x	
64	Cultural acceptance				X							x			x	x	x	x	x
65	Institutional requirements				X	x						x				x	x		x
66	Local development								x								x		
67	Responsibility					x						x					x		
68	Expertise															x			
69	Sustainable behavior															x		x	
70	Labor																		x
71	Future trends																		x
72	User friendliness /System perception											x					x	x	
73	Transparency																x		
74	Willingness to pay																x	x	
75	Convenience																x		
76	Current legal acceptability																x		
77	Willingness to change behaviour																	x	

Adapted from Balkema, source: Balkema, 2003 (A=Azar, B=Bengtsson, Bu=Butler, Em=Emmerson, E=ETC, F=Finnson, H=Helström, I = Icke, J = Jacobs, L = Lundin, M=Mels et al.). Source: Pierini, 2005 (O = Otterpohl et al., Ø = Ødegaard, K = Kärrman, Ba = Balkema, Br=Bracken, S = SWARD, DI = DIM SUM.)

From this review, it is possible to have an overview of the possible indicators per criteria and at the same time determine the "popularity of each indicator" in the 18 frameworks reviewed. It was also possible to check if there is a trend between number of indicators and time, and also to check the number of indicators defined per criteria.

Regarding to economical indicators, there were five indicators, they are sorted by frequency in the table 7.

Table 7: Review of economical indicators sorted by popularity

	Economical indicators	Frequency
1	Total annual Cost	9
3	Affordability	3
2	Labor	1
4	Use of surface area	1
5	Financial risk exposure	1

Regarding to environmental indicators, there were thirty five indicators, they are sorted by frequency in the table 8.

Table 8: Review of environmental indicators sorted by popularity

	Environmental indicators	Frequency
1	Nutrients reuse	14
2	Water reuse	11
3	BOD / COD Emissions	11
4	Energy reuse	10
5	Emissions of nutrients	10
6	Resources reuse	8
7	Sludge / waste production	8
8	Land area required / space	8
9	Biodiversity / land fertility	7
10	Optimal resource utilization /	6

11	Emissions of Heavy metals	6
12	Use of chemicals	6
13	Others emissions	5
14	Pathogen removal / health	4
15	Pollution prevention	4
16	Export of problems in time & space	3
17	Drinking water	3
18	Accumulation	2
19	Integration in natural cycles	2
20	Odor / noise / insects / visual	2
21	Discharge	2
22	Energy use	2
23	Contribution to eutrophication	2
24	Contribution to global warming	2
25	Household water	2
26	Construction materials	2
27	Raw materials	1
28	Impact on air	1
29	Desiccation	1
30	Extraction	1
31	CSO	1
32	Gas produced	1
33	Soil conditioner	1
34	Contribution to acidification	1
35	Micropollutants	1

Regarding to technical indicators, there were fourteen indicators, they are sorted by frequency in the table 9.

Table 9: Review of technical indicators sorted by popularity

	Technical indicators:	**Frequency**
1	Flexibility / adaptability	6
2	Endure shock loads / seasonal effects	5
3	Durability	4
4	Reliability / security	4
5	Ease of construction / low tech	2
6	Small scale / onsite / local solution	2
7	Maintenance	2
8	Robustness	2
9	Waste	1
10	Abuse of system	1
11	Possibility to use local competence for construction and O&M	1
12	Ease of system monitoring	1
13	Compatibility with existing systems	1
14	Quality of supplied water	1

Regarding to indicators related with health and hygiene, there were seven indicators; they are sorted by frequency in the table 10.

Table 10: Review of health and hygiene indicators sorted by popularity

	Health and Hygiene	**Frequency**
1	Direct transmission of infection	3
2	Indirect transmission of infection	3
3	Access to drinking water and sanitation	2
4	Protection of water resources	2
5	Risk of exposure to hazardous substances	2
6	Reliability / security	1
7	Spreading of toxic compounds	1

Regarding to socio-cultural indicators, there were sixteen indicators; they are sorted by frequency in the table 11.

Table 11: Review of socio-cultural indicators sorted by popularity

	Social-cultural indicators:	Frequency
1	Awareness / participation	7
2	Cultural acceptance	7
3	Institutional requirements	6
4	Competence / information requirements	5
5	Responsibility	3
6	User friendliness /System perception	3
7	Local development	2
8	Sustainable behavior	2
9	Willingness to pay	2
10	Expertise	1
11	Labor	1
12	Future trends	1
13	Transparency	1
14	Convenience	1
15	Current legal acceptability	1
16	Willingness to change behavior	1

From the inventory, it was done the graph, number of indicators per framework versus the year and it was obtained the figure 8. It is observed a slight trend to increase the number of indicators the years. The number of indicators per criteria is summarized in the figure 9.

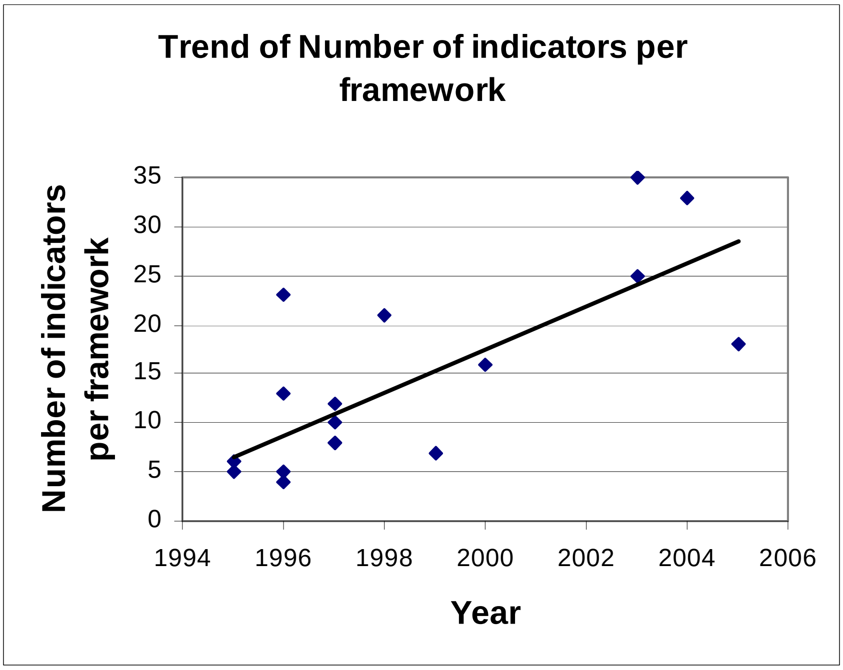

Figure 8. Trend of number of indicators per framework

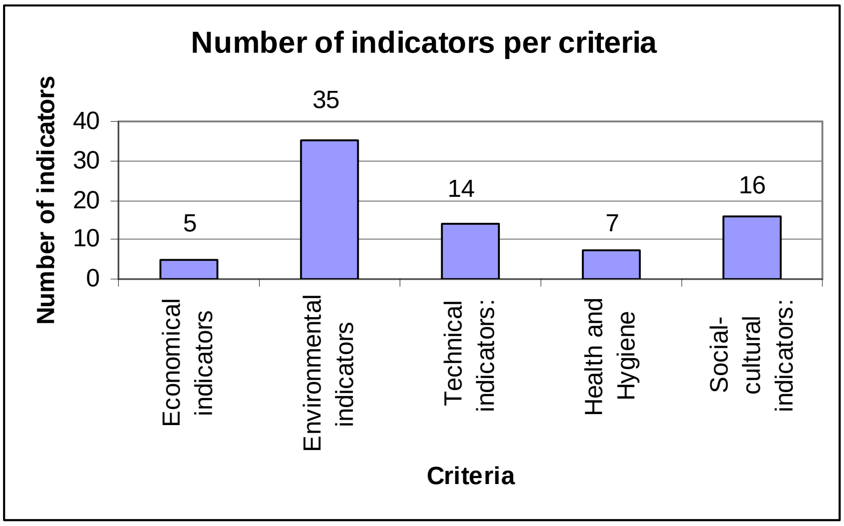

Figure 9. Number of indicators per criteria

From the review were found 42 different multi-criteria methodologies used in different projects for the assessment of water management, however there is none that can be selected as the most suitable for water management, each one has strengths and weaknesses. Based on those methodologies 18 frameworks were developed between 1995-2005, all of them have different set of indicators, in total 77 different indicators were listed and their "popularity" is shown in the tables 7 – 11. The number of indicators per framework varies between 5 to 35 and that this number was increasing over the years.

Starkl, (2004), concludes that "attempts to increase the sustainability of the Decision Making Process, face a dilemma: there is a need to develop comprehensive generic lists of criteria which guide the decision maker through the relevant aspects of sustainability. But the consideration of these aspects of sustainability in the DMP reduces it feasibility." This statement was confirmed, from 77 possible indicators, the existing frameworks evaluate maximum 35 of them, low number of indicators can not reflect the general situation, however a several indicators make difficult the application and evaluation of a framework.

4.4. Conclusions

In the last years, multi-criteria methodologies have become a popular aid in decision making processes with involvement of multi-objective approach and several stakeholders. Nevertheless, it has to be pointed out, that solving a multi-criteria problem often does not mean to find an optimum solution, but facilitates discussion and understanding of the different alternatives towards the finding of the most suitable solution. The range of available methodologies varies from simple ones like brainstorming to complex like computer based simulations. Even though this is an advance in decision science, the selection of the methodology turned into a "problem" by itself.

From the literature review, it was found that 42 different multi-criteria methodologies can be used for the assessment of water management, however none of them can be selected as the most suitable; each one has strengths and weaknesses. Based on some of those methodologies 18 frameworks were developed between the years

1995 – 2005. The main criteria involved in sanitation technology selection were health, social and institutional, environment, costs and system robustness. Each framework has a different set of indicators, and system's boundaries. In total 77 different indicators were listed and their "popularity" is shown in the tables 7 – 11. The number of indicators per framework varies between 5 to 35 and this number was increasing over the years. These frameworks also use different aggregations methods the most popular is the Life Cycle Approach but Material Flow Accounting, Total Cost Accounting and Outranking methodologies like Electre and Promethee are also used.

Starkl, (2004), concluded that "attempts to increase the sustainability of the Decision Making Process, face a dilemma: there is a need to develop comprehensive generic lists of criteria which guide the decision maker through the relevant aspects of sustainability. But the consideration of these aspects of sustainability in the DMP reduces it feasibility." This statement was confirmed, from 77 possible indicators, the existing frameworks evaluate maximum 35 of them, low number of indicators can not reflect the general situation, however several indicators make difficult the application and evaluation of a framework.

5. Optimization of the Framework

This chapter describes the optimization of the framework for urban sanitation assessment; beginning with the framework requirements and the objectives, and following with the description of each criterion with its set of indicators. This indicators selection was done based on literature review, data availability, relevance and measurability. This section also explains the aggregation and normalization methods used to achieve a unique score per criteria.

5.1. Framework Requirements

The structure of the framework is described in the box 1. Based on the previous literature review, on the existing framework, and on the requirements for the technical assessment; the optimization of the framework was done following these steps:

- Criteria review
- Definition of the objectives per criterion
- Review of the set of indicators per criteria
- Selection of methodology to calculate a score per criteria

Box 1. Framework elements
The framework has the following elements:
Objectives: basic aims of the framework.
Principles: essential areas covered by the framework, which help to assess the technological performance, and help to elaborate the meaning of objectives.
Criteria: set of variables that describe principles upon which a decision or judgment can be based
Indicators: measurable states which allow the assessment of whether or not associated criteria's aims are being met.

The first step for the optimization is to review the objectives of sanitation systems, then identify the main principles related to the technical performance and define a set of criteria to evaluate each principle. The main objectives for sanitations systems can be summarized as (Pierini, 2005):

- moving towards a nontoxic environment
- improving health and hygiene
- saving human resources
- conserving natural resources
- saving financial resources

Other objectives are:

- have a high degree of functional robustness and flexibility
- be adapted to local conditions
- be easy to understand and thus encourage responsible behavior by the users

The core objective of the framework is to assess technical performance of the different technologies, for that reason, only principles closely related with it were selected: health, environment, economy and technology, and a set of 7 sustainability criteria with their respective objectives where defined, see table 12. Having defined the criteria and the objectives, the following step is the review of the indicators per criterion. The indicators selection was done based on the characteristics of good indicators listed below (Pierini, 2005):

- Relevant: they must fit the purpose for measuring in order to show something about the monitored system that have to be known

- Easy to understand: indicators should be understood even by the people who are not experts
- Reliable: everyone can trust the information provided by the indicators
- Based on accessible data: the information is available or can be gathered while there is still time to act

Table 12: Objectives per criterion

Principle	Criteria	Objective
Health	Public Health Risk	Evaluate the public health risk related to a given technology due to the contact of inhabitants with faeces, urine, raw wastewater, treated wastewater or sludge.
Environment	Resources use	Evaluate to what extent a given technology makes an efficient use of the resources (water, energy, nutrients and chemicals).
	Impact on ecosystem	Evaluate to what extent a given technology impacts on the ecosystem (water and soil discharges).
Economy	Total costs	Evaluate the total cost of the system. (Capital and operational costs, including potential benefits).
Technology	System robustness	Evaluate system robustness, based on failure records, and possible user abuse.
	System invisibility	Evaluate to what extent a given technology is invisible for the users and the community.
	Contextual Independence	Evaluate to what extent a given technology is independent from external conditions.

However, in the development of the framework, “there is a trade-off between showing the complexity of a problem in all its facets and its simplification in order to make it understandable for all persons involved in decision processes. Either the process remains on a highly abstract level far away from the real problem, or it reduces the complexity too strongly and thereby looses too much information, so that the results do not adequately reflect the real nature of the decision problem anymore”, (Oman, 2004). The requirements of simplicity, comparability, interpretability may result in over-aggregation, over-simplification of complex relationships, and consequently misleading or even false representation, (Moeffaert, 2003).

The framework should have a set of indicators that clearly describe the system performance. It is important to avoid bias during indicators selection, since it can be done based only on the availability of data. “If indicator selection is unsatisfactory, the information obtained may be insufficient, thus stifling progress towards sustainability”, (White, 2006). To avoid this to some extent the proposed framework will have some auxiliary tables to track raw data and facilitate analysis. In the next sub-chapters the different criteria and their sets of indicators are described in detail. After selecting the indicators, different methodologies for aggregation were tested, and for each criterion it was selected one based on data availability, relevance according with the objectives and methodology convenience.

5.2. Contextual Independence

The different components of the system have an expected performance; however this performance can be influenced by external factors on-site. “The environment of a system is a set of elements and their relevant properties, which elements are not parts of the system but a change in any of which can produce a change in the state of the system. Thus a system’s environment consists of all variables that can affect its state.” Context can be defined as the external entities and conditions that need to be taken into account in order to understand system behavior, (Shah, 2007).

The contextual independence criterion aims to assess the influence of external factors like the environment, surroundings and circumstances on the system performance. For an adequate technical assessment, not only it is required to have a performance score but also to know the local conditions and how they can affect operation of a given system. The contextual independence is a constant value per technology and reflects its versatility. A high score in contextual independence means that this technology fits in different environments and local conditions; meanwhile, low score means that the technology can be used just under specific external conditions. The relevance of this criterion lies on the requirement of choosing sanitation technologies according to local context.

Lundin, (2002), mentioned the relevance of the external context and define reliable systems as those that can provide their service even when unexpected events occur such as an electricity delivery stop or a sudden temperature drop. Systems may fail but must be capable of recovering without undue effort or cost. Seasonal variations in loading and climate should be considered. Technical systems should also be designed and operated in ways that make them able to cope with changes; changes in the ecosystems (natural or man-made), in the technical components due to ageing or innovations, or in the demands and desires of society.

To analyze this criterion it was done a literature review and some meetings with two experts, Dr. Doctor Okke Braadbaart and the engineer David Castellanos, different categories were identified, see table 13. According to Braadbaart from previous studies, where technical performance has been evaluated, it has been noticed that external factors can strongly affect the results. The aspects to evaluate are: climate, socio-economic conditions, geological conditions, ecosystem conditions, dependence of other systems. Factors that may influence system performance are numerous and widely varied in nature, for instance social acceptance, habits or cultural believes, but they are not including in the scope of the framework. Also events like earthquakes or terrorist attacks can affect systems' performance but the uncertainty to predict their occurrence and impact makes not possible to assess them in this framework.

In the table 13 each aspect has a different color. Each system's component is evaluated in each aspect, as follows:
Score of Zero Sensitivity = 2
Score of Moderate Sensitivity = 1
Score of High Sensitivity = 0

Zero sensitivity refers to high performance and moderate sensitivity and high sensitivity refers to moderate performance and low performance of the sanitation system respectively. For the assessment of the contextual independence the minimum value per row will be identify, because this is the critical circumstances, and the score per aspect is equal to the average of the minimums score per row:

<u>Contextual Independence per Aspect:</u>

$$CI_{aspect} = \overline{Min\ \ Value_{per\ \ row}} \qquad \text{[Eq. 6.1]}$$

The contextual independence score per technology is the average of the contextual independence per aspect:

Contextual Independence Score per Technology:

$$CI_{tech} = \overline{CI_{aspect}} \quad \text{[Eq. 6.2]}$$

Table 13: Table A - Assessment of Contextual Independence

			Generation & separation				Collection, transfer & transport					Pre-treatment & treatment					
CONTEXTUAL INDEPENDENCE			Normal toilet	Vacuum toilet	Diverting toilet	Urinal	Vacuum station	Storage Tanks	Compost tank	Pipes	Trucks	Pump	Filters	Constructed wetlands	WWTP	Minimum value per row	Score per aspect
		System description															
Climate	Temperature	High >30℃															Average of the minimums
		Low <10℃															
	Rainfall	Intense (flooding)															
		Seasonal variation															
Socio economic conditions	Scale - Population size	Individual 1-10 connections															Average of the minimums
		Decentralized 10 - 10.000 connections															
		Centralized >10.000 connections															
	Population growth																
	Economic level[5] (GNI per capita)	low income < $905															
		medium income															
		high income>$11,116															
	Land availability	Land availability															
		Access to the site															
Geological conditions	Soil type	Sand															Average of the minimums
		Clay															
		Rock															
	Topography	Low slope															
		high slope															
Ecosystem conditions	Water availability																Average of the minimums
	Water quality (feasible for Sensitive areas lakes or groundwater)																
	Water table level																
Dependence of other systems	Water supply																Average of the minimums
	energy supply																
	Other (recycle water system)																
																Total score for Contextual Independence	Average of the scores per aspect

5.3. Public Health

Protection of public health is the most important sanitation objective and it is closely linked to hygiene. The entire sanitary system should minimize risks and safeguard public health. This covers the use of the sanitary installation, collection, transport, treatment and destination of the treated products.

[5] Economies are divided according to their gross national income (GNI) per capita, calculated using the World Bank Atlas method. The groups are: low income, $905 or less; middle income, $906 - $11,115; and high income, $11,116 or more. (Data from 2006) source: http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20420458~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html

Inadequate management of human waste can lead to direct or indirect disease transmission. Most of the pathogens causing diseases like cholera, typhoid, dysentery and other diarrhea diseases are originated from human and animal faeces. There are different routes of exposure, like ingestion, skin contact, or in some cases inhalation of aerosols, (Lohani, 1997). To prevent diseases it is necessary not only to have adequate infrastructure to dispose human waste but also to promote an adequate hygienic behavior, washing the hands after depositions, and hygienic food storage and food preparation.

Two common quantitative indicators for risk assessment are illness report and effluent e-coli concentration, despite their relevance, the available information it is not suitable for the assessment. And even though it is preferable the use of quantitative indicators in this case the assessment is done with qualitative data. With the literature review, it was found that illness report rates are low or null, only there are records when there are epidemics but isolated cases usually are not registered. Also, diarrhea cases can be related with food ingestion and taking into account that inhabitants do not stay the whole day at home, this indicator is not appropriate for this case, see table 14. Also it was found that in pilot projects those tests are not carried out regularly to have a statistical valid average. From previous studies it can be observed the range in which values of number of pathogens can change for raw wastewater, table 15. Due to the lack of precise information of microbial presence in the different fractions the assessment will be done by qualitative analysis.

Table 14: Diarrhea disease incidence per person per year n 2000, by region and age

Region	**Diarrhea disease incidence, all ages**	**Diarrhea disease incidence, 0-4 years**	**Diarrhea disease incidence,5-80+ years**
Developed regions	0.2	0.2 – 1.7	0.1-0.2
Developing regions	0.8 – 1.3	2.4 – 5.2	0.4-0.6
World average	0.7	3.7	0.4

Source: Pond, 2005

Table 15: Reported numbers of pathogens in wastewater [L^{-1}]

Pathogen	**Range**	**Country**
Bacteria		
Salmonella spp.	930 – 110,000	Finland
	8,900 – 290,000	Germany
Campylobacter spp.	500 – $4.4 \cdot 10^6$	Germany
Enteric viruses		
Enteroviruses	100 – 10,000	Italy
Rotavirus	<1 – 10,000	Netherlands
Norovirus	<1,00 – $1{,}6 \cdot 10^6$	Germany
Adenovirus	250 – 250,00	Spain
Protozoa		
Giardia cysts	1,100 – 52,000	Scotland
	100 – 9,200	Canada
Cryptosporidium oocysts	<20 – 400	Scotland
	1 - 560	Canada

Source: Ottoson, 2003

The World Health Organization (WHO), define wastewater recycling and reuse guidelines and/or regulations, “they have been traditionally and exclusively based on the determination of bacterial indicators and nematode eggs presence. Nevertheless, it has been demonstrated that: (a) virus presence is not well established by bacterial indicators, (b) the viability of nematode eggs is not determined, (c) parasites’ presence is not analyzed, (d) behavior of all pathogens once in the recycled water distribution systems and points of use is not known, (e) behavior of pathogens in the environment is also not known, and (f) chemical risk is not assessed. Additionally, it is to consider that risk associated with reuse is directly related to the final contact host-pathogen, or to chemicals ingestion and contact with the human body, (Salgot, 2003). “Comprehensive indicators or model organisms are strongly needed for better defining the risk associated to recycled water pathogens content” (Lucena, 2002).” Regarding sampling procedures and the subsequent analysis, there is the possibility to assess the quality reflecting a wider time span. Nevertheless, using classical analytical procedures, it is impossible to establish if there is a point problem, i.e. a really low level quality of water during few minutes that can compromise aquatic life for long time”. (Pond, 2005)

For the assessment of human health risk should be done a detailed study, one of the most common methodologies to measure this is the quantitative microbial risk assessment (QMRA), this is a sensitive tool that can estimate risks that would be difficult to measure. However, QMRA is only as good as the data available and the assumptions made, (Pond, 2005). Scott, 2004, describes its four stages of QMRA:

- Hazard identification (HI): This stage consists on the identification of the hazardous substances that can affect public health.

- Exposure Assessment (EA): In this step, the exposure is identified by measuring the dose, the duration, and the frequency of the exposure.

- Dose-response analysis (DRA): Not all the organism react in the same way, the response of each person can vary depend on sex, age, and other external conditions.

- Risk Characterization (RC): In this final step, based on the previous information can be assessed the risk. It integrates the previous phases.

A schematic view of the risk characterization can be found in the figure 10. It can be observed the pathogen-host properties influencing the sequence of events between the presence of a pathogen in excreta and measurable human disease attributable to excrete.

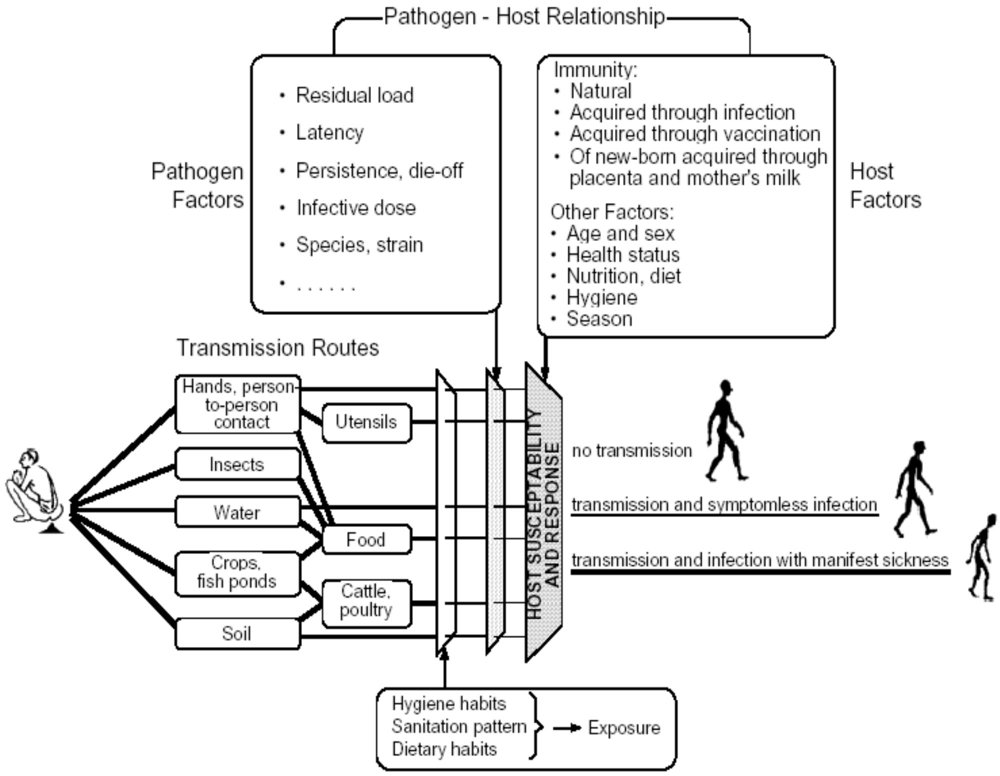

Figure 10. Pathogen-host relationship
Source: Rowe, 1995

Within this framework the two first stages, hazard identification and exposure assessment, will be assessed and a estimate risk will be assigned based on them, for the dose-response analysis it is necessary to analyze the group of inhabitants, and their characteristics and other external conditions, what makes this stage not doable in the scope of this work. Moreover, this dose-response assessment is only valid for the community studied, and then data extrapolation is not recommended.

In order to assess the hazard inventory and the exposure assessment, it is necessary to identify the potential risks to human health in wastewater; they are listed in the table 16.

Table 16: Different types of risks on wastewater

Microbiological risks	Chemical risks
Bacteria	Heavy metals
Viruses	Minerals, nutrients
Protozoa	Organic micro-pollutants
Nematodes	

Subsequently, the main wastewater streams generated by domestic activities are listed in the table 17, identifying the source, and their main properties. The column risk relates to the pathogen contamination. The concentrations of (micro) pollutants over log time periods and the adaptation of microorganism to specific stress conditions are real hazards that warrant special attention. The presence of micropollutants has only a potential health effect if associated with long-term exposure, while in the case of infectious microorganisms, effects can be associated with acute, or single dose, exposure, (Rowe, 1995). For this framework, only the microbiological risk will be assessed and it focuses on the inhabitants risk, there are also risks associates with external workers during treatment, transport or maintenance activities but it is assumed that in those cases, barrier control is done for risks minimization.

Table 17: Risk characterization per stream at domestic level

Name	Source	Nutrients	Organics	Microbial Risk	Properties
Black water	Toilets	high	high	high	the most problematic wastewater fraction
Yellow water	No-mix toilets or urinals (without or with little water flushing)	high	low	very low	very low solid content, problems arise from drug residues
Brown water	No-mix toilets	moderate	high	high	hygienic problems
Grey water	Bathrooms, washing machines, washing sinks, kitchen	low	moderate	very low	soluble and easily degradable organic content, reusable after treatment

Source: Resource Centre for Environmental Technologies. (http://www.crte.lu/mmp/online/website/content/water/76/125/144/index_EN.html).

The exposure is identified by measuring the duration, and the frequency of the exposure. For that it is done the following logical relations to facilitate the evaluation. See the risk exposure based on the frequency and duration of the exposure in the table 18.

Table 18: Risk exposure assessment

Frequency	Duration	Risk exposure	Score
Always	Long term	High	2
Often	Short	Medium	1
Seldom	Short	Low	0

For the identification of the system exposure pathways, it was developed the "table B", see table 20. According with Lohani, (1997), the risks can be categorized in a matrix on the basis of their frequency of occurrence and severity of consequences or damage. See figure 11

		Risk exposure (Frequency and Duration)		
		Low	**Medium**	**High**
Risk associated to the fraction	**Low Risk**	low	low	**Medium**
	Medium Risk	low	**medium**	**high**
	High Risk	**medium**	**high**	**High**

Figure 11. Risk assessment matrix
Source: Adapted from Lohani, 1997

With the result of the risk exposure (table 18), it is possible assess the risk with the matrix in the figure 12, based on the flows that are involved in the exposure and the type of exposure. The final assessment will be the maximum value per row.

<table>
<tr><th colspan="2"></th><th colspan="3">Risk exposure (Frequency and Duration)</th></tr>
<tr><th colspan="2"></th><th>Low =0</th><th>Medium=1</th><th>High=2</th></tr>
<tr><td rowspan="3">Risk associated to the fraction</td><td>Low Risk
Skin contact with: Yellow water, grey water, rainwater</td><td rowspan="2">Low</td><td rowspan="2">Low</td><td rowspan="2">Medium</td></tr>
<tr><td>Low Risk
Accidental intake by swimmers
Intake of food irrigated with treated wastewater</td></tr>
<tr><td>High Risk
Skin contact with: Black water , Brown water</td><td>Medium</td><td>High</td><td>High</td></tr>
</table>

Figure 12. Risk assessment matrix for the framework (simplified)
Source: Adapted from Lohani, 1997

In order to guarantee protection of public health is not enough to have the best performer in that criterion, moreover, it is necessary to link the sanitation system with hygiene promotion and measures needed for risk minimization. One of the aims of this assessment is to find vulnerable points in the system, and then define possible risk management actions to minimize risk; some examples are mentioned in the table 19.

Table 19: Examples of risk management

Risk	Risk management
Direct contact with raw waste water in the toilet or pretreatment area	- Promote hygiene - Restrict access to some areas - Use of gloves, and protection clothes to enter to some areas
Risk by ingestion of vegetables irrigated with waste water	- Crop restriction
Minimization risk	- Vaccination

Table 20: Table B: Pathways identification and Risk Assessment

		Generation / separation				Collection		Transfer & transport		Pre-treatment & treatment					Reuse or recycling				Disposal			
		Normal toilet	Vacuum toilet	Diverting toilet	Urinal	Storage Tanks	Compost tank	Pipes	Trucks	Pump	Filter	Constructed wetlands	Retention ponds	WWTP	Reuse of gray water	Fertilizers production	Crops Irrigation	Landscape	Drinking water source	Swimming waters	Ground water	**Risk per fraction**
System description																						
High Risk Skin contact with: Black water , Brown water	**Exposure (0-2) See table 18**																					
	Risk Low= 1 Medium=2 High=3 Based on fig 12																					**Max. Value per row**
Low Risk Skin contact with: Yellow water, grey water, rainwater	**Exposure (0-2) See table 18**																					
	Risk Low= 1 Medium=2 High=3 Based on fig 12																					**Max. Value per row**
Low Risk Accidental intake by swimmers Intake of food irrigated with treated wastewater	**Exposure (0-2) See table 18**																					
	Risk Low= 1 Medium=2 High=3) Based on fig 12																					**Max. Value per row**
Health risk associated per technology																						**Max. Value per column**

5.4. Impact on the ecosystem

When considering the environmental impact of sanitation systems, both emissions to different recipients (water, soil, and air), and resource use should be analyzed. In this sub-chapter discharges will be assess and in the next one the resource utilization will be addressed. Environmental protection is a current issue for governments and urban planners, nowadays, developed countries have adopted wastewater regulations that attempt to limit the environmental impact of wastewater effluent, for example by setting concentrations limits at discharge. In the European Union, according with the EU Urban Wastewater Treatment Directive EX 91/271, the discharges into surface water or ground water, to protect the environment, are shown in the table 21.

Table 21: Regulations by EU Urban Wastewater Treatment Directive EC 91/271

Parameter	Discharge Standard		Applies to
BOD	< 25	$mgO_2.l^{-1}$	
COD	< 125	$mgO_2.l^{-1}$	
Suspended Solids	< 35	$mgTS.l^{-1}$	
P total	< 2	$mgP.l^{-1}$	Plants < 100.000 p.e.
	< 1	$mgP.l^{-1}$	Plants > 100.000 p.e.
N total	< 15	$mgN.l^{-1}$	Plants < 20.000 p.e.
	< 10	$mgN.l^{-1}$	Plants > 20.000 p.e.

Source:http://ec.europa.eu/environment/water/water-urbanwaste/directiv.html

These standards are based on the concentration of these parameters in the effluent, for that reason dilution can mislead the interpretation of the discharge. In this framework the discharges will be expressed in kilograms of the substance discharged, per person per year. To have an idea about the average discharges per person per year see table 22.

Complex methodologies that can simulate environmental damage have been developed; however, data requirements are really high, specific characteristics about discharges and condition of the environment. This is very difficult, or even impossible, in some cases. If the information is not sufficient this damage approach will lead to underestimations of the environmental impacts.

Table 22: Characteristics per flow expressed as kg. $pe^{-1}year^{-1}$

Parameter	Urine	Faeces & Toilet paper	Grey water total	Household water
TS	7	19	26	52
VS	3	17	15	35
COD_{tot}	3	23	23	49
BOD_7	2	12	12	26
N_{tot}	4	0.5	0.6	5.1
P_{tot}	0.33	0.18	0.25	0.76
S_{tot}	0.26	0.06	0.17	0.49
K_{tot}	0.88	0.33	0.29	1.5

Source: Ottonson, 2003

For environmental assessment many methodologies have been developed, the most extended and used is the Life Cycle Assessment – LCA, as defined in ISO 14040 (1997E), is a “compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle". "The environmental impacts are often described as "potential impacts", because they are not specified in time and space and are related to an (often) arbitrarily defined functional unit", (Guinée, 2001).

Although, LCA has some drawbacks, assessing the whole life cycle requires lots of data and, the choices concerning discounting and/or a cut-off can have a decisive influence on the results; its standardized environmental impact categories let to assess separately the following environmental impacts: depletion of abiotic resources, depletion of biotic resources, impacts of land use, desiccation, climate change, stratospheric ozone depletion, human toxicity, ecotoxicity, photo-oxidant formation, acidification, eutrophication, etc.

For the framework, two impacts will be assessed: potential eutrophication and potential ecotoxicity. Eutrophication also called nutrient enrichment causes algal bloom in inlets and springs causing oxygen depletion and death of fish. Ecotoxicity, this impact category covers the impacts of toxic substances on aquatic, terrestrial and sediment ecosystems, (Guinée, 2001). For the framework, it will be assess only the discharges into water.

Eutrophication potential:

The eutrophication potential will be assessed per person per year, following the equation 6.3.:

$$eutrophication = \sum_i EP_i \times m_i \qquad \text{[Eq. 6.3]}$$

m_i : is the amount of substance i emitted to water in kg/pe.year

EP_i : Eutrophication Potential of substance i emitted to water, expressed in kg PO_4^3 - eq./kg

The indicator result is expressed in kg PO_4^3 equivalent. EP_i is the Eutrophication Potential for substance i emitted to air, water or soil, while m_i is the emission of substance i to air, water or soil. All the discharges are expressed in kilograms per person per year.

Guinée et al., 2001, their handbook provides characterization factors for more than 1500 different LCI-results[6], see table 23. For the framework the parameters selected to assess potential eutrophication are nitrogen, phosphorus and COD.

[6] LCI: Life Cycle Inventory

Table 23: Table C - Generic EP factors for characterizing eutrophying releases to air, water and soil.

Substance	**EP (in kg PO_4^{3-} - eq./kg)**
ammonia	0.35
ammonium	0.33
Nitrate	0.1
nitric acid	0.1
nitrogen	**0.42**
nitrogen dioxide	0.13
nitrogen monoxide	0.2
nitrogen oxides	0.13
Phosphate	1
phosphoric acid (H_3PO_4)	0.97
phosphorus (P)	**3.06**
phosphorus (V) oxide (P_2O_5)	1.34
COD	**0.022**

Source: Guinée, 2001 - Adapted from Heijungs et al., 1992

Ecotoxicity:

This impact category, it will be assess only the discharges into water. It will be also measure per person per year, see equation 6.4.

FAETP: Freshwater Aquatic EcoToxicity Potential

$$FAETP_i = \sum_i m_i \times FAETP_i$$ [Eq. 6.4]

m_i : is the amount of substance i emitted to water in kilograms per person per year

$FAETP_i$: Freshwater Aquatic EcoToxicity Potential of substance i emitted to water, expressed in kg 1,4-dichlorobenzene eq. The indexes of potential ecotoxicity are in the table 24.

Table 24: Generic FAETP factors for releases to water.

Substance	**Freshwater aquatic ecotoxicity FAETP inf. kg 1,4-dichlorobenzene eq.**
arsenic	2.1E+02
cadmium	1.5E+03
chromium	2.8E+01
copper	1.2E+03
lead	9.6E+00
mercury	1.7E+03
nickel	3.2E+03
zinc	9.2E+01

Source: Guinée, 2001 - Adapted from Huijbregts, 1999 & 2000

5.5. Resources use

The main purpose of the wastewater systems is to collect sewage and to reduce emissions and bacteria to acceptable levels. Moreover, sanitation systems should also optimize the use of resources. The main resource related with sanitation is water, and there is a high pressure in its conservation since water related problems have been increasing worldwide lately. But also energy consumption, production of fertilizers and use of chemicals are relevant. Although, pressure is increasing in resource conservation, there are no standards or limits that control resource use for sanitation.

Methodologies like LCA measures the resource use with the parameter: "abiotic depletion", for Heijungs et al (1992) in Guinée, (2001), for a given resource i, abiotic depletion was defined as the radio between the quantity of resource extracted (m_i) and the recoverable reserves of that resource (M_i)

$$Abiotic\ \ depletion = \sum_i \frac{m_i}{M_i}$$

[Eq. 6.5]

On one hand, this assessment would require also a deep insight into local conditions and to assess the amount of recoverable reserves of a source could be a complicated task; on the other hand, authors still differ in their conclusions for the assessment of the aggregating impact. Guinée, 2001 concluded that "there is as yet no consensus about what constitutes the best category indicator for "abiotic depletion". In response to that other approaches have been developed, based now on exergy content of the resources, but still there are no clear methodologies for their assessment.

For the assessment of this criterion, in the framework, normalization will be done by dividing each indicator by the difference of the maximum and minimum value, which maps all indicators into the range zero and one. Weighting will not be done in the framework, but according to local conditions could be assigned higher value to any of the resources if the pressure on its conservation is high. Then, best performer will be the technology that uses the fewer amounts of sources and the one that incorporates in the process reuse or recycle of resources.
The assessment will be comparative among the cases available, (previously should be check if there are outliers in the data, in order to avoid misleading of the evaluation. With this condition maximum and minimum value per indicator will be known. There are two different equations for the normalization, one for "consumption" of resources and the other for "productions, reusing or recycling" in order to facilitate the calculation of the final score.

The normalization for "resources consumption" will be done per indicator, see equation 6.6.:

$$d_{score} = \frac{d - d_{min}}{d_{max} - d_{min}}$$

[Eq. 6.6]

d=value of the indicator
d_{score}= normalized value of the indicator

The values will be transform, and they will be into the range of [0,1]. If $d=d^{min}$, the $d^{score}=0$. If $d=d^{max}$, then $d^{score}=1$.
In case that the minimum value is zero the equation can be reduced to:

$$d_{score} = \frac{d}{d_{max}}$$
[Eq. 6.7]

With this normalization high values of consumption will have as well a high score, and vice versa.

Normalization for “resources production or reusing, or recycling” will be:

$$d_{score} = \left| \frac{d - d_{min}}{d_{max} - d_{min}} - 1 \right|$$
[Eq. 6.8]

This is because a low value of production means a bad score, while high values will correspond to a good performer.

5.6. System robustness

A general definition of system robustness can be expressed as ability of a system, to continue to function despite the existence of faults in its component subsystems or parts. Robustness is defined narrowly as the ability of the system to maintain a level of performance even if the actual parameter values are different from the assumed values. (Uber et al., 1991).

GTZ divides the robustness as follows: System robustness: risk of failure, effect of failure, structural stability; Robustness against extreme conditions: Drought, Flooding. Robustness of use of system: shock loads, abuse of system. The robustness again extreme conditions are assessed in the contextual independence of the framework and the other two aspects are evaluated in system robustness.

Robustness should be defined as the capacity of the treatment system to reach a stable steady state under certain environmental and operational conditions. However, robustness should also be defined in terms of variability of the final product of the process, i.e. the effluent. Furthermore, robustness should be defined as the capacity of a system to cope with more severe environmental and operational variations.(Savic, 2005)

For Hellström et al., (2000), the robustness of the system is one important aspect of sustainability. It includes the sensitivity of the system concerning malfunctioning of equipment and instrumentation and it is also determined by the sensitivity of the system with regard to toxic substances and shock loads. Balkema, 2003 in her work defines robustness as the ability to cope with fluctuations in the influent and reliability as the sensitivity of the system to malfunctioning of equipment and instrumentation.

One of the most important technical parameters is the system robustness. For the framework, within this parameter analyses the technical performance mainly

by measuring the failure record and the possibility of the system of facing user abuse. Additional to the user abuse, the performance of the system can be affected by users, if they do not perform the adequate maintenance.
In order to make a technology assessment, the following indicators have been selected:

- Failure Record
- Maintenance required
- Shock load resistance - User Abuse

The failure record will be assess taking into account the average of failures of the system per year (Failure frequency) and the duration of the downtime. For that assessment an auxiliary table was developed, see table 25. This table helps to track which components are the most likely to present failures. For the final assessment the number total of hours downtime per year per system will be the indicator and normalization is required in order to make the aggregation, (see equations 6.6 and 6.7).

For the shock load resistance assessment, based on the literature review it was elaborated a list with the possible elements that can be trough into the system, the complete list can be observed in the table 43 in the annex. The objects or substances most unlikely were selected, and amount or dimension were estimated, see table 26. This set of questions is suitable for a system operator or a technician.

The question for the operators will be: If you flush the object or substance "x",
- Does it produce downtime? (Y/N)
- How long would it take to fix it? (Hours or days or months)

Table 25: Table D -Auxiliary table to assess failure record and maintenance required

		Generation & separation				**Collection**		**Transfer & transport**		**Pre-treatment & treatment**					
System description		Normal toilet	Vacuum toilet	Diverting toilet	Urinal	Storage Tanks	Compost tank	Pipes	Trucks	Pump	Filters	vertical reed bed	Retention ponds	WWTP	
Failure Record	Service life expected (years)														
	Failures per year (# / hh. year)														**Total (h/year)**
	Average of down time (hour)														
Total Number of downtime hours per year (hours / hh .year)															
Maintenance required (hours / year)															

Table 26: Table E - Undesirable objects and substances for the robustness test

Item	**Question**	**Unit of measure**

Paper/textile	Does a lumpy paper/textile object (e.g., diaper or towel, dimensions 20 x 20 x 10 cm) cause a stoppage?	Yes/no, if yes, estimated number of hours downtime per event (time needed to get system up)
Plastics	Does a plastic bag (dimensions 40 x 20 cm) cause a stoppage?	Yes/no, if yes, estimated number of hours downtime per event (time needed to get system up)
Bulky objects	Does a piece of stone (round, diameter 7 cm) cause a stoppage?	Yes/no, if yes, estimated number of hours downtime per event (time needed to get system up)
biodegradable	Does a discharge of either 5 liters of oil (engine oil or cooking oil) or 2 liters of solvents cause a stoppage?	Yes/no, if yes, estimated number of hours downtime for most serious shock load event (time needed to get system up)
	Does a discharge of 5 liters of fat cause a stoppage?	Yes/no, if yes, estimated number of hours downtime per event (time needed to get system up)

5.7. Invisibility

One parameter that was not assessed in the past with the conventional system is the invisibility. This criterion become relevant in decision making due to with the new technologies, it is possible to require to installation of some equipment in the household or in the neighborhood that is visible. The successful implementation of the sanitation system also depends on the acceptance from the users, from different studies has been found that users prefer invisible systems, that is one of the reason of the attachment to the old one, because once you flush your toilet, people do not have to worried again for wastewater, users do not participate in the treatment and do not see any part of it. For the scope of this framework, invisibility will be assessed by requirements of space and area and also the presence of nuisances: noise and odor.

Invisibility is a qualitative parameter and should be assessed objectively, space and area are straightforward indicators, volume required (indoor-outdoor) in m^3/pe, and area required in m^2/ pe, respectively; but for nuisance assessment, until now, not too much have been studied before, in qualitative terms, and the only available information is based on user perception, which means indicators based on subjective information, because a given level of exposure is experience differently by different individuals. For odor assessment report, it would be recommended to monitor the duration and intensity of the event and record some conditions like temperature and wind characteristics see table 28. However, decentralized and on-site systems are more likely to present nuisances due to their proximity with the inhabitants.

Table 27: Table F - Invisibility assessment based on area and space

		Normal toilet	Vacuum toilet	Diverting toilet	Urinal	Storage Tanks	Compost tank	Pipes	Trucks	Pump	Filters	sedimentation tank	reed bed	reed bed + urine tank	Retention ponds	WWTP	**Total**
Case	Volume (m3/pe)																
	Area (m2/pe)																

Table 28: Recommended scheme for recording odor events

Date	**Temperature**	**Duration of event**	**Odor Source**	**Intensity**

5.8. Total annual Cost

Within the cost assessment, the constructions cots, operational and maintenance costs and the connection fees will be evaluated, per household per year. The importance of the cost assessment is to verify if the system is affordable and also to check with local social-economic conditions if the community is willing to invest in the selected technology. Decision makers should be aware that costs can vary a lot from country to country, not only technical device’s costs but also labor cost; then direct comparison is not recommended. Always should be compared with local salaries and currencies.

In fact, because of their size, small communities do not benefit from the economies of scale possible with the construction of wastewater management facilities for larger communities. As a result, conventional wastewater management facilities for small communities often cost significantly more per capita to construct, when compared to those for larger communities (Metcalf and Eddy, 1991 in Galvao et al, 2005).

Each project has different characteristics, and also they incur different expenses, and then for cost estimation has to be adapted for each case, some examples of costs estimations are shown in the annex, tables 44 to 50.

5.9. Framework for Urban Sanitation Assessment

The final framework has seven criteria and 21 indicators; they are shown in the table 29, with a short description per indicator.

5.10. Aggregation and Normalization

In order to make information more readable and comparable, it is necessary to normalize the data. All the scores will be converted into a scale from 0 to 100, the score 0 means low performance, while 100 means high performance. The normalization parameters per indicator and the aggregation methods are indicated in the table 30.

Table 29: Framework for Urban Sanitation Assessment

Indicator		units	Description
Key Performance Indicator (KPI) 1: Contextual independence			
	Is the technology sensitive to the following aspects:		
1	Climate	High Sensitivity = 1 Moderate sensitivity = 2 Zero sensitivity = 3	Assessment of the influence of external factors like the environment, surroundings, circumstances on the system performance. (**use table A)**
2	Socio-economic conditions		
3	Ecosystem conditions		
4	Geological conditions		
5	Other utilities		
Key Performance Indicator (KPI) 2: Public Health			
6	Risk of skin contact with (black water or brown water)	High risk = 3, Medium risk= 2, Low risk =1	Identification of hazardous substances, pathways and exposure, to estimate risk to public health **(use table B)** Qualitative risk assessment
7	Risk of skin contact with (grey water, rain water, or yellow water)		
8	Risk of accidental ingestion on swimming waters where treated wastewater is discharged		
Key Performance Indicator (KPI) 3: Impact ecosystem - Discharges of:			
9	Potential Eutrophication	kg PO_4^{3} - eq./ pe. Y	Potential eutrophication produced by the discharges of COD, N and P per person per year. See factors in **Table C**
10	Potential Ecotoxicity	kg (1,4 - DCB eq) / pe . y	Potential ecotoxicity produced by heavy metals discharged, per person per year. See factors in **Table C**
Key Performance Indicator (KPI) 4: Resources use			
11	Net energy consumption = Energy consumption - Energy recovered	Kwh/pe.y	Energy consumption minus energy recovered of the system per Kwh per person per year
12	Net water consumption	m^3 /pe.y	Drinking water consumption per m^3 per person per year
13	Nutrients recovered	kg /pe.y	Nutrients recovered in kilograms per person per year
14	Use of chemicals	kg /pe.y	Use of chemicals in kilograms per person per year
Key Performance Indicator (KPI) 5 : System Robustness			
15	Failure record	h /pe . year	Total number of hours of system breakdown per year due to failures **(see table D)**
16	Shock load resistance	h /pe . year	Estimate number of hours of potential system breakdown per year due to user abuse **(see table E)**
17	Operation & Maintenance	h / pe year	Total number of hours of maintenance required per year **(see table D)**
Key Performance Indicator (KPI) 6 : System Invisibility			
18	space per household	m^3/pe	Indoor - outdoor space required by the system in m^3/pe **(see table F)**
19	Area per household	m^2/pe	area required by the system in m^2/pe**(see table F)**
20	Nuisance	High = 3, Medium = 2, Low =1	Level of nuisance produced by noise and smell
Key Performance Indicator (KPI) 7 : Annual Cost			
21	Annual cost	Euro/hh y	Annual cost, including capital and maintenance costs. Total cost of the system per household per year

Table 30: Final Framework for urban sanitation assessment

	Indicator	units	Normalization and aggregation
Key Performance Indicator (KPI) 1: Contextual independence			
	Is the technology sensitive to the following aspects:		
1	Climate	High Sensitivity = 1 Moderate sensitivity = 2 Zero sensitivity = 3	**Aggregation:** Average of minimums **Target:** 3 **Normalization:** $d_{score} = (d - d_{min}) \times 100 / (d_{max} - d_{min})$
2	Socio-economic conditions		
3	Ecosystem conditions		
4	Geological conditions		
5	Other utilities		
Key Performance Indicator (KPI) 2: Public Health			
6	Risk of skin contact with (black water or brown water)	High risk = 3, Medium risk= 2, Low risk =1	**Aggregation:** Find minimum value **Target:** 1 **Normalization:** If d= 1 , then d_{score} 100 If d= 2 , then d_{score} 50 If d= 3 , then d_{score} 0
7	Risk of skin contact with (grey water, rain water, or yellow water)		
8	Risk of accidental ingestion on swimming waters where treated wastewater is discharged		
Key Performance Indicator (KPI) 3: Impact ecosystem - Discharges			
9	Potential Eutrophication	kg PO_4^3 - eq./ pe. Y	**Aggregation:** According to LCA (see equations 6.3 and 6.4) **Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
10	Potential Ecotoxicity	kg (1,4 - DCB eq) / pe.y	
Key Performance Indicator (KPI) 4: Resources use			
11	Net energy consumption = Energy consumption - Energy recovered	Kwh/pe.y	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
12	Net water consumption	m^3 /pe.y	
13	Nutrients recovered	kg /pe.y	**Target:** As high as possible **Normalization:** $d_{score} = (d - d_{min}) / (d_{max} - d_{min}) \times 100$
14	Use of chemicals	kg /pe.y	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
			Aggregation: Average
Key Performance Indicator (KPI) 5 : System Robustness			
15	Failure record	h /pe . year	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
16	Shock load resistance	h /pe . year	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
17	Operation & Maintenance	h / pe year	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
			Aggregation: Average
Key Performance Indicator (KPI) 6 : System Invisibility			
18	space per household	m^3/pe	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$
19	area per household	m^2/pe	
20	Nuisance	High = 3, Medium = 2, Low =1	**Target:** 1 **Normalization:** If d= 1 , then d_{score} 100 If d= 2 , then d_{score} 50 If d= 3 , then d_{score} 0
			Aggregation: Average
Key Performance Indicator (KPI) 7 : Annual Cost			
21	Annual cost	Euro/hh y	**Target:** As low as possible **Normalization:** $d_{score} = \lvert [(d - d_{min}) / (d_{max} - d_{min})] -1 \rvert \times 100$

5.11. Conclusions

The mean of the multi-criteria framework is to facilitate discussion during decision making process, in that sense; transparency of the methodologies is required, in order to be trusted for the different stakeholders.

The main drawback of the existing framework is the lack of an aggregation method to assess each criterion; an aggregation method is required to take into account the contribution or relevance of each indicator in the final score, and also to perform data analysis in which a wide spectrum of units of measure are involved. Other drawbacks found were the widely definition of some indicators leaving room for different interpretations, they should be disaggregated for a better understanding an appropriate assessment. Moreover imprecision about the unit of measure, some indicators are expressed per person while others are expressed per household, this creates confusion and it is a potential for calculations errors. Also with the actual framework it is not possible to track the raw-data; just a final indicator value is included, this makes difficult data validation and verification. Some questions are based on user's perception, which is hard to assess and compare and not always is a good indicator for system's performance.

Different methodologies found in the existing frameworks were tested for the optimization of the framework. After that, it can be concluded that modeling the systems would be the best approach to measure impacts of sanitation systems, however due to high data requirements, it is not feasible, and the most feasible alternative is to calculate "potential" effects. This occurs in the assessment of health risk, and impact on the environment, where multiple variable and several uncertainties are involved. Previous assessments based on Life Cycle Assessment showed that system boundaries influence significantly the results; also in order to make an appropriate "cradle to grave" assessment, data requirements are high. The methodologies based on cost shows difficulties to make some of the equivalences, it is based on costs assumptions lacking sometimes of transparency, and the resulting "Total Cost" doesn't offer suitable information for discussion during decision making process. Outranking methods are as good as the suppositions made, those methods require weight definitions, and only experts can do that based on their knowledge and experience.

There is no consensus about the influence of the methodology in the results. But what it is clear is that different methods apply different assumptions, weights or normalizations, users should be aware of them to achieve the expected results. The methodology should also suit with data availability, to avoid misleading results. Sophisticate software capable to make complex analysis have been developed, however the quality of the results depends on the quality of the input data, complex methods have high data requirements and considerable time allocation, while simple methods are less sensitive to uncertainties and a less precise result is achieve in short time.

Due to each methodology has strengths and weakness, different methodologies were used in this framework, each criterion is evaluate separately, to reach at the end a set of seven scores, one per criteria. First of all to facilitate to match the performance with local conditions and second to avoid aggregation and subjective weighting, that affects transparency and traceability.

Each criterion has a different methodology assessment as follows:

- Contextual Independence: to evaluate to what extent a given technology is independent from external conditions, it was developed a checklist to measure the degree of sensitivity of the different system components to external factors.

- Health Risk Assessment: for evaluating the public health risk related to a given technology due to the contact of inhabitants with faeces, urine, raw wastewater, treated wastewater or sludge. It was used the approach of Qualitative Microbial Risk Assessment. (QMRA) in order to assess the potential risk of exposure.

- Impact on the Ecosystem: to evaluate to what extent a given technology impacts on the ecosystem. It was done based on the approach of Life Cycle Assessment (LCA). To measure the potential impact of the discharges, the two considered aspects were potential eutrophication and potential ecotoxicity.

- Resources Use: to evaluate to what extent a given technology makes an efficient use of the resources (water, energy, nutrients and chemicals). A check list of resources involved in sanitation is included, and normalization per indicator is done based on the maximum and minimum values of the systems under study.

- System Robustness: the evaluation was done based on failure records, and possible user abuse. A failure record scheme is developed in order to characterize failures and also a user abuse questioner was developed to determine shock load resistance. Normalization per indicator is done based on the maximum and minimum values of the systems under study.

- Invisibility: to evaluate to what extent a given technology is invisible for the users and the community. A check list of the area and space required was done and assessment of the user perception for nuisances. Also normalization per indicator is done based on the maximum and minimum values of the systems under study.

- Total Cost: the total cost of the system is calculated by estimating the annual cost, taking into account construction investment and, operation and maintenance costs per year.

6. Testing the Framework

The objective of this chapter is to test the framework, and besides make an assessment of the data availability. The factors influencing the assessment results are input data and the framework, as it can be observed in the figure 13.

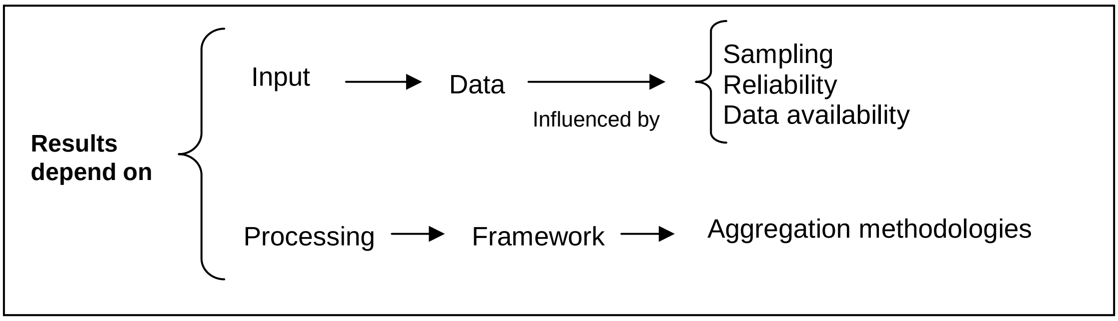

Figure 13. Factors influencing results

The framework was preliminary tested using information from previous studies in order to asses data input, the chosen systems were the conventional system in the Netherlands and some pilot projects in the Netherlands, Sweden and Norway, a short description is included in the table 31. The information was obtained from Betuw, (2005) and Telkamp (2006).

From this pre-test it was possible to evaluate how complete was the information available and what are the main gaps. After this preliminary test, and after filling data gaps, some cases were selected for the final assessment that will help to test the framework by itself.

Table 31: Pilot projects used for the preliminary testing

Case	Country	Location	Project	System
1	The Netherlands	Utrecht	Het groene dak	Separation of black,
2	The Netherlands	Arnhem	Polderdrift	grey and rain water
3	Sweden	Norrköping	Ekoporten	Separation of Urine, brown and rain water
4	Sweden	Stockholm	Skogaberg	Separation of black, grey and rain water
5	Sweden	Stockholm	Understenshöjden	Urine separation
6	Sweden	Stockholm	Gebers	Separation of Urine, brown and rain water
7	Norway	As	Kaja	Separation of black,
8	Norway	Bergen	Torvetua	grey and rain water

6.1. Preliminary test

The framework was tested, with the available information; however during this process it was found out that data availability is limited. An overview of the results is included in the table 32.

Table 32: Results of the Preliminary Test

			Conventional	Understens	Groene Dak	Polderdrift	Skogaber	kaja	Ekoporten	Gebers	Tovertua
Key Performance Indicator (KPI) 1: Contextual independence											
	Is the technology sensitive to the following aspects:										
1	Climate	High Sensitivity = 1 Moderate sensitivity = 2 Zero sensitivity = 3									
2	Socio-economic conditions										
3	Ecosystem conditions										
4	Geological conditions										
5	Other utilities										
Key Performance Indicator (KPI) 2: Public Health											
6	Risk of skin contact with (black water or brown water)	High risk = 3, Medium risk= 2, Low risk =1	1	1	1	1	1	1	2	2	1
7	Risk of skin contact with (grey water, rain water, or yellow water)		1	1	1	1	1	1	1	1	1
8	Risk of accidental ingestion on swimming waters where treated wastewater is discharged		1	1	1	1	1	1	1	1	1
Key Performance Indicator (KPI) 3: Impact ecosystem - Discharges:											
9	Potential Eutrophication	kg PO_4^{3} - eq./ pe. Y	1.24	unknown	unknown	0.25	1.95	unknown	unknown	unknown	unknown
10	Potential Ecotoxicity	kg (1,4 - DCB eq)	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
Key Performance Indicator (KPI) 4: Resources use											
11	Net energy consumption = Energy consumption - Energy recovered	Kwh/pe.y	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
12	Net water consumption	m³ /pe.y	46.5	56	32	25	36	unknown	38	42.3	42
13	Nutrients recovered	kg /pe.y	0	1.75	0	0	unknown	unknown	2648.6	5.58	3.05
14	Use of chemicals	kg /pe.y	unknown	unknown	0	0	unknown	unknown	unknown	0	0
Key Performance Indicator (KPI) 5 : System Robustness											
15	Failure record	h /pe . year	0.0019	2	0.2	0.24	1	2.16	unknown	2	2
16	Shock load resistance	h /pe . year	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown	unknown
17	Operation & Maintenance	h /pe . year	unknown	32	18	16	2100	156	11.89	12	12
Key Performance Indicator (KPI) 6 : System Invisibility											
18	space per household	m³/pe	unknown	0.5	10	0.17	0.2	unknown	**2.54**	6.83	0.5
19	area per household	m^2/pe	unknown	.23	14.7	2.88	0.75	unknown	**7.70**	0.14	0.3
20	Nuisance	High = 3, Medium = 2, Low =1	1	1	2	1	1	1	1	1	2
Key Performance Indicator (KPI) 7 : Annual Cost											
21	Annual cost	Euro/hh y	572	512	628	1011	710	648	1506	386	unknown

After the preliminary test it can be concluded that, regarding contextual independence, this aspect was not included in the previous studies, and no information is recorded about how external parameters can affect system's performance. For public health the exposure routes and the risk of exposure were complete. Concerning impact on the ecosystem, there is no enough information, when flows separation is done, different discharges have their own characteristics, and not all of them are monitored. Partial information is available for potential eutrophication and no information related to heavy metals discharges. The resources use data is partial as well; water consumption is known while there are uncertainties about energy consumption, use of chemicals and recovery of nutrients. For the system robustness assessment the information about maintenance is available and the failure record also but some uncertainties about duration of the failures was found, regarding user abuse there is no information due to this question was not included in the previous questionnaire; and nuisances are score based on user's perception because not objective information is available. The information related to total annual cost was complete. In conclusion, the main gaps are in contextual independence, discharges into the environment, and resources use.

However, it is necessary to make some assumptions in order to test the framework, based on literature review some gaps were filled out for conventional and 4 more cases, see table 33.

Table 33: Pilot projects used for testing the framework

Case	Country	Location	Project	System
1	The Netherlands			Conventional system
2	The Netherlands	Arnhem	Polderdrift	Separation of black, grey and rain water
3	Sweden	Norrköping	Ekoporten	Separation of Urine, brown and rain water
4	Sweden	Stockholm	Understens	Urine separation
5	Sweden	Stockholm	Gebers	Separation of Urine, brown and rain water

6.2. Final Assessment

In the paragraph is described the assessment of the 5 selected systems.

Contextual Independence

The first criterion is the contextual independence, for that assessment, it was developed the auxiliary table A. To fill in the table, each component of the system was identified, after that the sensitivity of each component was evaluated from 1 to 3 (1= High Sensitivity, 2= Moderate Sensitivity and 3=Zero Sensitivity). To evaluate the contextual independence the minimum score per row was chosen, and average per aspect was the score for the framework. In the table 34 it is summarized the contextual independence assessment for the different technologies.

Public Health Assessment

For public health assessment, it was designed the table B; in which exposure routes are identified and the level of exposure is indicated to evaluate the risk. For this assessment all the possible exposure routes of the system were identified, after that for each exposure route was evaluated the risk of skin contact or accidental intake based on the table 18. The health assessment for the different systems is shown in the table 35.

Impact on Ecosystem

The assessment of impact on ecosystem is divided in two categories, potential eutrophication and ecotoxicity. Information regarding these aspects is not completely known. Then, for the purpose of testing the framework some assumption were made concerning nitrogen, phosphorus and COD discharges to evaluate potential eutrophication, as is shown in the table 36. Assumptions for ecotoxicity parameters were not possible.

Resources Use

The information is directly filled out in the framework.

System Robustness

The information regarding system failure and maintenance is in the table 37. Information for shock load resistance was not available and assumptions were not possible.

Invisibility

For the assessment of invisibility, it was used the table 38 to calculate the total space and area required for the system. For nuisance assessment, people's perception measured by Betuw, (2005), it was used.

Cost

Annual costs estimations from Betuw 2005, were used. See tables 43 to 49.

The final assessment is shown in the table 39, including the normalization.

Table 34: Table A -Contextual Independence Assessment

Conventional

CONTEXTUAL INDEPENDENCE			Normal toilet	Pipes	WWTP	Minimum	Score per aspect
System description			x	x	x	Minimum	
Climate	Temperature	High >30℃	3	3	3	**3**	**3.0**
		Low <10℃	3	3	3	**3**	
	Rainfall	Intense (flooding)	3	3	3	**3**	
		Seasonal variation	3	3	3	**3**	
Socio economic conditions	Scale - Population size	Individual 1-10 connections	3	3	1	**1**	**2.33**
		Decentralized 10 – 10.000 connections	3	3	3	**3**	
		Centralized >10.000 connections	3	3	3	**3**	
	Population growth		3	3	3	**3**	
	Economic level*	low income	2	3	1	**1**	
		Medium income	3	3	2	**2**	
		high income	3	3	3	**3**	
	Land availability	Land availability	3	3	2	**2**	
		Access to the site	3	3	3	**3**	
Geological conditions	Soil type	Sand	3	3	3	**3**	**2.40**
		Clay	3	1	3	**1**	
		Rock	3	3	3	**3**	
	Topography	Low slope	3	3	3	**3**	
		high slope	3	2	3	**2**	
Ecosystem conditions	Water availability		1	3	3	**1**	**1.67**
	Water quality (feasible for Sensitive areas lakes or groundwater)		2	3	3	**2**	
	Water table level		3	2	3	**2**	
Dependence of other systems	water supply		1	3	3	**1**	**1.00**
	energy supply		3	3	1	**1**	

Polderdrift

CONTEXTUAL INDEPENDENCE			Normal toilet	Pipes	Fat removal sedimentation tank	Constructed wetlands	WWTP	Minimum	Score per aspect
System description			x	x	x	x	x		
Climate	Temperature	High >30℃	3	3	3	3	3	**3**	**2.5**
		Low <10℃	3	3	3	3	3	**3**	
	Rainfall	Intense (flooding)	3	3	3	1	3	**1**	
		Seasonal variation	3	3	3	3	3	**3**	
Socio economic conditions	Scale - Population size	Individual 1-10 connections	3	3	1	3	1	**1**	**2.00**
		Decentralized 10 – 10.000 connections	3	3	3	3	3	**3**	
		Centralized >10.000 connections	3	3	3	3	3	**3**	
	Population growth		3	3	1	1	3	**1**	
	Economic level*	low income	2	3	3	3	1	**1**	
		Medium income	3	3	3	3	2	**2**	
		high income	3	3	3	3	3	**3**	
	Land availability	Land availability	3	3	2	1	2	**1**	
		Access to the site	3	3	3	3	3	**3**	
Geological conditions	Soil type	Sand	3	3	3	3	3	**3**	**2.60**
		Clay	3	2	2	3	3	**2**	
		Rock	3	3	3	3	3	**3**	
	Topography	Low slope	3	3	3	3	3	**3**	
		high slope	3	2	3	3	3	**2**	
Ecosystem conditions	Water availability		1	3	3	3	3	**1**	**1.67**
	Water quality (feasible for Sensitive areas lakes or groundwater)		2	3	3	2	3	**2**	
	Water table level		3	2	3	2	3	**2**	
Dependence of other systems	water supply		1	3	3	3	3	**1**	**1.00**
	energy supply		3	3	1	3	1	**1**	

Understenshöjden

CONTEXTUAL INDEPENDENCE			Diverting toilet	Storage Tanks	Pipes	Trucks	WWTP	Minimum	Score per aspect
System description			x	x	x	x	x	Minimum	
Climate	Temperature	High >30℃	3	3	3	3	3	**3**	**3.00**
		Low <10℃	3	3	3	3	3	**3**	
	Rainfall	Intense (flooding)	3	3	3	3	3	**3**	
		Seasonal variation	3	3	3	3	3	**3**	
Socio economic conditions	Scale - Population size	Individual 1-10 connections	3	3	3	3	1	**1**	**1.78**
		Decentralized 10 – 10.000 connections	3	2	3	3	3	**2**	
		Centralized >10.000 connections	3	2	3	3	3	**2**	
	Population growth		3	3	3	3	3	**3**	
	Economic level*	low income	2	3	3	3	1	**1**	
		Medium income	3	3	3	3	2	**2**	
		high income	3	3	3	3	3	**3**	
	Land availability	Land availability	3	1	3	3	2	**1**	
		Access to the site	3	1	3	2	3	**1**	
Geological conditions	Soil type	Sand	3	3	3	3	3	**3**	**2.60**
		Clay	3	3	1	3	3	**1**	
		Rock	3	3	3	3	3	**3**	
	Topography	Low slope	3	3	3	3	3	**3**	
		high slope	3	3	3	3	3	**3**	
Ecosystem conditions	Water availability		2	3	3	3	3	**2**	**2.33**
	Water quality (feasible for Sensitive areas lakes or groundwater)		3	3	3	3	3	**3**	
	Water table level		3	3	2	3	3	**2**	
Dependence of other systems	water supply		3	3	3	3	3	**3**	**2.00**
	energy supply		3	3	3	3	1	**1**	

Gebers

CONTEXTUAL INDEPENDENCE			Diverting toilet	Storage Tanks	Compost tank	Pipes	Trucks	WWTP	Minimum	Score per aspect
System description			x	x	x	x	x	x	Minimum	
Climate	Temperature	High >30℃	3	3	1	3	3	3	1	**2.50**
		Low <10℃	3	3	3	3	3	3	3	
	Rainfall	Intense (flooding)	3	3	3	3	3	3	3	
		Seasonal variation	3	3	3	3	3	3	3	
Socio economic conditions	Scale - Population size	Individual 1-10 connections	3	3	3	3	3	1	1	1.67
		Decentralized 10 – 10.000 connections	3	2	2	3	3	3	2	
		Centralized >10.000 connections	3	2	1	3	3	3	1	
	Population growth		3	3	3	3	3	3	3	
	Economic level*	low income	2	3	3	3	3	1	1	
		Medium income	3	3	3	3	3	2	2	
		high income	3	3	3	3	3	3	3	
	Land availability	Land availability	3	1	2	3	3	2	1	
		Access to the site	3	1	2	3	2	3	1	
Geological conditions	Soil type	Sand	3	3	3	3	3	3	3	2.60
		Clay	3	3	3	1	3	3	1	
		Rock	3	3	3	3	3	3	3	
	Topography	Low slope	3	3	3	3	3	3	3	
		high slope	3	3	3	3	3	3	3	
Ecosystem conditions	Water availability		2	3	3	3	3	3	2	2.33
	Water quality (feasible for Sensitive areas lakes or groundwater)		3	3	3	3	3	3	3	
	Water table level		3	3	3	2	3	3	2	
Dependence of other systems	water supply		3	3	3	3	3	3	3	2.00
	energy supply		3	3	3	3	2	1	1	

Ekoporten

CONTEXTUAL INDEPENDENCE			Diverting toilet	Storage Tanks	and Aquatron	Pipes	Trucks	WWTP	Minimum	Score per aspect
System description			x	x	x	x	x	x	Minimum	
Climate	Temperature	High >30℃	3	3	1	3	3	3	1	**2.50**
		Low <10℃	3	3	3	3	3	3	3	
	Rainfall	Intense (flooding)	3	3	3	3	3	3	3	
		Seasonal variation	3	3	3	3	3	3	3	
Socio economic conditions	Scale - Population size	Individual 1-10 connections	3	3	3	3	3	1	1	1.67
		Decentralized 10 – 10.000 connections	3	2	2	3	3	3	2	
		Centralized >10.000 connections	3	2	1	3	3	3	1	
	Population growth		3	3	3	3	3	3	3	
	Economic level*	low income	2	3	3	3	3	1	1	
		Medium income	3	3	3	3	3	2	2	
		high income	3	3	3	3	3	3	3	
	Land availability	Land availability	3	1	2	3	3	2	1	
		Access to the site	3	1	2	3	2	3	1	
Geological conditions	Soil type	Sand	3	3	3	3	3	3	3	2.60
		Clay	3	3	3	1	3	3	1	
		Rock	3	3	3	3	3	3	3	
	Topography	Low slope	3	3	3	3	3	3	3	
		high slope	3	3	3	3	3	3	3	
Ecosystem conditions	Water availability		2	3	3	3	3	3	2	2.33
	Water quality (feasible for Sensitive areas lakes or groundwater)		3	3	3	3	3	3	3	
	Water table level		3	3	3	2	3	3	2	
Dependence of other systems	water supply		3	3	3	3	3	3	3	2.00
	energy supply		3	3	1	3	2	1	1	

Table 35:Table B - Health Risk Assessment

		Conventional			Polderdrift					Understenshojden				Gebers					Ekoporten				
		Normal toilet	WWTP	Risk per fraction	Normal toilet	Fat removal + sedimentation tank	Constructed wetlands	WWTP	Risk per fraction	Diverting toilet	Storage Tanks	WWTP	Risk per fraction	Diverting toilet	Storage Tanks	Compost tank	WWTP	Risk per fraction	Diverting toilet	Storage Tanks	Compost tank	WWTP	Risk per fraction
System description		x	X		x	x	x	x		x	x	x		x	x	x	x		x	x	x	x	
High Risk Skin contact with: Black water , Brown water	**Exposure (0-2)**	0	0		0	0	0	0		0	0	0		0	0	1	0		0	0	1	0	
	Risk Low=1 Medium= 2 High=3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	1	1	2	1	2
Low Risk Skin contact with: Yellow water, grey water, rainwater	**Exposure (0-2)**	0	0		0	0	2	0		0	0	0		0	0	0	0		0	0	0	0	
	Risk Low=1 Medium= 2 High=3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Low Risk Accidental intake by swimmers, Intake of food irrigated with treated wastewater	**Exposure (0-2)**	0	0		0	0	0	0		0	0	0		0	0	0	0		0	0	0	0	
	Risk Low=1 Medium= 2 High=3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 36: Table C -Assessment of Potential Eutrophication

		Factors	Conventional		Polderdrift		Understends		Gebers		Ekoporten	
	substance	EP (in kg PO_4^3 – eq./kg)	Discharge in kg	EP (in kg PO_4^3 – eq./kg)	Discharge in kg	EP (in kg PO_4^3 – eq./kg)	Discharge in kg	EP (in kg PO_4^3 – eq./kg)	Discharge in kg	EP (in kg PO_4^3 – eq./kg)	Discharge in kg	EP (in kg PO_4^3 – eq./kg)
Potential Eutrophication	nitrogen	0.42	1.63	0.68	0.04	0.02	0.47	0.20	0.511	0.21	0.5694	0.24
	phosphorus	3.06	0.15	0.46	0.07	0.21	0.25	0.77	0.219	0.67	1.022	3.13
	COD	0.022	4.41	0.10	0.75	0.02	24	0.53	17.48	0.38	7.46	0.16
			Total	**1.24**	**Total**	**0.25**	**Total**	**1.49**	**Total**	**1.27**	**Total**	**3.53**

Table 37: Table D - System Robustness Assessment

			Generation & separation				Collection			Transfer & transport				Pre-treatment & treatment						
	System description		Normal toilet	Vacuum toilet	Diverting toilet	Urinal	faeces bin	Storage Tanks	Compost tank	urine Pipes	Trucks	Drain	Drum	Pump	Filters	Aquatron	reedbed	Retention ponds	WWTP	
Polderdrift	Failure Record	Failures per year (# / pe. Year)															0.24			**Total (h/year)**
Polderdrift	Failure Record	Average of down time (hour)															1			
Polderdrift	**Total Number of downtime hours per year (hours / pe .year)**																0.24			0.24
Polderdrift	**Maintenance required (hours / pe . year)**																16			16.00
Understens	Failure Record	Failures per year (# / pe. Year)								2										**Total (h/year)**
Understens	Failure Record	Average of down time (hour)								1										
Understens	**Total Number of downtime hours per year (hours / pe .year)**									2										2.00
Understens	**Maintenance required (hours / pe . year)**			32																32.00
Gebers	Failure Record	Failures per year (# / pe. Year)								2										**Total (h/year)**
Gebers	Failure Record	Average of down time (hour)								1										
Gebers	**Total Number of downtime hours per year (hours / pe .year)**									2										2.00
Gebers	**Maintenance required (hours / pe . year)**						12													12.00
Ekoporten	Failure Record	Failures per year (# / pe. Year)			0.03							0.11	0.50			0.2	2.00			**Total (h/year)**
Ekoporten	Failure Record	Average of down time (hour)			1							1	1			1	1			
Ekoporten	**Total Number of downtime hours per year (hours / pe .year)**				0.03							0.11	0.5			0.2	2			2.84
Ekoporten	**Maintenance required (hours / pe . year)**																			11.89

Table 38: Table F - Assessment of Invisibility

		Generation & separation				Collection		Transfer & transport		Pre-treatment & treatment							
		Normal toilet	Vacuum toilet	Diverting toilet	Urinal	Storage Tanks	Compost tank	Pipes	Trucks	Pump	Filters	sedimentation tank	reed bed	reed bed + urine tank	Retention ponds	WWTP	**Total**
Polderdrift	Volume (m3/pe)											0.17					0.17
	Area (m2/pe)												2.88				2.88
Understenshodjen	Volume (m3/pe)					0.50											0.50
	Area (m2/pe)											0.23					0.23
Gebers	Volume (m3/pe)					6.6		0.23									6.83
	Area (m2/pe)						0.14										0.14
Ekoporten	Volume (m3/pe)					0.85	1.38					0.31					2.54
	Area (m2/pe)													7.7			7.70

Table 39: Final Assessment and Normalization

			DATA					NORMALIZATION				
	Indicator	**units**	**Conventional**	**Polderdrift**	**Understens**	**Gebers**	**Ekoporten**	**Convent.**	**Polder.**	**Unders.**	**Gebers**	**Ekopo.**
	# dwellings	units	7866107	40	44	32	18					
	Population	Pe	15732214	60	160	70	35					
	Typology	Qualitative	Mixed	houses	houses	apartments	apartments					
	Construction date	Descriptive	Since 1920	1997	1995	1998	1996					
Key Performance Indicator (KPI) 1: Contextual independence												
	Is the technology sensitive to the following aspects:											
1	Climate	High Sensitivity = 1 Moderate sensitivity = 2 Zero sensitivity = 3	3.0	2.5	3.0	2.5	2.5	100.00	75.00	100.00	75.00	75.00
2	Socio-economic conditions		2.3	2.0	1.8	1.7	1.7	66.67	50.00	38.89	33.33	33.33
3	Ecosystem conditions		2.4	2.6	2.6	2.6	2.6	70.00	80.00	80.00	80.00	80.00
4	Geological conditions		1.7	1.7	2.3	2.3	2.3	33.33	33.33	66.67	66.67	66.67
5	Other utilities		2.0	1.0	3.0	3.0	3.0	50.00	0.00	100.00	100.00	100.00
	Score	Average						**64.0**	**47.7**	**77.1**	**71.0**	**71.0**
Key Performance Indicator (KPI) 2: Public Health												
6	Risk of skin contact with (black water or brown water)	High risk = 3, Medium risk= 2, Low risk =1	1	1	1	2	2	100	100	100	50	50
7	Risk of skin contact with (grey water, rain water, or yellow water)		1	1	1	1	1	100	100	100	100	100
8	Risk of accidental ingestion on swimming waters where treated wastewater is discharged		1	1	1	1	1	100	100	100	100	100
	Score	Minimum value						**100**	**100**	**100**	**50**	**50**
Key Performance Indicator (KPI) 3: Impact ecosystem – Discharges												
9	Potential Eutrophication	kg PO_4^3 – eq./ pe. Y	1.24	0.25	1.49	1.27	3.53					
10	Potential Ecotoxicity	kg (1,4 – DCB eq)										
	Score	Average of normalization per indicator	6.23E+08	1.24E+08	7.48E+08	6.37E+08	1.77E+09	**69.75**	**100.00**	**62.14**	**68.87**	**0.00**

Key Performance Indicator (KPI) 4: Resources use												
11	Net energy consumption = Energy consumption – Energy recovered	Kwh/pe.y	10.23									
12	Net water consumption	m³ /pe.y	46.5	25	56	42.34	37.96	30.65	100.00	0.00	44.06	58.19
13	Nutrients recovered	kg /pe.y	0	0	1.75	5.58	2648.6	0.00	0.00	0.07	0.21	100.00
14	Use of chemicals	kg /pe.y		0			0					
	Score	Average of normalization per indicator						**15.32**	**50.00**	**0.03**	**22.14**	**79.10**
Key Performance Indicator (KPI) 5 : System Robustness												
15	Failure record	h /pe . year	0.0019	0.24	2.00	2.00	2.84	100.00	91.78	29.59	29.59	0.00
16	Shock load resistance	h /pe . year										
17	Operation & Maintenance	h / pe. Year	30	16	32.00	12.00	11.89	9.94	79.55	0.00	99.43	100.00
	Score	Average of normalization per indicator						**54.97**	**85.66**	**14.79**	**64.51**	**50.00**
Key Performance Indicator (KPI) 6 : System Invisibility												
18	space per person	m³/pe	0.00	0.17	0.50	6.83	2.54	100.00	97.56	92.68	0.00	62.74
19	area per person	m^2/pe	2.55	2.88	0.23	0.14	7.70	68.03	63.73	98.77	100.00	0.00
20	Nuisance	High = 3, Medium = 2, Low =1	1	1	1	1	1	100	100	100	100	100
	Score	Average of normalization per indicator						**89.34**	**87.10**	**97.15**	**66.67**	**54.25**
Key Performance Indicator (KPI) 7 : Annual Cost												
21	Annual cost	Euro/hh y	572	1011	512	386	1506	**83.39**	**44.20**	**88.75**	**100.00**	**0.00**

6.3. Results

The final results, after normalization and aggregation are shown in the table 40. These values vary between 0 and 100. The score 100 represents the best performer. Those values are represented in a radar plot in the figure 14. The axes were divided in tree areas, (0 to 33, 33 to 67 and 67 to 100), to visualize the low – medium – high performance respectively.

Table 40: Normalized and aggregated scores

		Conventional	Polderdrift	Understens	Gebers	Ekoporten
1	Contextual Independence	64	48	77	71	71
2	Public Health	100	100	100	50	50
3	Impact Ecosystem	70	100	62	69	0
4	Resources Use	15	50	0	22	79
5	System Robustness	55	86	15	65	50
6	System Invisibility	89	87	97	67	54
7	Annual Cost	83	44	89	100	0

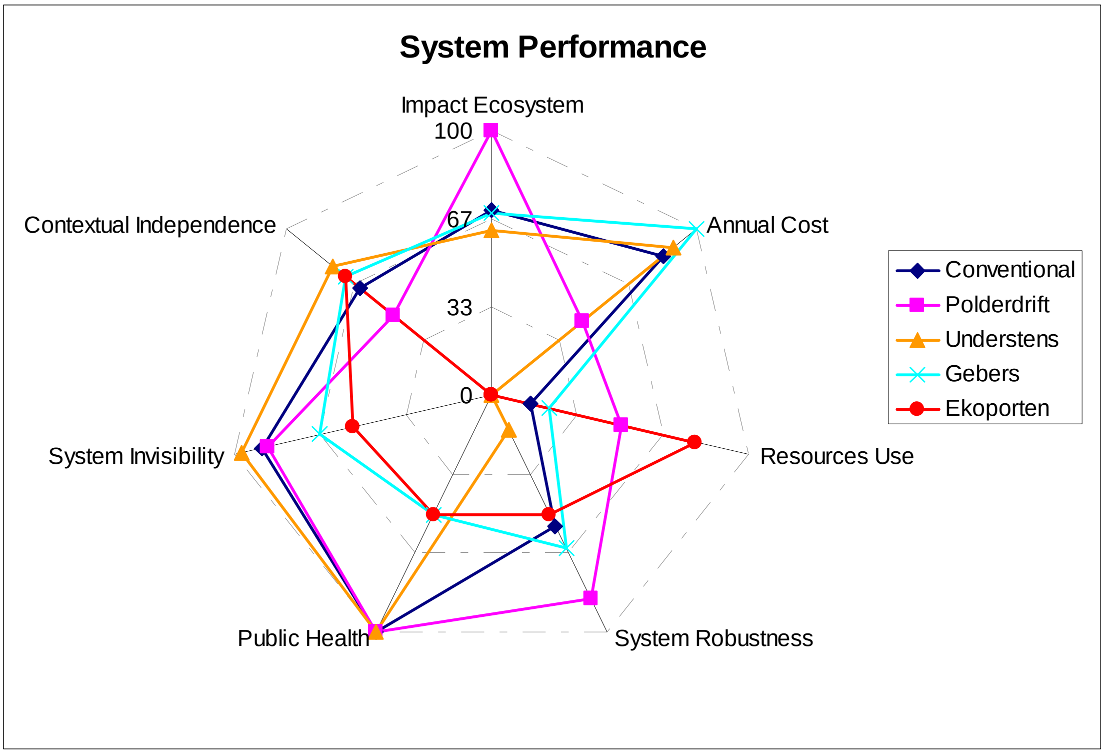

Figure 14. Final Result for the Technology Assessment

With this graph is it possible to compare the performance of each system regarding each criteria, and it is also possible to identify the trade-offs of each system. As expected, none of the technologies can be chosen as the "best" all of them have different levels of performance in different aspects.

6.4. Conclusions

Regarding sampling, it was done based on data available, not statistical sampling was done. Each system uses different technologies, and it is not possible to assess a technology based only in one case. More cases are needed with the same technology in order to make statistical analysis.

Data is the most important part of the assessment, and their quality and relevance affect the whole decision making process. For urban sanitation assessment there is still lack of data, some of the measures are isolated, and do not have statistical value, and data validation is still difficult. Due to limited information, it makes difficult the identification of outliers.

After testing the framework, the main data gaps are in contextual independence, discharges into the environment, and resources use. Regarding contextual independence and shock load resistance, those aspects were not included in the previous studies. For public health the exposure routes and the risk of exposure were complete. Concerning impact on the ecosystem, only some of the flows are monitored, then partial information is available for potential eutrophication and no information related to heavy metals discharges. The resources use data is partial as well; water consumption is known while there are uncertainties about energy consumption, use of chemicals and recovery of nutrients. For the system robustness assessment the information about maintenance and failure record is available however some uncertainties about duration of the failures were found. For the invisibility assessment the area and space were available and nuisances were score based on user's perception because not objective information is available. The information related to total annual cost was complete. In the table 32, a detailed overview of the missing data is founded.

In order to minimize data gaps, it is needed to collect information regarding resources use and total discharges of nitrogen, phosphorus, COD. Also, for an optimal assessment of the contextual independence, it is required to have an expert's opinion that can evaluate the different technologies. The main recommendation for data collection is to fill out the auxiliary table designed with the framework in order to make possible to track the information. There are not formal records of failure, maintenance, nuisances, exposures to harmful substances, etc. Data available in those aspects are based on interviews, what increase the data range variation. If, it would be possible to give the tenants a copy of the table for system robustness and public health, they could record for one or two months by themselves real data about exposures, maintenances and failures, that information would be more reliable.

Even though a cost criterion is often decisive, a results interpretation should be done before make a decision. Costs assessment is strongly influence by the scale of the project, also security factors are used due to uncertainties and the implementation of a back up system (usually conventional sewer) to prevent calamities increases as well costs of novel technologies.

Despite the fact that the conventional system has been used for many years, there are still uncertainties about its performance. Only data at national level is available, moreover, it is necessary to compare conventional system with non-conventional in a similar scale, for that it is recommended to monitor a conventional system in a neighborhood or a small city.

Concerning the framework, for health assessment, it is still necessary to work more in the dose-response assessment in order to make a quantitative risk assessment. Currently for impact on environment is only assessed discharges into water, but also there are discharges into soil and air, they can also be included in the framework and be analyzed with the Life Cycle Approach. They are not included now because of the lack of information. The resources use and invisibility are aggregated by average of the indicators; it means that all the indicators have the same weight, more methodologies have to be tested in order to find one that allow a most appropriate weighting. The radar plot is helpful to have an overview of the system performance and facilitates technologies comparison per criteria; it also makes possible the easily identification of the trade-offs of each system.

7. Conclusions

The main objective of this research was the optimization of the existing multi-criteria framework for the performance assessment of urban sanitation systems. The optimization was done by identifying the drawbacks of the existing framework. The improvements were based on literature review, including the analysis of existing frameworks and also based on the specific requirements according with the objectives, and data availability and measurability. After improving the framework a test was performed to assess data, propose improvements for the framework and recommend further research.

Multi-criteria methodologies have become a popular aid in decision making processes with involvement of multi-objective approach and several stakeholders. Nevertheless, it has to be pointed out, that solving a multi-criteria problem often does not mean to find an optimum solution, but facilitates discussion and understanding of the different alternatives towards the finding of the most suitable solution. From the literature review, it was found that 42 different multi-criteria methodologies can be used for the assessment of water management, however none of them can be selected as the most suitable; each one has strengths and weaknesses. Such a large spectrum of possibilities turned into a “decision problem” by itself.

Based on multi-criteria methodologies 18 frameworks were developed between 1995-2005, all of them have different set of indicators, in total 77 different indicators were listed and their “popularity” is shown in the tables 7 – 11. The number of indicators per framework varies between 5 to 35 and this number was increasing over the years. These frameworks also used different aggregations methods the most popular is the Life Cycle Approach but Material Flow Accounting, Total Cost Accounting and Outranking methodologies like Electre and Promethee are also used. The fact, behind this boom of methodologies, is that still there is no one methodology able to assess different systems. This situation becomes a drawback, because, when it is chosen a methodology and some indicators, there is already an effect on the results.

The lack of an aggregation method was the main drawback of the existing framework. Other shortcomings found were the widely definition of some indicators and ambiguity about their units of measurement. Impossibility of tracking raw-data made difficult data validation and verification. Additionally, the inclusion of subjective questions, based on user’s perception, complicated the analysis, and could include bias in the results.

Results from frameworks based on Life Cycle Assessment showed that system boundaries influence significantly the results; also data requirements are high. The methodologies based on cost shows difficulties to make some of the equivalences and the resulting “Total Cost” doesn’t offer suitable information for discussion during decision making process. Outranking methods require definition of weights per indicator; this task should be done only by experts, in order to get valid results. There is no agreement about how the methodology affects the results. But what it is clear is that different methods apply different assumptions, weights or normalizations, and are suitable for some objectives.

The methodology should also suit with data availability, to avoid misleading results. Sophisticate software capable to make complex analysis have been developed, however the quality of the results depends on the quality of the input data, complex methods have high data requirements and considerable time allocation, while simple methods are less sensitive to uncertainties and a less precise results are achieve in short time.

Different methodologies found in the existing frameworks were tested for the optimization of the framework. Due to each methodology has strengths and weakness, different methodologies were used in this framework, each criterion is evaluate separately, to reach at the end a set of seven scores, one per criteria. First of all to facilitate to match the performance with local conditions and second to avoid aggregation and subjective weighting, that affects transparency and traceability. For health Risk Assessment, it was used the approach of Qualitative Microbial Risk Assessment. (QMRA); to assess Impact on the Ecosystem, it was used the Life Cycle Assessment approach (LCA); for Total Cost, estimations taking into account construction, operation and maintenance per year were made; finally for the assessment of Contextual Independence, Resources Use, System Robustness and Invisibility a set of check lists and auxiliary tables were designed in order to assess each parameter, and simple aggregations methods were used.

The main data gaps founded during testing the framework were related to discharges into the environment, and resources use. Concerning impact on the ecosystem partial information is available, not all the flows are monitored, then the total discharges of the systems are unknown. The resources use data is partial as well; water consumption is known, while energy consumption, use of chemicals and recovery of nutrients is unknown. Regarding contextual independence and shock load resistance, those aspects were not included in the previous studies. For public health the exposure routes and the risk of exposure were complete. For the system robustness assessment the information about maintenance and failure record is available however there are some uncertainties about duration of the failures. For the invisibility assessment the area and space were available and nuisances were score based on user's perception because not objective information is available. The information related to total annual cost was complete. However, there are not formal records of failure, maintenance, nuisances, exposures to harmful substances, etc. Data available in those aspects are based on interviews, what increase uncertainty.

In order to minimize data gaps, it is needed to collect information regarding resources use and total discharges of nitrogen, phosphorus, COD. In addition, for an optimal assessment of the contextual independence, it is required to have an expert's opinion that can evaluate the different technologies. Besides information like system failures or inhabitants' exposures should be recorded in order to have data reliable. Even though the conventional system has been used for many years, there are still uncertainties about its performance, it is necessary to gather data of conventional system in a neighborhood or a small city, to make it comparable with the non-conventional cases.

For further improvements of the framework, it is still necessary to work more in the dose-response assessment in order to make a quantitative risk assessment. Currently for impact on environment is only assessed discharges into water, but also discharges into soil and air are relevant, this assessment can be included when if those discharges are monitored as well. The resources use and invisibility are aggregated by average of the indicators; it means that all the indicators have the same weight, more aggregations methodologies have to be tested in order to find one that allow a most suitable weighting.

Further research should be focus on collection of missing data for the cases already studied, mainly in total discharges and resources use. It is also needed to gather information regarding conventional system in a comparable scale to the non-conventional systems. For selection of new cases to monitor, it would be useful to select similar technologies that allow statistical data assessment and also facilitates data validation. It is required to test more aggregation methodologies to improve the assessment of resources use, system robustness and invisibility.

A call of attention should be done, if new data is collected in order to fill the gaps, the system configuration should be checked because small changes in the system configuration can affect system performance. Also should be taken into account that the performance of some components can have variations over time. Ideally to measure system performance, systems should be independent, the back up systems make difficult a proper system performance assessment.

Acronyms

BAT: Best available technique
DMP: Decision making process
DSM: decision support method
EcoSan: Ecological sanitation
KPI: Key Performance Indicator
LCA: Life Cycle Assessment
LCI: Life Cycle Inventory
MCDA: Multiple Criteria Decision Aid
O&M: Operation & Maintenance
QMRA: Quantitative Microbial Risk Assessment
SWARD (Sustainable Water industry Asset Resource Decisions)
SWITCH:
WHO: World Health Organization
WWTP: waste water treatment plant

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Annex

Table 41: Existing framework for Global Sanitation Assessment

	Sanitation system description	
0.1	Can you describe the technical and managerial features of the reclamation system (process train, ownership, management, size, and so on)?	Descriptive answer - Use the sheet Process train Case 1 or 2
0.2	Were adaptations made to the system as originally installed?	Yes / no
0.3	- If yes, what and why?	Descriptive answer
0.4	What is the reactor size of the various unit process of the process train?	M3
0.5	What is the maximal capacity of the system (or system parts)?	m3/day
0.6	What is the average capacity of the system (or system parts)?	m3/day
0.7	How many persons are connected to the system for wastewater treatment?	number
0.8	What is the occupied area of the process train equipment, expressed in m2?	M2
	Key Performance Indicator (KPI) 1: Public health	
1.1	Is there a chance of inhabitants of the neighborhood to come into direct contact with waste water?	Yes / no - if yes describe the place / pathway
	Through which pathways is (treated) wastewater discharged to surface water and ground water	Description of discharge points to ground and / or surface water and volume discharged (m3/day)
	Which of the water resources is potentially used for human consumption (including swimming)	
	What is the volume of effluent-water production per household per year discharged through these pathway	m3 / person /year
	What is the average water quality for pathogens for these pathways (after the treatment) using e-coli as indicator?	e-coli per 100 ml
1.2	To what extent does that sanitation system spread pathogenic bacteria to water resources that are used for human consumption, including swimming water	m3 of water resources that are contaminated per person (with max. 1000 e-coli per 100 ml)
	KPI 2: impact on eco-system	
	What is the volume of effluent-water production per person per year, by effluent type?	m3 / household /year
	What is the average effluent quality of water for BOD at the various discharge points?	Gram / m3
	What is the average effluent quality of water for COD at the various discharge points?	Gram / m3
	What is the average effluent quality of water for nitrogen at the various discharge points?	Gram / m3
	What is the average effluent quality of water for phosphorous at the various discharge points?	Gram / m3
	What is the average effluent quality of water for heavy metals at the various discharge points?	Microgram / m3
	What is the average effluent quality of water for micro pollutants at the various discharge points?	Microgram / m3
2.1	What is the average discharge of BOD, COD to surface water and / or groundwater per person per year	Grams of BOD, COD per person / year
2.2	What is the average discharge of nitrogen to surface water and groundwater per household per year	Grams of nitrogen per person / year
2.3	What is the average discharge of phosphorus to surface water and groundwater per household per year	Grams of P per person / year
2.4	What is the average discharge of heavy metals to surface water and groundwater per household per year	Grams of heavy metals per person / year
2.5	What is the average discharge of micropollutants to surface water and groundwater per household per year	Grams of micro pollutants per person / year
	What is the production of sludge and other by products per household per year?	Kg. / household / year
	How are these sludge and by products processed, discharged?	
	What is the average effluent quality of sludge for heavy metals and micro pollutants?	Milligram / kg dry matter
2.6	What is the average discharge of heavy metals and micro pollutants to soil per person per year?	Grams of heavy metals and micro pollutants per person / year

	KPI 3: resources use	
3.1	What is the energy consumption per household per year for the sanitation system?	Kwh or joules /hh/year*
	What amount of energy is recovered from the treatment process per household per year?	Kwh/hh/year
3.2	What is the volume of drinking water usage per household per year?	m3/hh/year
	What is the volume of water recycled from the sanitation system per household per year?	m3/hh/year
3.3	What is the amount of nitrogen recovered from the waste stream and recycled per household per year?	Kg. / hh / year
3.4	What is the amount of phosphate recovered from the waste stream and recycled per household per year?	Kg. / hh / year
3.5	How many kilograms of chemicals does the sanitation system use per household per year?	Kg. / hh / year
	KPI 4: System robustness	
	Is the sanitation system being monitored? How?	Descriptive answer
4.1	**System failures**	(hours per year)
	What is the amount of system failures per year?	Times
	What is the average downtime per failure?	Hours
	What is the nature of the system failure	Describe the malfunctioning part(s) and its / their problem(s)
	What is the cause of the system failure	Power cut / water supply failed / other (describe)
4.2	**Operation**	(hours per year or €/ year)
	Who operates the system?	Descriptive answer
	What are the operational requirements	Descriptive answer
	What is the time input for operation?	h / year
	What is the financial input for operation /	€ / year
4.3	**Maintenance**	(€ / year)
	Did you experience any problem with any of the parts of the wastewater management system?	Yes / no – if yes, describe
	What is the yearly financial input for maintenance	€ / year
	What is the yearly time input for maintenance?	h / year
4.4	**How frequent does the process exceed the effluent standards**	Times / year
	KPI 5: invisibility and user comfort	
5.1	How many hours per household unit per year of operations or maintenance activity does the process train require from its users? (this could also involve extra cleaning, for e.g. vacuum toilet?)	Hours/household/year
5.2	What area of above-ground indoor space on household premises does the process train equipment require expressed in m3 per household?	M3/household
5.3	What area of above-ground outdoor space on household premises does the process train equipment require expressed in m3 per household?	M3/household
5.4	What area of above-ground space in the residential area (neighborhood) does the process train equipment require expressed in m3? (make sure you can convert to m3 per household later on)	M3/household
5.5	What is the maximum noise level produced on the household premises by the process in dB when in operation?	dB
5.6	Does the process produce unpleasant odours on household premises during operation?	yes / no
5.7	How many odor level events happen per year?	Number
5.8	What do you not like about your sanitation system?	Descriptive answer
	KPI 6: costs	
6.1	What is the up-front capital investment per person in EURO and local currency of the process train?	EURO/person
6.2	How much did the householder invest in the sanitation system?	EURO/household
6.3	What is the estimated useful (service) life of the process train in years?	Years
6.4	What is the estimated annual per household operating cost in EURO of the process train?	EURO/household/year
6.5	What is the estimated annual per maintenance operating cost in EURO of the process train?	EURO/household/year

	KPI 7: external sensitivity	
	How sensitive is the process to:	
	- changes in climate (rainfall)	
	- changes in climate (temperature)	
	- changes in climate (availability of water)	
	- density of the population	
	- soil composition	
	- natural disasters (earthquakes, floods, etc)	
	- soil composition	

*hh: household

Source UEM group, Wageningen University.

Table 42: Existing MCDA methodologies used in water management and their main characteristics

	Methodology	Description	Advantages	Disadvantages
1	Cost-Benefit Analysis (CBA)	Choose the alternative with the largest surplus of benefits over costs. This methodology estimates the cost of the consequences of a project, and works with the willingness to pay for the benefits as well as the willingness to accept the compensation the following analysis can be developed in a CBA: 1. Contingent Valuation (WTO-Willingness to Pay and WTA - Willingness to accept 2. Contingent Ranking: In this method people are asked to establish a ranking among several options 3. Stated preferences: A value for a place based on people's preferences 4. Travel costs 5. Hedonic Pricing[M]	Allows the integration of two fundamental concepts: Economic development and environmental objectives. It combines a market value for costs with non-market values for environmental gains obtained. It is easy to use and calculate since it compares the gains in reduction of an environmental damage with the total cost to achieve that reduction. .[M]	Since it works with non-market values sometimes it is necessary to work with shadow prices which are not easy to determine [M]
2	Cost-Effectiveness Analysis (CEA)	Choose the alternative with the smallest cost to benefits ratio. Used when the objective cannot be valuated but can be defined. It seeks to meet the objective at the least cost. [M]	It is useful because combines economic development with environmental objectives [M]	Does not consider secondary effects [M]
3	Life Cycle Assessment (LCA)	It analyzes the whole life of a product. It is usually used in combination with IO. Quantifies the inputs which go into a project in the supply chain, during all of its life. [M]	The procedure is a good one to identify components and actions that participate in a project independent of the price [M]	Lots of data needed as well as a thorough information about the supply chain Does not consider some social issues such as the loss of amenities It is difficult to define the boundaries [M]
4	Life Cycle Impact Assessment (LCIA)	It is the assessment after the Life cycle inventory, this methodology assess the impacts on the different criteria [M]		
5	Geography information System (GIS)	It is a specialized software with the capability to deal with spatial information.[M] Provide spatial information on many different issues and has the ability to superimpose the effects and impacts	GIS is the only technique that graphically shows the superimposing, and then cumulative effects of many different impacts. In some circumstances it can identify areas that comply with established thresholds. Very useful to indicate relationships and effects interrelationships.[M]	It does not have the capability to indicate secondary and tertiary effects- Usually an expensive proposition -Does not show temporal effects. [M]
6	Analytical Hierarchy Process (AHP)	Produce a prioritized set of projects or alternatives using pair-wise comparisons[M] Helps the decision making process by providing weight to criteria and alternatives, as well as a ranking of alternatives	Provides a good selection of alternatives for the stakeholders to decide Easy to understand and employs a dedicated software Works well for subjective issues [M]	The mathematical basis of the method has been somehow questioned On the other hand it is difficult to explain to a non-mathematical audience The method is subjective Is not too appropriate for a large number of alternatives [M]
7	Mathematical Programming	It consists in constructing a mathematical model, where real conditions are represented as closely as possible. It provides an optimal solution, and as a consequence the best selection out of a listing of competing projects or alternatives[M] Helps the decision making process by selecting an alternative, or providing a ranking of them and by determining non-subjective values to criteria. It supplies an optimal selection of alternatives considering many different criteria and different objectives [M]	Allows the determination of criteria weights without human intervention Complements LCA and IO analysis Can work with a large number of alternatives and criteria[M]	-It is based in matrix algebra and can be difficult to explain The formulation of a problem can be difficult [M]

8	Risk Assessment	Estimates the probabilities and degree of vulnerability to humans and the environment [M]	Establishes a cause and effect relationship [M]	- the determination of risk values is not an easy task It is also necessary to know the standard deviation of the mean value [M]
9	Dollar value appraisal	The objective is to make a selection based on how much value is obtained with one dollar invested in the project. Usually some economic and environmental restrictions are used. [M]		
10	Classical utility analysis (UA)	UA is based on a rationale decision model and in turn on the set up of an objective system with measurable criteria which are aggregated to a total value. a very problematic area is the definition of the weights: as a political definition of weights easily can turn into endless debates, this exercise is often done by experts, who are not legitimized to do so. Regarding the acceptance of UA based methods, both advocates and opponents exist. In the field of urban water management, simplified variants of the UA are used on a routine basis. [S]	In principle there are no limits to the method, even ordinal data can be processed, depending on the used variant. Further, instead of monetary values, weights and utility values may be used. [S]	Again, it exhibits several structural weaknesses, depending on which criteria shall be combined. In particular, as mentioned in Scholles (1997), The major disadvantage of a UA may be its susceptibility to manipulation. [S]
11	Ecological Risk Analysis	ERA is a time efficient method to carry out an assessment and aggregation of impacts based on a matrix in terms of a few verbal qualifications. It uses a global index based on ordinal data and is particularly useful to combine intangible criteria or to give a quick survey about the overall assessments of alternatives. [S]		This simplicity is a weakness, too, as in complicated problems with many criteria, where decision aid methodology is needed, ERA will not be able to differentiate between the plausible alternatives.[S]
12	Cost Comparison (based on net present value, annuity)	In principle, this method is sufficient, if the benefit of the compared methods may be considered to be similar.[S]		Weak points are the uncertainties of the estimations of investment and operation costs as well as of the parameter of the cost comparisons (interest rate, economic vs. technical life time, etc.). As analyzed in Starkl et al. (2002), investment as well as O&M costs depend considerably on the economic climate and hence may regularly fluctuate between 10 and 30%. Practice has shown that cost comparisons offer several possibilities for manipulation.[S]
13	ORWARE	It is basically a tool for material and substance flow analysis. Based on the calculated flows, several LCA based indices may be calculated. URWARE improves the LCA based methods insofar, as it provides comprehensive databases for urban water relevant unit processes, which may be combined to any system. Hence in practice it considerably alleviates and standardizes the application of LCA based methods (modeling 84 substances), but it is currently still under development. [S]		It is again a more theoretically oriented decision support tool. A steady-state material flow model is developed for evaluating the environmental impact of organic waste management activities in different geographical areas, especially focusing on the return of nutrients to arable land. All the 43 indicators being are chemical compounds, such as BOD, metals, nutrients, etc. [M]

14	ELECTRE I - II(Outranking)	An outranking method where the predominant idea is that an alternative can be eliminated if it is dominated by others alternatives. The various versions of ELECTRE differ in their use of thresholds, weights, outranking relations and credibility index.[I]		
15	PROMETHE II (Index of outranking)	An out ranking method based on the ELECTRE procedure, which utilizes the decision maker's preferences. The two versions of Promethe differ by providing either a partial or total pre-order of the alternatives[I]		
16	Multi-attribute Utility Theory (MAUT)	Based on the construction of a decision maker's utility function in order to represent his preference structure[I]		
17	simple Multiple Attribute Rating Technique (SMART)	Simple version of the MAUT procedure[I]		
18	Absolute veto rule	Reject alternatives which violate any statutory limit. [B]		
19	BPEO index (example of a LCA)	Given certain statutory limits ti and measurements xi for the impact i of alternative x, minimize the sum Pi xi /ti.[B]		
20	Compromise Programming	Choose a feasible alternative (satisfying e.g. statutory limits) with the least distance [B]		
21	Eigenvector Method	Given a matrix of quotes of preferences of one alternative over another, then the components of the normalized eigenvector to the largest. [B]		
22	Individual Veto Rule	If with respect to a criterion i the impact of the alternative x exceeds the impact of y by a certain veto threshold, then x cannot be better than y. [B]		
23	Majority Election (Intuitive outranking)	When two alternatives are compared, prefer the one with more arguments in its favor. [B]		
24	Majority Vote (Intuitive Contingent index)	Choose the alternative which for most criteria is the best one. [B]		
25	NAIADE (Novel Approach to Imprecise Assessment and Decision Environments)	Individual linguistic impact assessments are transformed and accumulated by means of fuzzy operations, using entropy in defining objective weights.[B]		
26	Random Dictatorial Rule	Draw a criterion at random and apply it to assess the alternatives.[B]		
27	Seniority Rule (used e.g. in ORESTE)	The most important criterion that is not indifferent about the alternatives decides.[B]		
28	Simulated Arbitration (Example of DEA)	Define f(x) =Piwiui(xi), where the utilities ui are computed from the levels xi of the impact i of alternative x. Given an issue, maximize y(x), the minimal value of f(x) over all positive weights wi with sum 100 and the constraint ‘‘f(x) is maximal in the issue’’.[B]		
29	SMART (Example of MAUT)	Maximize Piwiui(xi), where xi is the level of the impact i of alternative x and the positive weights wi and utilities ui are elicited from the DM and satisfy certain restrictions (e.g. weights add up to 100).[B]		
30	Strong Dictatorial Rule	Assess the alternatives by means of a decisive criterion.[B]		
31	Environmental Impact Assessment (EIA)	Provides the main structure and data for all of other techniques. Assess the impact of an activity on the environment. [M]		
32	Material Input per Unit of service (MIPS)	Relates material input over life cycle to final service delivered to user[I]	Quantity material intensity of products/services. Identify key materials inputs[I]	High requirements of data & uncertainty in definition of end-use service[I]

33	Environmental Risk Assessment (ERA)	Hazard identification. Effects assessment. Exposure assessment[I]	Comprehensive evaluation of the probability that damage or adverse effects will occur. [I]	Very high requirements of data. Difficulties in the determination of effects of and exposure to a range of chemicals[I]
34	Material Flow Accounting (MFA)	Accounts in physical units for flow of material through a specific region. [I]	Provides info on contribution to sustainability of bulk or specific material flows. [I]	High requirements of data. Needs to be supplemented by assessment of environmental impacts of flows. [I]
35	Cumulative Energy Requirements Analysis (CERA)	Quantify primary energy requirement for products and services in a life-cycle perspective[I]	Quantify energy intensity of products/services, also identify options for energy savings[I]	High requirements of data. Needs to be supplemented by assessment of environmental impacts of energy generation/use [I]
36	Environmental Input-Output Analysis (Env.IOA)	Display all flows of goods and services, and interconnections between them [I]	Allows consistent treatment of environmental and economic factors [I]	Very high requirements of data. Does not only focus in the key components. Assumes linear production relationship [I]
37	Analytical Tools for Eco-design (Eco-design tools)	Matrices relating different life cycle stages to extraction, intervention, or emissions. Check list for key questions or points of attention [I]	Relative quick and easy means of identifying key environmental impacts [I]	Lacking comprehensive assessment of environmental impacts [I]
38	Life Cycle Costing (LCC)	Identify all internal and external costs over the life-cycle of a product or service [I]	Puts a monetary value on emissions and resource use quantified in life cycle inventories, and environmental and health effects in impact assessment [I]	Very high requirements of data. Practical and conceptual difficulties in assigning monetary values to environmental impacts [I]
39	Total cost Accounting (TCA)	Long term, comprehensive analysis of full range of internal costs and savings from pollution prevention and environmental projects [I]	Comprehensive costs and savings inventory. More precise cost allocation. Long term horizons. Use of profitability indicators. [I]	Very high requirements of data. Difficult to identify and assess all long-term costs and savings. [I]
40	Social Impact Assessment (SIA)	Measures the opportunities and constraints faced by individuals and groups. [I]		
41	Social Capital Assessment Tool (SOCAT)	Analysis of social networks using qualitative and quantitative instruments [I]		
42	Agent-based modeling (ABM)	Agent based social modelation is a form of modeling complex adaptive systems. [I]		

Sources: Munier, 2004; Starkl, 2005; Brunner, 2004; IWA, 2004

Table 43: Classification of undesirable objects and substances that users flush into the sewerage

Hygienic materials	Bulky	Plastics	Other non biodegradable materials
Cleaning clothes-wipes	High density Paper Towels	Condoms	Engine oil
Sanitary napkins	Stones	Plastic bags	Solvents
Tampons	Wood sticks	Elastic bands	Cooking fat
Nappies	Cardboard		Paint
Incontinent pads	Constructive materials		Pesticides
Cotton bud stick	Leaves		Pharmaceuticals
Razor blades	Other solids (coins, toys, etc.)		Cigarettes butts
Surgical bandages			Balls
Dental floss			Hair clips

Table 44: Investment and operational cost for conventional WMS

Aspect	Cost (€/household)	Expected lifetime (year)	Costs (€/y)
sewerage system*	3500	25	237.5**
WTP*	875	25	
sewerage taxes			104***
water-board fee			139***
water supply			92
Total Costs			**572**

*(Mels *et. al.*, 2004a) **Annuity considering an interest of 2.5 % *** 2 p/hh

Sources: Betuw, 2005

Table 45: Investment and operational cost for Het Groene

Aspect	Amount of hh	Cost (€)	Cost (€/hh)	Expected lifetime*** (y)	Costs (€/y)
Grey water installation - pump	10	22,690* - 300	2,269	30 - 15	278#
Rainwater recycling - pump	22	30,630* - 300	1,393	50 - 15	
Inner garden and pond - ground + pipes - work - other	66	53,775* -40,387 - 7,261 - 6,126	815	50	
Gustavberg system connection	1	650**	650	50	
WTP			875		47#
Maintenance					50
Sewerage taxes					39.5
Water-board fee					139
Water-supply					74.3
Total cost					**628**

* (Website het groene dak) ** (Het Groene Dak, 1992) *** (Post, *pers. com.*) # considering an interest of 2.5 % and lifetime of 25 years

Sources: Betuw, 2005

Table 46: Investment and operational cost for Polderdrift

Aspect	Cost (€/hh)	Expected lifetime** (y)	cost (€/y)
Grey water installation - pumps	4,333*	20 - 10	353#
Rainwater recycling - pumps - pipes - retention area	2,170*	50 - 10 - 20	
Sewerage connection	3500	25	238#
Conventional WTP	875	25	
Maintenance and energy			141***
Sewerage taxes			104
Water-board fee			139
Water supply			36
Total Cost			**1011**

* (Pötz and Bleuzé, 1998) ** (Engelen, *pers. com*) ***(Koopmans, *pers. com.*) # considering an interest of 2.5 % and lifetime of 25 years

Sources: Betuw, 2005

Table 47: Investment and operational cost for Ekoporten

Aspect	Cost (€)	Cost (€/hh)	Expected lifetime (y)	Cost (€/y)
Complete installation - reedbed - composting device - urine	320000 - 15000 - 10000	17.800	50 - 10 - 10 - 50	966#
water supply & treatment				112
Monitoring and maintenance	7700			428
Total cost				**1506**

considering an interest of 2.5 % and lifetime of 25 years

Sources: Betuw, 2005

Table 48: Investment and operational cost for Skogaber

Aspect	Cost (€)	Cost (€/hh)	Expected lifetime (y)	Cost (€/y)
- Disposar and - double sewerage	254000	1900	- 25 - 50	510#
Treatment plant - membranes	570000 - 106000	4300	25 - 5	
Conventional sewerage system	211000	1600	50	
Research and sampling	211000	1600	-	
Water-supply				200
Total cost				**710**

considering an interest of 2.5 % and lifetime of 25 years

Sources: Betuw, 2005

Table 49: Investment and operational cost for Understens

Aspect	Cost (€)	Cost (€/hh)	Expected lifetime (y)	Cost (€/y)
Urine separating toilet - porcelain - wooden seat	33924	 - 654 - 126	 - 30 -13	41.8#
Urine pipes & tanks	Unknown	Unknown	30	40*
Black and grey water	4375			237.5**
Urine transport	1690			38.5
Water supply				147
Maintenance				7
Total cost				**512**

*assumed, ** Dutch price for connection and treatment, # considering an interest of 2.5 % and lifetime of 25 years

Sources: Betuw, 2005

Table 50: Investment and operational cost for Gebers

Aspect	Amount of households	Cost (€)	Cost (€/hh)	Expected lifetime** (y)	Cost (€/y)
Grey water connection	32	42260	1320	100	243.7
Urine separating toilet and feces collection	30	95000	3170	30-50	
Urine transport					37
Water-supply					105
Total cost					**386**

Sources: Betuw, 2005