Hamburg University of Technology
Institute of Wastewater Management and Water Protection

Master Thesis:
Framework to Assess the International Adaptability of the Urban Sanitation System implemented within the Project Saniresch

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Hamburg, November 22nd 2010

Statement of Honour

I hereby declare that I personally have completed the present scientific work. The ideas obtained from other direct or indirect sources have been indicated clearly.

This work has neither been submitted to any other course or exam authority, nor has previously been published,

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Date: 22.11.2010

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Abstract

There is a need to evaluate the adaptability of urban sanitation systems imported from high-income economies to low-income and fast-growing economies due to the fact that a large number of these technology transfer projects dramatically fail as a result of inadequate evaluations of their local adaptability, which causes enormous economical looses and large amounts of resources wasted. Hence, the goal of this research is to develop a framework to assess the adaptability of the sanitation system implemented within the SANIRESCH project in urban areas of fast-growing economies. Furthermore, the potential key factors with regards to the adaptability of both the sanitation system and the potential areas of implementation will be identified. The methodology designed to achieve these objectives is based in the first place in the identification of a broad inventory of indicators with regards to the sanitation system (technology wise indicators) and the urban areas of fast-growing economies (location wise indicators). Secondly, due to the state-of-the-art of the sanitation system assessed (an innovative urban sanitation system still at a developing stage) it was considered necessary to carry out a Multi-Criteria Decision Analysis (MCDA) to assess the performance of the system compared to a selection of potential competitors in Germany. Thirdly, the Integrated Assessment Adaptability Framework (IAAF) was developed and exemplarily tested in Sao Paulo (Brazil) and Durban (South Africa). Such framework combines the broad inventory of adaptability indicators with a subsequent elicitation of the local key adaptability indicators carried out by local stakeholders. The main outcome is a final list of local key adaptability indicators, which will be used to operate a MCDA embedded in the framework. The evaluation of the adaptability will be carried out taking into account the previous fulfilment of a specific set of requirements which will be chosen by the local stakeholders. This research has found that the performance of the sanitation system implemented within the SANIRESCH project in Germany is moderate but similar to the other innovative sanitation systems analysed and also similar to the conventional wastewater system in Hamburg. However, these results must be treated carefully due to specific characteristics of the sanitation systems assessed, the methodology and the collection of the data. Another important outcome of this research is that the crucial factors that determine the adaptability of the system in urban areas of fast-growing economies are the capacity to pay for the system, the capacity to maintain and operate the system from a technical viewpoint, the capacity to provide a regular availability of flush water and a regular availability of electricity and finally, the capacity to assure institutional acceptability for both the operation of the system and the reuse of the final product. Moreover, the implementation of the system must be socio-cultural desirable and/or desirable from a health and hygiene viewpoint and/or desirable from an ecological viewpoint with regards to the potential area of implementation. With regards to the IAAF, it is concluded that the adaptability at a city level cannot be adequately assessed because there is a need to decrease the scale of the analysis (i.e. at least at district level). Even though this limitation, the implementation of the framework in Sao Paulo indicates that the system has a high potential to be successfully implemented in this city. Oppositely, the system has a high potential to be unsuccessful if it is implemented in Durban. Due to the fact that the data used for testing the framework comes from the strictly qualitative evaluation of only one representative per city, the IAAF should be operated again combining qualitative and quantitative data in order to increase the robustness of the results. The framework should be used as an aid to the decision-making process and management of the data to help in the visualization of the information as well as to facilitate the discussion process.

Key words: urban sanitation system, fast-growing economies, adaptability, MCDA, Integrated Adaptability Assessment Framework (IAAF)

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List of abbreviations

GTZ	German Technical Cooperation Agency
IAAF	Integrated Adaptability Assessment Framework
MAP	Magnesium-Ammonium-Phosphate
MBR	Membrane Biological Reactor
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
PE	Polyethylene
SANIRESCH	SANItaryRecyclingESCHborn
UDDT	Urine Dry Diversion Toilets
UD flush toilet	Urine-Diversion flush toilets

List of symbols

CH_4	Methane
CO_2	Carbon dioxide
MAP	Magnesium-Ammonium-Phosphate
MgO	Magnesium Oxide
N	Nitrogen
NO_2	Nitrogen oxide
P	Phosphorous

1. Introduction

1.1 Background

By 2050 70% of the world's urban population will be located in urban areas of low-income and fast-growing economies (UNhabitat, 2010). However, many of these urban areas do not have enough capacity to provide sanitation to the impending population growth (Bracken, et al. 2008). Currently "more than one fourth of the people living in urban areas lack safe drinking water and basic sanitation" (Bracken, et al. 2008).

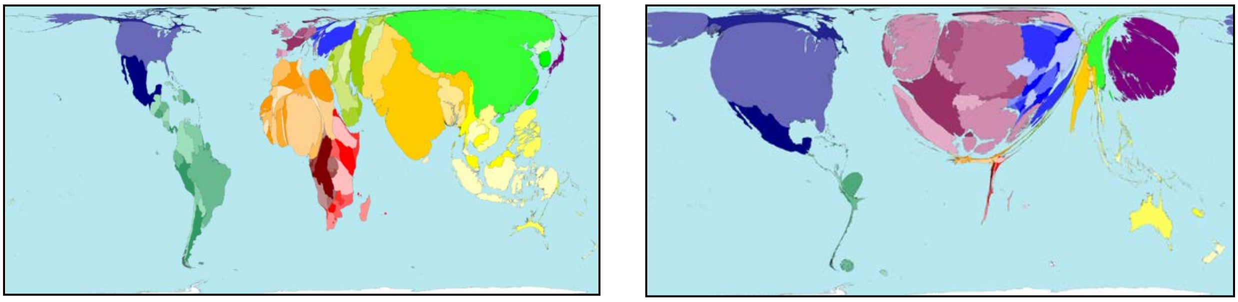

Figure 1: Urban growth (left) and coverage of conventional sanitation (right). In the figure is shown that it is precisely the parts of the world with a steeper population growth where there is a lack of conventional access to sanitation. Source: (WorldMapper 2004 (left); 2005 (right))

Even though some of the problems related to the lack of water supply and sanitation could be solved by implementing conventional wastewater systems (Wilderer, 2004), the total costs for both the installation and operation of the conventional wastewater system as well as the limited time available to distribute the investment costs over a reasonable period of time causes that this activity is economically inefficient in most low-income and fast-growing economies (Wilderer, 2004). Furthermore, conventional systems are usually disposal oriented and the reuse potential of the wastewater streams is not taken into account (Bracken, et al. 2008). In addition, these systems put an enormous pressure on the water resources as well as require high amounts of energy to remove effectively pollutants contained in the wastewater (Langergraber & Muellegger, 2005). Due to these facts, there is a need to implement innovative and alternative wastewater systems because conventional wastewater systems are not an exportable solution to emerging and low-income economies (Bracken, et al. 2008).

There is a large variety of innovative sanitation systems. According to Lindner (2007), innovative sanitation systems can be divided into two groups:

- Low-tech solutions: areas with a low level of technical support and/or low income populations.
- High-tech solutions: areas with a minimum standard of technical support and possibilities for the financing of investment and operating costs. High-tech solutions can achieve similar standards of quality than end-of-pipe systems.

The main objective of a sanitation system should be "to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable, the system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources" (Zürbrugg, et al., 2009; Schertenleib & Parnesar, 2008).

The large number of innovative urban sanitation systems which have multiple technological components and possibilities of treatments as well as the lack of information and data available due to the fact that most of the systems are relatively new, create a "barrier for scaling up the implementation of ecological sanitation" (Agudelo, et al. 2007). Hence, the choice of a sanitation system is a complex process, and not always the systems implemented in a specific area are the most appropriated to the local context and preferences and values of the stakeholders. Due to these facts the traditional methods to assess urban sanitation systems do not achieve to adequately assess the innovative urban sanitation systems.

Therefore, there is a need to develop new decision-making technologies which are able to deal with all the new characteristics of the innovative sanitation systems and adequately incorporate the sustainability principles into the decision-making process. This is especially necessary to evaluate the adaptability of urban sanitation systems imported from high-income countries to emerging and low-income economies. In these countries, a large number of technology transfer projects dramatically fail due to inadequate evaluations of the adaptability of such technological projects, which causes enormous economical looses and large amounts of resources wasted (Dunmade, 2002).

1.2 Goals and Objectives

The goal of this investigation is to develop a framework to assess the adaptability of the urban sanitation system implemented within the SANIRESCH project in urban areas of fast-growing economies. To achieve this goal it is necessary to accomplish the following specific objectives:

- To identify the weaknesses and strengths of the sanitation system with regards to its adaptability in urban areas of fast-growing economies.

- To identify the potential factors of urban areas of fast-growing economies that can play a role in the adaptability of the sanitation system developed within the SANIRESCH project.

- To analyse and compare the sanitation system with potential competitors currently available in the German market.

- To develop an assessment framework that facilitates the assessment of the adaptability of the sanitation system implemented within SANIRESCH.

- To test the framework in order to evaluate the adaptability of the sanitation system in Sao Paulo (Brazil) and Durban (South Africa).

1.3 Area of study

The research of the adaptability of the sanitation system implemented within the SANIRESCH project focuses on urban areas of fast-growing economies. Firstly, it is considered that it is necessary to limit the analysis to urban areas due to the intrinsic characteristics of the system design. This system is a demonstration project implemented in a multi-storey building (the headquarters of the German Technical Cooperation Agency [GTZ]) in Eschborn, Germany (an urban area of a high-income country). Hence, to demonstrate the potential of ecological sanitation in urban areas of high-income countries the system should work efficiently and provide high quality standards (a malfunctioning of the system could cause a bad image of ecological sanitation systems). Furthermore, the user's interface as well as the use of the collection component should not differ from the conventional system in order to avoid a low acceptability of the system. This implies that the collection and treatment technologies are within a range of techniques which can be considered high-tech options. Such techniques are especially (or exclusively) recommendable for urban areas of high-income countries because basically in these areas the level of welfare is high enough to pay for these type of technologies as well as there are the required materials, natural resources, energy, the technical know-how and the technical development to support the system. Furthermore, the conventional sanitation system is also widely implemented, thus the sanitation standards of those areas are very high. Similarly, aspects like the nuisance of the system, the acceptability of the system, the standards of quality of the final product and the impact on the environment of the system are very important in those areas because the acceptability of an innovative system in high-income countries usually focus in the socio-cultural and ecological dimension. Under the current state-of-the-art of innovative urban sanitation systems, this is better approached with high-tech solutions, always that there are enough financial, technical, materials, natural and energy resources to implement the system. Furthermore, the system requires a constant source of flush water –due to the fact that the development of urine dry diversion toilets (UDDT) is not developed enough when it comes to multi-storey buildings- as well as a regular supply of electricity. Such characteristics are usually only available in urban areas (with the exception of most of the rural areas of high-income countries -a very low percentage out of the total-).

Fast-growing economies are approached in this research because in these type economies there is an urge to improve the sanitation infrastructure which implies that there could be a demand of alternative sanitation systems. This is due to the enormous population pressure and urbanisation rate which causes that the environment is highly degraded with significant water and recovery of nutrients necessities. Furthermore, these economies have a higher potential of investment and capacity to pay for these systems (if compared to low-income countries) as well as usually a certain level of technical know-how and institutional capacity to adapt faster these systems. Another important fact is that in fast-growing economies there is still the opportunity to implement sanitation systems incorporating sustainability criteria and innovative sanitation principles that differ from conventional sanitation systems (because there is not a total coverage of conventional sanitation). In addition, due to the intrinsic characteristics of emerging economies as well as characteristics of the sanitation system implemented within the SANIRESCH project it could be argued that in fast-growing economies the factors that could play a role in the adaptability of these systems are more equilibrated than in high- and low-income countries. Hence, in high-income countries the implementation of innovative sanitation systems is mainly dominated by financial, socio-cultural, and environmental factors. Furthermore, the system has already been implemented in Germany, which is considered a high-income country. Thus, it can be assumed that the processes that will determine whether this technology can be successfully implemented or not in high-income countries will be very similar than in Germany. On the other hand, the adaptability of a sanitation system in a low-income country is strictly dominated by the financial, technical, materials and natural resources and energy dimensions. Hence, it appears reasonable to assume that these countries need sanitation systems designed with a completely set of different goals than the ones used to design the sanitation system within the SANIRESCH project.

Part I: Methodology

2. Methodology

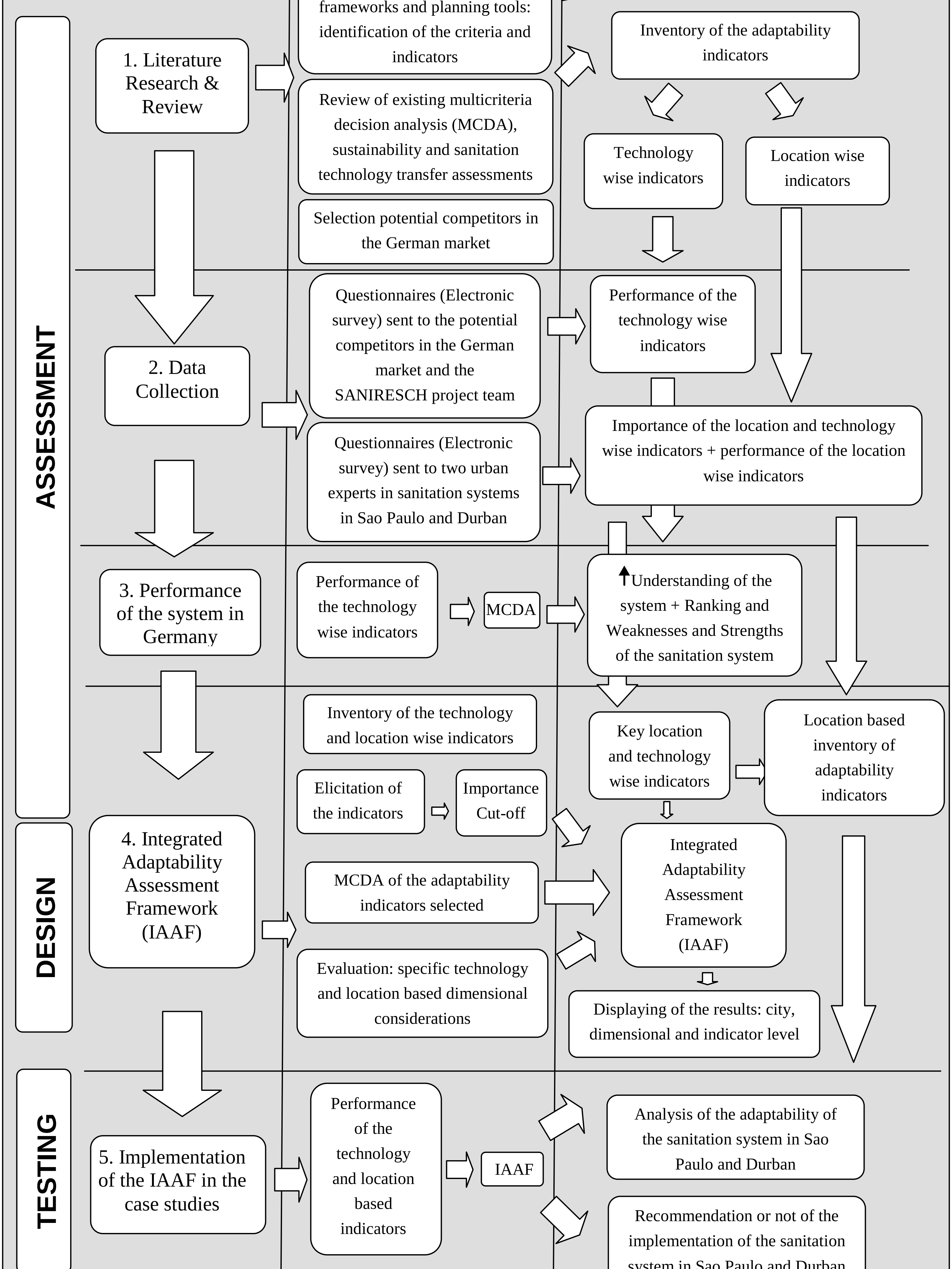

Figure 2: Diagram of the methodology used in this investigation

In this section, the methodology designed to achieve the objectives of this investigation is described and discussed.

2.1 Literature Review

2.1.1 Conceptual background

During this stage different aspects with regards to the use of frameworks to assess urban sanitation systems were extensively investigated (see section 3.7). The operational basis of the multi-criteria evaluation techniques (MCA) and specifically multi-criteria decision analysis (MCDA) to assess technology transfer related issued and urban sanitation systems were also analysed (see section 3.5). Finally, an exhaustive research about the potential competitors of the sanitation system implemented within the SANIRESCH project in the German market was developed (appendices section I). The outcome of this section was to provide a conceptual background to support the basis of this study.

2.1.2 Inventory of the adaptability criteria

2.1.2.1 Selection of the dimensions

"Dimension is the highest hierarchical level of analysis and indicates the scope of the objectives, criteria and indicators" (Munda & Nardo, 2008). In this study, the criteria are classified under 8 different dimensions:

- Financial
- Health and Hygiene
- Technical
- Socio-Cultural
- Ecological
- Materials and Natural Resources
- Energy
- Institutional

The selection of these dimensions responds to the necessity of incorporating to the design of new sanitation systems criteria with regards to the health and hygiene, the environment and natural resources, the technology and operation of the system, the financial and institutional issues and the socio-cultural aspects (Schertenleib & Parnesar, 2008).

In this study, the environment dimension has been further divided in the "ecological", "materials and natural resources" and "energy" dimensions due to the fact that it prevents trade-offs between criteria that this investigation approaches to analyse separately. For instance, if the materials and naturals resources criteria are classified together with the energy under the environmental dimension, it is possible that during the process of ranking two different sanitation systems, low scores in the energy criteria are compensated by high scores in the materials and natural resources dimensions (or vice versa). This fact could cause that two sanitation systems are ranked in a similar position when actually one is very energy intensive but low in consumption of materials and the other is low in energy consumption but materials intensive. A third possibility could also cause that a sanitation system which shows moderate performance in both set of criteria is ranked as a similar option than the two previous examples. The problem arises because these two (or three) sanitation systems equally ranked have actually different characteristics.

Each of these 8 dimensions contains a range of criteria and qualitative indicators. For every criterion, a set of qualitative indicators is suggested.

2.1.2.2 Basic considerations to select the indicators

The indicators have been selected according the guidelines proposed by Foxon, et al. (2002):

- The indicators must be broadly applicable to all the options to ensure the comparability of the options.
- The indicators must be comprehensive and cover all the dimensions used in the assessment.
- The indicators must have enough reliable numerical or qualitative data.
- The selection process of the different indicators must be transparent. The stakeholders should be able to identify the indicators, understand them and to be able of proposing new ones.

2.1.2.3 Selection of the criteria and indicators

The criteria and indicators have been selected in order to include all the aspects of sustainability that can play a role in the adaptability of foreign urban sanitation systems to fast-growing economies. The selection has been made from an extensive and exhaustive literature review which comprised 37 scientific papers focusing on the assessment of urban water sanitation systems: sustainability criteria for decision-making studies, multi-criteria decision analysis, the development of frameworks to assess urban water sanitation systems and further investigation about water and wastewater technology transfer to fast-growing economies. A table summarising the literature source for each criteria can be found in the electronic attachments of this report, section 1. Subsequently to this pre-selection, the criteria and qualitative indicators identified were analysed with regards to the objectives of this investigation. In addition, the frequency of the criteria initially identified in the literature review was also assessed. Some of the indicators were reinstated and/or combined to form new indicators which could serve better the goals of this study, as it is shown in the electronic appendices section 2.

The qualitative indicators were divided in the categories "Technology wise" and "Location wise". The technology wise indicators assess parameters with regards to the sanitation system used within the SANIRESCH project and they will provide the basis for the MCDA of the innovative sanitation systems in Germany. Hence, such indicators are independent of the implementation area and also intrinsic characteristics of the sanitation system implemented within the SANIRESCH project. The location wise indicators are in reference to the potential factors that can play a role in the adaptability of the sanitation system in urban areas of fast-growing economies. Thus, such indicators are strictly dependent on the implementation area of the sanitation system assessed in this study. The final inventory of the criteria and qualitative indicators is attached below in the tables 2 and 3. Furthermore, the number of indicators per dimension is also displayed in the figure 3. From the criteria and indicators identified during the literature review it can be highlighted that the technical, ecological and socio-cultural dimensions are the categories with a higher number of indicators identified. The total number of indicators initially identified during the literature review is 257.

Hence, the main outcome of this part of the investigation is a broad inventory of criteria and indicators. These indicators will be used to assess the urban sanitation system implemented within the SANIRESCH project as well as its adaptability to urban areas of fast-growing economies after a previous elicitation of the local stakeholders involved in the decision-making process.

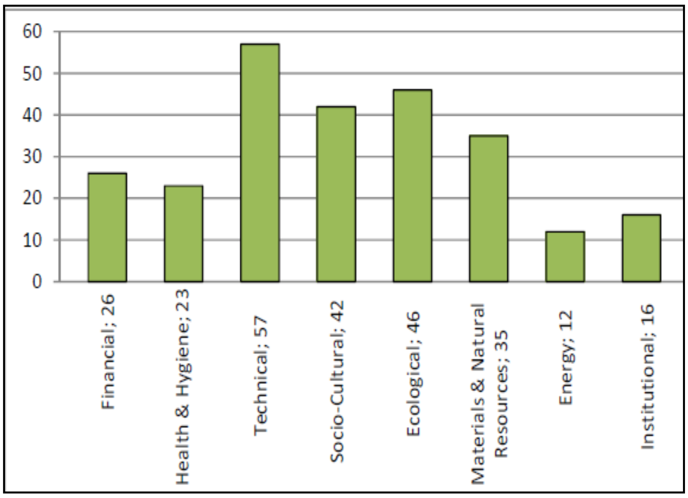

Figure 3: Total number of criteria identified during the literature review and classified under the dimensions proposed by this study

Table 1: Total number of criteria identified during the literature review versus the number of criteria selected (technology-wise and location-wise) to assess the adaptability of the SANIRESCH project

Dimension	Number of indicators (Literature)	Number and indicators (selected)
Financial	26	**19**
Health & Hygiene	23	**13**
Technical	57	**19**
Socio-Cultural	42	**20**
Ecological	46	**20**
Materials & Natural Resources	35	**15**
Energy	12	**9**
Institutional	16	**13**
Total	257	**125**

2.1.2.4 Definitions of the qualitative indicators

A complete list of the indicators selected to assess the sanitation system implemented within the SANIRESCH project is shown in the table 2 (technology wise criteria) and table 3 (location wise criteria).

Table 2: Definition of the technology wise criteria and their objective*. *direction of the change desired: positive: maximisation of the criteria, negative: minimisation of the criteria

Dimension	Indicator	Definition	Objective
Financial	**Investment costs**	- Those program costs required beyond the development phase to introduce into operational use a new sanitation system.	Negative
	Treatment costs	- The costs required to operate a sanitation system.	Negative
	Maintenance costs	- The costs of the labour required to maintain the system.	Negative
	Replacement costs	- The costs required to replace the parts of the system which do not work satisfactorily. E.g.: Spare Parts, Innovation Investments, etc.	Negative
	Reuse costs	- The costs required to apply the final product to reuse or dispose.	Negative
	Transport costs	- The costs required to distribute the final product from the treatment to the reuse or disposal.	Negative
	Direct benefits	- The benefits obtained from recycled products (soil amender, fertiliser, energy, reclaimed water, etc.). - Potential for private business. - Benefits resulting from the trading reductions of CO_2 emissions.	Positive
Health & Hygiene	**Safe collection**	- Collection of the wastewater in a hygienically and safe manner. - High hygienic standard within the toilet and the washing areas.	Positive
	Safe disposal	- Disposal of waste products in a hygienically and safe manner.	Positive
	Exposure to pathogens	- Potential Risk of skin contact with any of the separated fractions (yellow water, black water, recycled product).	Negative
	Exposure to hazardous substances	- Potential Risk to the Health due to the exposure to hazardous substances in the life cycle of the technology.	Negative
	Risk of the final product	- Potential Risk of the final product to the human health. E.g. In the case of agriculture reuse, it can be measured by the presence of hazardous compounds in the fertiliser or soil conditioner.	Negative
Technical	**System adaptability to different types of users**	- Potential usability for different type of users: E.g. Children, old people, handicapped people, etc. - Usability for both sexes and their specific requirements.	Positive
	Scale of the system	Space requirements of the system.	Negative
	Complexity	- Simple construction and low level of technical skills required. - Simple operational procedures.	Negative
	Treatment efficiency	- Quality of the final product. - Performance of the technology in removing conventional wastewater constituents.	Positive

Dimension	Indicator	Definition	Objective
Technical	**Treatment capacity**	Potential capacity for wastewater (influent) acceptance per day.	Positive
	Technological versatility	- Possibility for extension of system capacity and change in loads. - Possibility to change the treatment process and to adapt it to different types and size of buildings. - Ability for the treatment to be flexible in unique or urgent situations (e.g. work without electricity) or when new information about technical development is obtained (breakthroughs). - Adaptability to existing environmental conditions, e.g. high groundwater level, geology, etc. - Flexibility and adaptability of its technical elements to the existing infrastructure and to demographic and socio-economic developments.	Positive
	Durability	- Level of alerts. - Service interruptions.	Positive
	Operational & Maintenance (O&M) requirements	- The functionality and the ease with which the system can be monitored by the local community and/or maintained by technicians. - Operational requirements and competence (i.e. number and qualification of the operational personal, operational safety, emergency measures). - Maintenance can be performed by any operating personnel. - Staffing required to operate the plant.	Negative
	Robustness	- Level of alerts. - Service interruptions.	Positive
	Nuisance of the system	- Level of nuisance produced by noise and smell during the collection.	Negative
	Quality of the final product	- Level of impurities in the final product.	Positive
Socio-Cultural	**Appropriateness**	- Appropriateness to the local cultural context (acceptable to use).	Positive
	System aesthetics	- High convenience and high level of privacy. - Attractiveness.	Positive
	Comfortability	- Ease to clean and maintain for the users and operating personnel.	Positive
	Reliability	- Confidence in the system.	Positive
Ecological	**Potential greenhouse gases emissions (GHG)**	- Contribution to Climate Change: emissions of NO_2, CO_2 and CH_4.	Negative
	Potential water pollution	- Potential contamination of the water bodies.	Negative
	Potential eutrophication	- Overfertilization of the water bodies with P.	Negative
	Potential soil pollution	- Potential contamination of the soil.	Negative
	Hazardous substances (final product)	- Heavy metals and persistent organic compounds present in the final product. - Persistent chemical substances release by means of the final product.	Negative
	Micropollutants (final product)	- Pharmaceutical residues and hormones in the final product.	Negative
Materials & Natural Resources	**Chemicals use**	- Amount of chemical substances used during the operation of the system.	Negative
	Water consumption	- Water consumed during the lifecycle of the system.	Negative

Dimension	Criteria	Definition	Objective
Materials & Natural Resources	**Collection of renewable water sources**	- Rainwater harvesting. - Groundwater recharge.	Positive
	Reuse of treated wastewater	- Potential reuse of treated wastewater.	Positive
	Recovery of nutrients	- Amount of N and P in the final product.	Positive
	Raw materials use	- Raw materials intensitivity. I.e. The use of raw materials.	Negative
	Fossil fuels demand	- Amount of petrol consumed within the system.	Negative
	Recovery of organic matter	- Amount of organic matter in the final product.	Positive
Energy	**Energy required**	- Potential Energy consumed (heat, fuels and electricity) compared to a conventional wastewater system plant.	Negative
	Energy reused	- Energy recovered and reused within the system. E.g. thermal energy.	Positive
	Energy efficiency	- Potential Energy consumed per unit of wastewater or human excreta treated.	Positive
	Energy generation	- Energy generated as a result of operating the system.	Positive
Institutional	**Training requirements**	- Need to learn to operate the system.	Negative
	Institutional acceptance	- Institutional acceptance of the sanitation system in terms of legal and regulatory frameworks. - Political (government developers and/or policy makers) support. - Current legal acceptability	Positive
	Compliance	Operational compliance of the existing regulations.	Positive

Table 3: Definition of the location wise criteria and their objective*direction of the change desired: positive: maximisation of the criteria, negative: minimisation of the criteria

Dimension	Criteria	Description and Guiding Question(s)	Direction
Financial	**Level of welfare in the city**	Is the level of welfare high in the city? E.g. Basic well-being of the individuals and society focusing on the financial situation and related indicators.	Positive
	Investment & Funding options: private and/or public	Can the costs of SANIRESCH be totally or partially covered by public and/or private local and/or national and/or international investment and/or funding agencies? E.g. -Possibility for establishment of lines of credits and/or provision of equipment and materials. - Provision of grants and subsidies to implement SANIRESCH; -Provision of funding from external business companies (international investors who want to have a business in the zone); -Rate of external inversion in the area.	Positive
	Potential service fees	Are users disposed or able to pay a fee for the sanitation services provided by SANIRESCH? E.g.-Fee to use the toilette; -Fee to use the final product (agriculture).	Positive
	Price of the water	Is the municipal water supply expensive in the area? E.g. Price of the tap water.	Negative
	Price of the soil amender	Is it expensive to get soil amender to increase the organic matter of the soil? I.e. Price of the soil compost.	Positive

Dimension	Criteria	Description and Guiding Question(s)	Direction
Financial	**Price of the chemical fertilisers**	-Is expensive to get chemical fertilisers in the area? -Are they subsidised? -Is it cheaper than obtain the urine and soil amender through SANIRESCH? I.e. Price of the chemical fertilisers.	Positive
	Industrial agriculture	-Is there an agricultural industry in the area? -How important is the agricultural industry? I.e. Importance of the agricultural industry in the area.	Positive
	Market for wastewater recycled products	-Is there a demand for reclaimed water? Is there a demand for organic fertiliser and soil amender? I.e. Market opportunities for the final product(s).	Positive
	Increase of local welfare	Is there an increase of the local welfare of the area as a consequence of the SANIRESCH use? E.g.-Business opportunities; -Local employment improvement: local people working as a operating and maintenance personnel in SANIRESCH.	Positive
	Financial feasibility	Is SANIRESCH expected to yield a profit that would justify the costs to implement the system? I.e. Profitability of the technology.	Positive
	Financial efficiency	Are the estimated potential costs of SANIRESCH higher than the costs of the local conventional wastewater system? I.e. Local cost efficiency of SANIRESCH.	Positive
	Cost of access to sanitation	Is it expensive to access to adequate sanitation in the area? I.e. Cost of access to sanitation as % of household income.	Positive
Health & Hygiene	**Regular access to conventional wastewater treatment and sewage facilities**	Is there a regular access to the conventional wastewater system in the city? I.e. Sanitation Coverage: Coverage of conventional sewage pipes and centralised wastewater treatment in the city.	Negative
	Distribution of conventional toilet facilities	Is there a regular presence of conventional sanitation collection systems? I.e. Extent of toilet coverage.	Negative
	Need for sanitation improvement	Is there a need for an improvement of the sanitation? I.e. situation of the sanitation in the area of implementation.	Positive
	Availability of clean water	Is there available water hygienically safe? I.e. safe water availability in the area.	Positive
	Availability of sanitation	Is the sanitation available? I.e. availability of sanitation.	Negative
	Incidence of water-borne diseases	Is there a high incidence of water-borne diseases in the area? I.e. incidence of water-borne diseases in the city.	Positive
	Exposure to hazardous substances	Is there an exposure to hazardous substances through the reuse of wastewater products? I.e. Heavy metals and persistent organic compounds presence in the final product and/or persistent chemical substances release by means of the final product.	Positive
	Exposure to micropollutants	Is there an exposure to micropollutants through the reuse of wastewater products? I.e. Pharmaceutical residues and hormones in the final product.	Positive

Dimension	Criteria	Description and Guiding Question(s)	Direction
Technical	**Capacity to import technological products –to operate SANIRESCH-**	Is there capacity to import the technological products (UD flush toilettes, Waterless Urinals, Polyethylene (PE) tanks, MAP reactor, MBRs) needed to operate SANIRESCH? I.e. Capacity to import the technological products needed to operate the system.	Positive
	Logistics capacity to distribute imported technological products	Is there the logistical capacity to distribute technological systems, spare parts and maintenance materials from high-income countries? I.e. Technical logistic capacity to distribute technological compounds.	Positive
	Area availability	Is there space available to implement sanitation systems in buildings in the area? I.e. Open space availability to implement SANIRESCH E.g. In Eschborn the treatment area is not enough space to treat all the wastewater.	Positive
	Scale of implementation	Is very extensive the potential area of implementation of SANIRESCH? I.e. Area and/or number of inhabitants availability to implement SANIRESCH.	Positive
	Availability of technical know-how	Is there technical knowledge to operate the system? I.e. availability of technical know-how.	Positive
	Local availability of spare parts	Are the spare parts for SANIRESCH locally and/or nationally available? I.e. Locally and/or nationally manufacturing of spare parts for SANIRESCH.	Positive
	Local and/or national availability of SANIRESCH's technological products	-Are the technological compounds of SANIRESCH locally and/or nationally available? -Is there a technological market for MBRs and MAP in the country? I.e. Locally and/or nationally manufacturing of MBRs, UD flush toilettes, MAPs, Polyethylene (PE) Collection Tanks and pipes.	Positive
	Average time required to obtain imported spare parts	Is there a need to wait a long time to get the repairs and spare parts? I.e. Waiting time to get replacement parts (important for unexpected malfunctioning of the system).	Negative
	Functionality of the final product	Is the SANIRESCH product functional to the local needs? I.e. Usability of the final product compared to the one obtained with the conventional wastewater system in the area and/or fertilisers and compost competitors.	Positive
	Level of decentralised sanitation systems	Is there a tendency towards decentralised sanitation systems in the area? I.e. Level of implementation of decentralised sanitation systems	Positive
Socio-Cultural	**Demand of the final product**	Is there a famer demand for the products obtained with SANIRESCH? I.e. Farmer demand for organic fertilisers and/or soil amender and/or reclaimed water to irrigate the crops.	Positive
	Farmer acceptability	Do farmers would accept to use organic fertilisers and soil amender from human excreta? I.e. Farmer willingness to utilise excreta recycled products.	Positive

Dimension	Criteria	Description and Guiding Question(s)	Direction
Socio-Cultural	**Acceptability of the final product**	Do consumers would accept to eat agricultural cultivated with organic fertilisers and soil amender from human excreta? I.e. Consumer willingness to eat agricultural products cultivated with human excreta.	Positive
	User acceptability	-Do the users would accept the change in the habits when using the SANIRESCH toilets? -Would be SANIRESCH accepted for the users? I.e. Acceptability to use the SANIRESCH toilet.	Positive
	Cultural obstacles	Are there cultural barriers that could complicate the implementation of SANIRESCH? E.g. -Cultural psychology regarding the sanitation in the city (taboos, men and women behaviour when urinating, disposal of menstrual pads, etc.). -Perception of human excreta, and devices for managing faeces and urine. -Religion of the users and farmers and its influence to the adaptability of SANIRESCH.	Negative
	Aesthetics standards	Are the sanitation aesthetic standards high in the area? E.g. In areas where the sanitation coverage is very low, the tolerance to bad odours and human excreta is higher.	Positive
	Age distribution of the population	Is the population of the area predominantly young? I.e. Youth bulge of the area: The age distribution can play a role in the level and requirements of awareness and maintenance of the sanitation systems. E.g. "young population" (population percentage of ages 1-14 above 30% and ages above 75 under 6%) might show lower levels of compromise, awareness and respect towards the need of implementing sanitation systems and its adequate use.	Positive
	Population density	Is it a highly dense urban area? I.e. Population pressure in the area: Population density affects both how crowded dwellings are, and how much space there is between houses.	Negative
	Rural influence	Is the urban area strongly influenced by agriculture? I.e. Level of rural influence: There is a strong influence of agriculture in the area.	Positive
	Urbanisation rate	Is there a fast development of the city? -I.e. There is a high percentage of population going to live to the cities: High percentage of buildings, new business areas and infrastructures (logistics); -Fast Urban Development.	Positive
	Education improvement	Could the implementation of SANIRESCH increase the access to education in the area? E.g. The implementation of the sanitation decreases the number of water-borne diseases, which allows to the children to attend more hours at the school.	Positive
	Increase of livelihood	Could SANIRESCH increase the livelihood of the population in the implementation area? I.e. Increase in the number of jobs, personal security (indoor sanitation system), better health and aesthetics.	Positive
	Gender inclusion	Does SANIRESCH Promote gender and parity issues in the area? I.e. Impact of SANIRESCH in gender issues and human dignity.	Positive

Dimension	Criteria	Description and Guiding Question(s)	Direction
Socio-cultural	**Society practising anal cleansing**	Is water used to cleanse after defecation? I.e. Use of water after defecation instead of toilet paper or others products.	Negative
Ecological	**Annual precipitation**	Is there an elevated amount of annual rainfall? I.e. Annual rainfall in the area.	Negative
	Freshwater quality	Are the water bodies polluted due to the lacking of adequate sanitation facilities? I.e. Pollution level of the freshwater bodies.	Positive
	Water ecotoxicity	Are there high levels of water ecotoxicity related to sanitation? Potential risk for biological, chemical or physical stressors to the water ecosystems.	Positive
	Terrestrial ecotoxicity	Are there high levels of terrestrial ecotoxicity related to sanitation? Potential risk for biological, chemical or physical stressors to the terrestrial ecosystems.	Positive
	Aerial ecotoxicity	Are there high levels of aerial ecotoxicity related to sanitation? Potential risk for biological, chemical or physical stressors to the aerial ecosystems.	Positive
	Food scarcity	Is there an exhaustion of food resources in the area? E.g. Low yield of the crops due to the lack of nutrients and aridness of the soil as well as water pollution.	Positive
	Soil nutrient depletion	Is there a lack of nutrients in the soil? I.e. Soil depletion of the area.	Positive
	Richness of soil organic matter	Is there soil rich in organic matter? I.e. Organic matter in the soil.	Negative
	Landscaping Complexity	Is the landscape inappropriate to implement low-cost sanitation techniques? I.e. Difficulties to implement conventional and low-cost sanitation techniques: pit latrines and sewer ditches due to the landscape.	Negative
	Physical water scarcity	Is there a lack of water due to environmental reasons? I.e. Physical water scarcity in the area.	Positive
	Economical water scarcity	Is there a lack of water due to a lack of human capital and institutional resources? I.e. Economical water scarcity in the area.	Negative
Materials & Natural Resources	**Groundwater supply**	Does the area rely on groundwater supply for drinking? I.e. The area depends on groundwater supply for drinking and irrigation uses.	Positive
	Flush water availability	Is there a lack of water for flushing? I.e. Regular availability of water to flush the toilet.	Positive
	Regular water supply for 24h	Is there a regular water supply of water? I.e. Availability of a regular water supply.	Positive
	Reclaimed water use	Is reclaimed water used in the area? I.e. Agricultural, urban, forestry use of treated wastewater.	Positive
	Urban agriculture	Is urban agriculture practised in the area? E.g. Extent of vegetable gardens and orchards in the urban area.	Positive
	Availability of local materials	Are local materials available to totally or partially construct, repair and maintain SANIRESCH? I.e. Availability of local materials to operate SANIRESCH.	Positive
Energy	**Availability of energy (electricity)**	Is there electricity available in the area? I.e. Availability of electricity in the area.	Positive
	Price of the energy (electricity)	Is it expensive the electricity in the area? I.e. Price of the electricity.	Negative

Dimension	Criteria	Description and Guiding Question(s)	Direction
Energy	**Regular access to electricity**	Is there an access to electricity at a regular basis? I.e. Regular electricity supply (24h).	Positive
	Suitability of an intensive energy technology	Are there deficiencies in the supply of energy in the city? I.e. Suitability of an intensive energy technology.	Positive
	Consumption of reused energy (Biogas)	Is Biogas produced and used in the area? I.e. Generation and use of Biogas as an alternative energy in the area.	Negative
Institutional	**Need for capacity building**	Is there a need for capacity building in the area? I.e. Need for capacity building.	Negative
	Legal acceptability	Is there a clear division of the responsibilities with the sanitation and resource oriented sanitation? I.e. Legal windows and room for interpretation in executing the policies or there is little ambiguity about what can be done or not.	Positive
	Rigidness of regulation standards	Is there a strict legal regulation relating sanitation and reuse of final products in the agriculture? I.e. -Quality requirements of the excreta and reclaimed water in terms of pathogens, salt and nutrient contents. -National and local standards with regards to water quality and reuse of excreta and reclaimed water.	Negative
	Legal ambiguity	Is there a clear division of the responsibilities with the sanitation and resource oriented sanitation? I.e. Legal windows and room for interpretation in executing the policies or there is little ambiguity about what can be done or not.	Negative
	Reliable conveyance	Is there a reliable sanitation conveyance system? I.e. Reliability of conveyance (private or public pipe system).	Positive
	Reliable transport	Is there a reliable sanitation transport system? Reliability of transport (private or public transport system).	Positive
	Organisational Capacity	Is there the capacity to develop skills or competence to operate complex technological systems? I.e. Capacity of the area to provide self-capacity building.	Positive
	Awareness Capacity	Is there the capacity to address awareness and informational needs? I.e. Capacity to increase public understanding about sanitation issues.	Positive
	Service Providers Availability	Are there sanitation service providers in the area? I.e. Availability of service providers who can offer collection, maintenance and transport services.	Positive
	Public Sanitation Ownership	Is sanitation provided by the government? I.e. Extent of public sanitation provision in the area.	Positive
	Need for training requirements	Is there a need to train the local stakeholder to use and operate the system? I.e. Need for training requirements.	Negative

2.2 Questionnaires

To collect the data necessary to carry out this research two different types of questionnaires were designed. Both questionnaires were embedded in an electronic survey format using the software “surveyguizmo$_{TM}$”.

2.2.1 1st questionnaire

The first questionnaire was designed to obtain the performance values of the technology wise indicators selected in the literature review. The link to this questionnaire was sent by e-mail to one representative of each sanitation system assessed in the MCDA. The main outcome of this questionnaire is the performance of the technology wise indicators with regards to the sanitation systems assessed in Germany. The questionnaire can be accessed on-line in URL address: http://www.surveygizmo.com/s3/364321/c57ac9b7d6c3 or it is also included in the electronic attachments in the section 3.

2.2.2 2nd questionnaire

The second questionnaire, which can be consulted in the electronic attachments, section 4, was designed to obtain the preferences and values of the stakeholder group "experts on sanitation" representing the urban areas of fast-growing economies. Furthermore, the questionnaire also included a section where the technical evaluation of the key technological components of the system as well as the adaptability of the system to the urban area were assessed by means of direct questions combined with a qualitative evaluation of the components. The link to the questionnaire was also sent by e-mail. However, in this case, a soft-copy of the on-line questionnaire (pdf document) was also attached to the mail in order to alleviate difficulties due to weak internet connections. The main outcome of this questionnaire was to obtain data about the importance and values of the technology wise and location wise indicators of the potential areas of implementation in Sao Paulo and Durban as well as the technical evaluation of the adaptability of the system in such cities.

2.3 Multi-Criteria Decision Analysis (MCDA)

In this section, the methodological foundations of the MCDA operated in this study are defined and discussed. As Munda, et al. (1994) recommends, the structure of this MCDA consists of the following parts.

2.3.1 Goal of the MCDA

Prior to the assessment of the adaptability of the sanitation system it was considered necessary to enhance the understanding of the sanitation system implemented within the SANIRESCH project. Therefore, a MCDA to assess the performance of the SANIRESCH project against a set of potential competitors in the German market was designed. By operating the MCDA it is possible to identify which technology wise indicators play a significant role in the performance of the sanitation system. Furthermore, it is also possible to compare and rank the sanitation systems included in the analysis.

2.3.2 Generation of alternatives

The sanitation systems assessed in the MCDA were chosen with regards to two main characteristics. Firstly, a similarity in at least one of the components parts of the sanitation system, which facilitates the increase in the understanding of the technological components of the system implemented within the SANIRESCH project. Secondly, only systems that have been developed within the German (and Austrian) market were selected due to the fact that it is considered that they share equivalent financial resources, similar level of development of the technologies and also similar social background. Hence, the alternatives included in the analysis are: the ecological housing state in Lübeck-Flintenbreite (Hamburg, Germany), the solarCity in Linz (Austria) and the pilot system implemented in the Hamburg University of Technology (TUHH, Hamburg, Germany), the Looloop system. Furthermore, the conventional wastewater system in Hamburg is also included in the analysis. An exhaustive description of the alternatives is attached in the appendices section I.

2.3.3 Choice of the evaluation criteria

The alternatives were evaluated with regards to the technology wise criteria elicited during the literature review (section 2.1.2).

2.3.4 Weighting process

The weights were given to the dimensions instead of to the indicators. The decision between giving weights to the indicators or to the dimensions is a complex step in any MCDA. Weighting directly the indicators adds several drawbacks to the MCDA process, which are discussed in Munda, et al. (1994). However, there is not a right answer and depends on the preferences and objectives of the MCDA process. In this case, the weights were given directly to the dimensions because thus the number of indicators under the same dimension does not affect the overall weight of the dimension in the final aggregation. Therefore, the number of indicators within one dimension does not determine the importance of the dimension. To weight the dimensions also causes that the indicators under the same dimension have the same weight, which is a result of the weight of the dimension, ideally previously chosen by the stakeholders.

This MCDA has been operated by giving equal weight to the dimensions. To calculate the weight of each criterion, the total number of indicators under the same dimension was divided by the total final weight of the dimension. However, the MCDA has also been operated including the average weight of the dimensions given by the representatives of the sanitation systems assessed in the MCDA with the exception of the conventional system. The different weights that the representatives could give to the dimensions are shown in the table 4.

Table 4: Details for the weights of the dimensions

Categorisation	Score	Definition
Normal	1	The effect of this dimension is moderate (1x).
Important	2	The effect of this dimension is double (2x) with regards to the dimensions categorised under "normal".
Crucial	3	The effect of this indicator is triple (3x) with regards to the dimensions under "normal".

2.3.5 Aggregation procedure

The simple average weighting (SAW), which is the most commonly applied decision rule (Mysiak, et al., 1995) is the aggregation procedure method used in this investigation to operate the MCDA. The formula is shown in the figure 4. The main reasons are the simplicity of the method (with regards to the calculation and the interpretation of the results) and the transparency that this linear additive model provides to the MCDA (Hurley, et al. 2008).

$$[\ \Phi SAW\ (ai) = \sum_{j=1}^{v} Wj \times aij\ ]$$

Figure 4: Mathematical Aggregation Procedure of the Simple Average Weighting (SAW) method (ϕ: performance of the alternative; a: score of the criteria and w: weight of the criteria) Source: (Mysiak, et al. 2005)

2.3.6 Data collection

A crucial step in any MCDA is the availability and quality of the data because it determines the outcomes of the decision-making process (Munda, et al. 1994). Due to the fact that all the sanitation systems assessed are pilot and/or demonstration projects which still are on a very initial stage of its development (Looloop, SANIRESCH) or implementation (SANIRESCH and solarCity), there is no availability of enough robust data with regards to specific parts of mainly the phase 2 of the SANIRESCH project, like the Magnesium-Ammonium-Phosphate (MAP) reactor and the MBRs (Winker, 2010_c). Similarly, some components of the phase 1 of the system are being currently optimised and there is not robust quantitative data (Winker, 2010_c). Therefore, this study decided to carry out a strictly qualitative MCDA reflecting the preferences and values of the so called "experts on sanitation" stakeholder group. It was decided that the components of this stakeholder group could only be the designers and implementers of the sanitation systems assessed due to the fact that they are the only ones with enough knowledge to provide qualitative data based on their knowledge and experience about the systems to operate the MCDA. In the case of the conventional wastewater system in Hamburg, the representative of the system was an expert of such system.

2.3.7 Categorisation of the qualitative indicators

The representatives were asked to compare their sanitation system to an ideal conventional wastewater system having the same size than their system. With regards to the conventional system, the exact same procedure was asked but comparing the system with an ideal generalisation of an alternative urban wastewater system. The representative of the systems evaluated the indicators with regards to the qualitative categorisation shown at the left side of the table 5. To have a minimum common ground to establish such comparison, the experts were asked to compare their sanitation system according to the mathematical expression shown in the section 2.3.7.1. In addition, a pictorial representation was also added in order to help them to understand the process (figure 5).

To operate the MCDA, the qualitative evaluation of the experts was converted to a numerical value according to the categorisation show at the right side of the table 5. Positive indicators imply that the desired objective is maximising the effect of such indicators. Negative indicators imply that the desired objective is minimising the effect of such indicators.

Table 5: Details for scoring depending on the direction of the indicators

Qualitative categorisation	Score (Positive indicators)	Score (Negative indicators)
Much Lower	1	5
Lower	2	4
Approximately equal	3	3
Higher	4	2
Much Higher	5	1

2.3.7.1 Mathematical expression:

- Much Lower: y= [-∞, -50] % of x
- Lower: y= (-50, -10) % of x
- Approximately equal: y= [-10, 10]% of x
- Higher: y= (10, 50) % of x
- Much Higher: y= [50, ∞] % of x

y= sanitation system
x= Conventional Wastewater System with the same characteristics

2.3.7.2 Visualisation

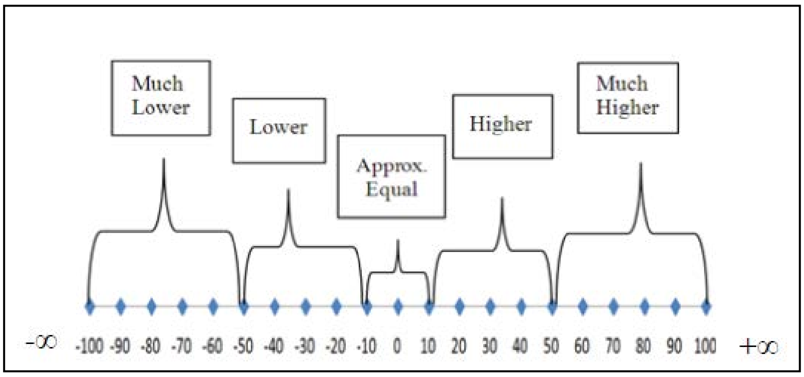

Figure 5: Graphical display of the mathematical categorisation process

2.3.8 Parameters used to operate the MCDA

As previously mentioned, the MCDA is operated in three different ways. Firstly, the scores of the technology wise indicators were calculated at a dimensional level. The subsequent aggregation of the dimensions allows calculating a final score per system. Secondly, the MCDA were operated at a system level, considering the different components of the sanitation systems, as recommended by Münch & Mels (2007). Finally, the technology wise indicators were taken into account without considering trade-offs amongst indicators as recommended by Agudelo (2007) and Agudelo, et al. (2007).

Table 6: Parameters used to operate the MCDA

	Number of indicators	Weight of each dimension	Maximum score dimension	Weight of each indicator	Maximum score of each indicator
Financial	13,0	100,0	500,0	7,7	38,5
Health and Hygiene	10,0	100,0	500,0	10,0	50,0
Technical	24,0	100,0	500,0	4,2	20,8
Socio-cultural	16,0	100,0	500,0	6,3	31,3
Ecological	14,0	100,0	500,0	7,1	35,7
Materials and Nat. Resources	15,0	100,0	500,0	6,7	33,3
Energy	10,0	100,0	500,0	10,0	50,0
Institutional	12,0	100,0	500,0	8,3	41,7
Total	114,0	800,0	4000,0		

2.3.9 Limitations and assumptions

2.3.9.1 Quality of the data

The data comes from the strictly qualitative evaluation of one representative of the designing and implementing team of each system assessed, which includes the classical shortcomings of considering exclusively the subjective preferences and values of a group of individuals, which are extensively discussed in the social research methods literature (Richards, 2009). This decision was made due to the sate-of-the-art of the sanitation systems (i.e. very innovative and initial stage of its development) assessed in the MCDA, which caused a general lacking of extensive quantitative data available. Hence, the only way to assess these systems was by means of including the qualitative evaluation of the only stakeholder group with enough knowledge to evaluate the systems, the experts which designed, implemented and are currently monitoring the systems. The main weakness of this approach is that it is possible that differences in the way of interpreting and evaluate the results are reflected in the final outcome in the MCDA. For instance, two experts could evaluate the same process under different categories depending on the personal evaluation and experience of each expert. In order to alleviate this situation, it was proposed a specific categorisation method (see section 2.3.7).

Furthermore, the fact that only one representative was approached is also a serious source of uncertainty due to the fact that it does not allow alleviating this effect with the answers of other experts evaluating the same criteria. A consequence of only processing the data of one expert per alternative is that the results cannot be statistically processed. Therefore, this factor needs to be taken into account like a potential source of uncertainty.

Notwithstanding, the use of strictly empirical quantitative methods and data in general and specifically to operate a MCDA also has its shortcomings. Amongst these drawbacks, it is important to stress the fact not always it is possible, or at least, not without a significant level of uncertainty, to translate all the values of the different criteria to quantitative units. A classical example of this incommensurability of the values focusing on the economic dimension is the impossibility to translate to monetary units all the criteria in a cost-benefit analysis. Another classical example is the impossibility to translate to quantitative values the criteria related to the socio-cultural dimension, where public confidence and perceptions of the risk from a technological point of view are affected by more than just quantitative values of the level of risk (Kuzma et al, 2008).

The strength of using this methodology is that the preferences and values of the “experts on sanitation” stakeholder group are reflected, that currently is the only data available at this stage of the sanitation system implemented within the SANIRESCH project. Hence, the qualitative evaluation of the experts on sanitation is a first step to increase the understanding of the system, which is the main goal to carry out the MCDA rather than to decide in a normative way which system is the best.

2.3.9.2 Methodology

The methodology used to obtain the data has the following shortcomings:

- The categorisation method has a significant drawback. The fact of using an ideal conventional wastewater system as a reference value adds uncertainty and inaccuracy to the results. This situation is equivalent for the conventional system, the reference of which is an ideal representation of an alternative system. The problem arises due to the huge range of potential systems that can be used as a reference systems and the fact that by using one or the other the results change. For instance, it is not the same a conventional system which recycles the P and N that one that it does not. This is a crucial flaw of the categorisation method and it should be improved in further research. A way to solve this shortcoming it is using a specific system as a reference model. In the case of this study, such system should have been the conventional wastewater system in Hamburg. However, this was not carried out because of the possibility that not all the experts were aware of such system. On the other hand, the conventional system should have been compared with the SANIRESCH project. However, the problem arises again due to the fact that it was not possible that the expert selected to represent this system could have all the data necessary to compare the conventional system to the system implemented within the SANIRESCH project. However, such problems could have been significantly alleviated by carrying out focus groups or semi-structure interviews with the representatives of the systems. Hence, a specific system could have been chosen and the characteristics of such system explained to the experts during the workshop or interview. However, in this case this approach was no feasible due to the lack of time and resources of both this research team and the representatives of the systems.

2.3.9.3 Decision-making process

The tool is not a strictly normative tool approaching to identify the optimal solution but to explore trade-off amongst conflicting criteria. Due to the characteristics and drawbacks of the MCDA carried out in this study, the results should be considered as indicative results. The final numerical results should not be given as much importance as the information and trends contained in the analysis of the indicators and components of the systems. The fact that one alternative has a higher score only indicates that such system shows a higher performance taking into account the indicators used, the information available (which comes from the qualitative evaluation of one representative of the systems) and the aggregation procedure method.

However, the information provides trends and indications about the factors that play a role in the assessment of the sustainability of these sanitation options. Due to the intrinsic nature of the MCDA and also due to the limitations and constraints of the conceptual design of the MCDA applied in this investigation, the results should be treated as a way to improve the understanding of the decision making process of ranking the different alternatives. Hence, it should serve to help the decision-making process. Such understanding is not achieved by aggregating the scores of the criteria within the dimensions and subsequently aggregating the scores of the dimensions within the sanitation system. In order to identify the factors that play a role in the adaptability of the sanitation system within the SANIRESCH project there is a need to analyse this system with regards to the components of the system and the indicators. Even though it is possible to rank the alternatives with regards to the individual dimensions and the final aggregation of such dimensions, it is dangerous because there is a total trade-off between not only the criteria used in the analysis but also the dimensions.

2.4 The Integrated Adaptability Assessment Framework (IAAF)

In order to assess the adaptability of the sanitation system implemented within the SANIRESCH project in urban areas of fast-growing economies, it was developed a tool which could assist in the decision-making process: The "Integrated Adaptability Assessment Framework" (IAAF).

2.4.1 General description of the IAAF

The framework has its basis in a set of adaptability indicators with regards to the sanitation system (technology wise indicators) and the potential characteristics of the urban area where the system wants to be implemented (location wise indicators). Such set of indicators is used as a broad inventory of all the potential factors that can play a crucial role in the adaptability of the system in urban areas of fast-growing economies. Subsequently, the stakeholders and actors involved in the decision-making elicit the technology wise and location wise indicators which play a crucial role in the urban area from the broad inventory. This process is carried out by evaluating the importance of the technology and location wise indicators with regards to the adaptability of the system in the area of implementation. Subsequently to this elicitation process, a MCDA is operated taking into account the values of the adaptability indicators and the specific objectives per each indicator (i.e. maximisation or minimisation). Such values are obtained by means of the direct evaluation of the stakeholders. A crucial step of the IAAF is to obtain both the importance of the adaptability indicators as well as the local values of the location wise indicators (the values of the technology wise are included within the IAAF and are independent of the area of implementation). To collect the data, a semi-structured interview for each stakeholder representative combined with focus groups with all the stakeholders is recommended within the IAAF. In the case that it is not possible to carry out such processes, a questionnaire should be the method to obtain the preferences and values of the local stakeholders. With the values of the adaptability indicators, a MCDA is operated in two different ways, at a dimensional and at an indicator level. When the results of the MCDA are obtained, an evaluation of the adaptability is carried out by applying specific preferences at a dimensional level. After this process, the adaptability of the sanitation system can be assessed. However, due to the intrinsic characteristics of the framework and the complexity of assessing the adaptability of a sanitation system at a city scale, more than a normative result, this framework should be used as a tool to improve the understanding and highlight both the indicators and the dimensions which play a role in the adaptability of the sanitation system. Due to the fact that operating the IAAF requires a high investment of time and resources, a quick-scan method is also included within the IAAF in order to identify quickly if the potential area of implementation has the minimum requirements to implement the IAAF.

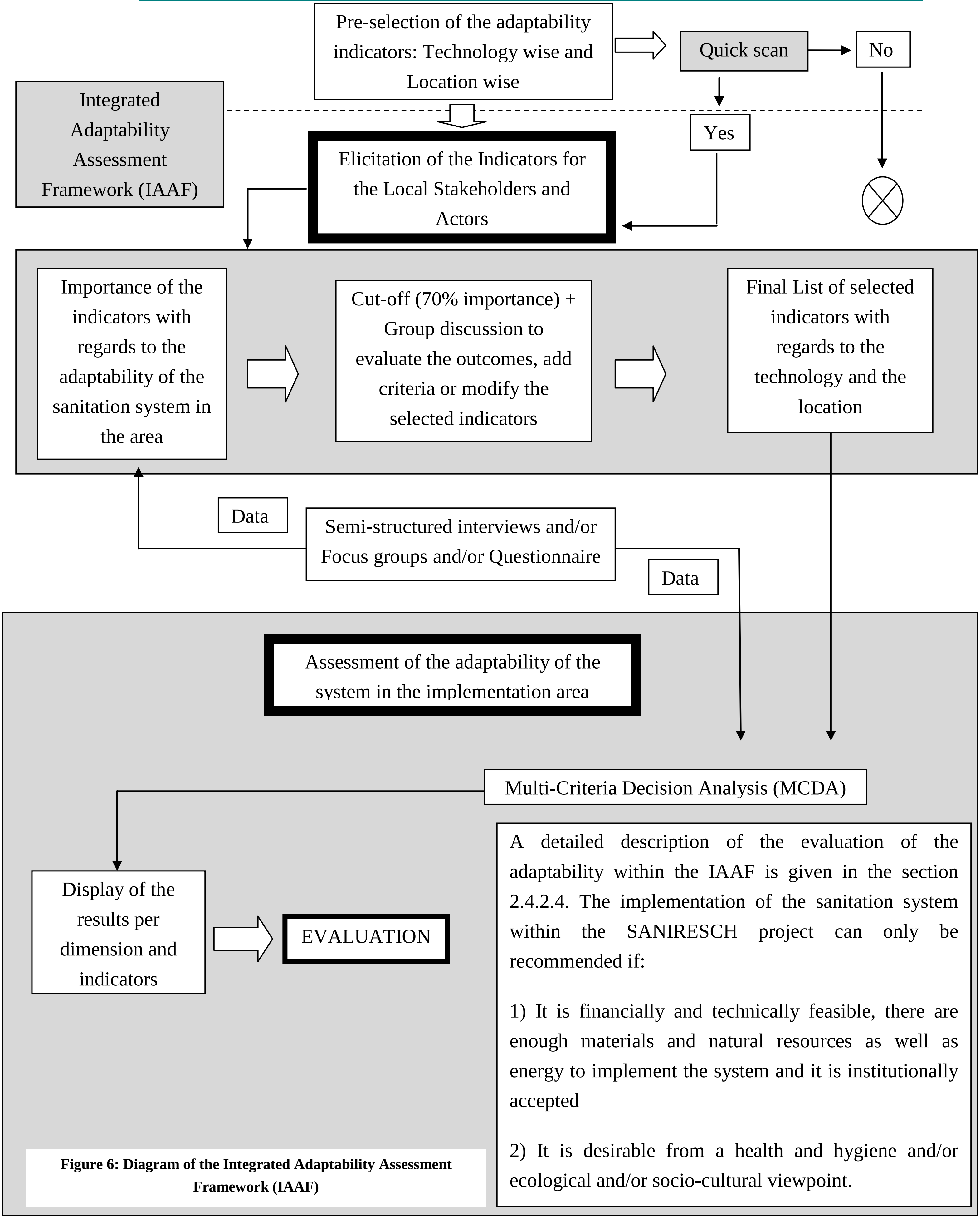

Figure 6: Diagram of the Integrated Adaptability Assessment Framework (IAAF)

2.4.2 Analysis of the IAAF

In this section, the framework is described and analysed.

2.4.2.1 Inventory of the indicators

A pre-selection of the technology wise and location wise indicators which can play a role in the adaptability of the urban sanitation system implemented within the SANIRESCH project in fast-growing economies has been carried out by means of the literature review discussed in the section (see section 2.1.2). The outcome of this step is an inventory of all the potential factors that can play a role in the adaptability of the sanitation system in urban areas of fast-growing economies. Such inventory will serve as the basis of the IAAF due to the fact that the assessment of the adaptability will be carried out taking into account the indicators identified in this list.

2.4.2.2 Source of the data

To obtain the data necessary to implement the framework, semi-structured interviews for each stakeholder representative and actor involved in the decision-making combined with joint discussion groups have to be carried out. However, in the case that this is not possible, the data can also be obtained by only semi-structured interviews and/or focus groups and/or questionnaires.

2.4.2.3 Elicitation of the local indicators

The IAAF is a location based framework. Due to this fact the stakeholders and actors involved in the decision making process carry out the elicitation of the indicators. The elicitation process starts with a selection of the key location and technology wise indicators with regards to the potential area of implementation, which is carried out by means of applying a cut-off for the indicators with an importance lower than a specific value (which will be decided by the stakeholders). Therefore, the indicators below this minimum importance score will not be selected as key indicators.

To evaluate the importance, the stakeholders are asked to rank the importance of each indicator based on their knowledge, experience, preferences and values referring to 6 different qualitative categories. These categories include the following levels: “irrelevant” (0); “Very low” (1); “Low” (2); “Moderate” (3); “High” (4) and “Very high” (5). For the evaluation of the importance, the framework uses as a reference the elicitation process proposed by Kuzma, et al. (2008). The methodology is simple and consists of applying a cut-off for the levels ranging from 0 to 3 (approximately less than 70% importance). However, this cut-off can be discussed in real case applications with the actors and stakeholders. Hence, there is the possibility to increase or decrease the cut-off level if the local stakeholders are interested to do it.

For controversial indicators, a discussion with the stakeholders to decide the inclusion or not of such indicators is also included within the IAAF. The framework contemplates that the local stakeholders and actors add missing specific key indicators with a local effect during the elicitation process. This feature adds flexibility and local adaptability to the IAAF.

It is important to highlight that specific indicators that do not pass the cut-off can also be included depending on the preferences of the stakeholders and actors involved in the decision-making.

2.4.2.4 Evaluation of the adaptability

In this step, the indicators selected are evaluated. The source of the data to carry out such evaluation is a crucial step. With regards to the technology wise indicators, the IAAF already includes the values of such indicators, which are independent of the potential area of implementation and inherent characteristics of the sanitation system. The values of the location wise indicators will be qualitatively evaluated by the local stakeholder and actors.

2.4.2.5 Processing of the data

The adaptability of a sanitation system in a specific area is a complex decision-making which depends on a multitude of factors, most of them at a local scale. As stated by (Munda, et al. 1994), it is not possible to have a unique solution for complex problems. Hence, in order to improve the understanding of the problem and be aware of which factors are either lost or won in the process of adapting the technology, the scores of the dimensions are calculated firstly after aggregating all the indicators. The values of the location wise and technology wise indicators are used to operate a MCDA. Such final aggregation is converted to a scale of 10, which simplifies the evaluation of the data. Secondly, the scores of the indicators are compared without allowing trade-offs amongst themselves. In both cases the results are displayed by means of radial plots.

The final decision with regards to the adaptability of the system to the potential area of implementation will be carried out taking into account specific technology and location based dimensional considerations. Such considerations are inspired by an evaluation framework proposed by FAO (2008; 2009_a) included in the project “Livelihood Adaptation to Climate Change Project, LACC II” (FAO, 2008; 2009_a; 2009_b).

- **LACC Evaluation Framework for Adaptation Options**

  The LACC framework considers that a technology option for adaptation to climate change is suitable if it meets a set of 4 main indicators with their respective sub-indicators for each indicator (FAO, 2009_a; 2009_b). Within the LACC framework, the technology options are qualitatively prioritised according such indicators. Hence, a technology will be considered "unsuitable", "acceptable", "recommended", "highly recommended" or "ideal" depending on the level of fulfilment of the indicators (FAO, 2009_a; 2009_b).

2.4.2.6 Adaptability requirements

The implementation of the system will be suitable in a specific urban area if the following requirements are met:

I. It is financially feasible.
II. It is technically feasible.
III. There are enough materials and natural resources to implement the system.
IV. There is enough energy to operate the system.
V. It is institutionally accepted.
VI. It is desirable from a health and hygiene viewpoint.
VII. It is desirable from an ecological viewpoint.
VIII. It is desirable from a socio-cultural viewpoint.

These eight requirements respond to the eight dimensions used to classify the inventory of adaptability indicators (both the technology and location wise indicators). The method proposed to determine if these requirements are fulfilled is by operating a MCDA. In this study, the MCDA is operated using the qualitative evaluation of one representative of the SANIRESCH project team (technology wise indicators) and the representatives of the study cases, one for each city evaluated.

It is necessary to stress that a high score in the financial, technical, materials and natural resources, energy and institutional (requirements I-V) imply that these dimensions are feasible to be fulfilled with regards to the adaptability of the sanitation system within the SANIRESCH project. A high score in the health and hygiene, ecological and socio-cultural imply that the area of implementation needs an improvement in these dimensions, which is regarded as a positive feature in the adaptability of the sanitation system.

Within the IAAF, the analysis of the adaptability will be carried out according to the following quantitative prioritisation:

- A city will be unsuitable for the adaptability of the sanitation system if any of the requirements from I-V show a score lower than 5. The city will also be unsuitable for the adaptation is all the requirements from I-V are higher than 5 but all the requirements from VI-VIII are lower than 5.

Table 7: Evaluation procedure within the IAAF to determine the unsuitability of the adaptation

Requirement	Dimension	Score	Score	Outcome
I-V	Financial	Any < 5	indifferent	Unsuitable
	Technical			
	Materials and Naturals Resources			
	Energy			
	Institutional			
VI-VIII	Health and Hygiene	indifferent	All < 5	
	Ecological			
	Socio-cultural			

A city will be acceptable for the adaptability of the sanitation system if all the requirements from I-V show a score from 5 to 6 and at least one of the requirements from VI-VIII shows a score from 5 to 6. The other two requirements can be lower than 5.

Table 8: Evaluation procedure within the IAAF to determine the acceptability of the adaptation

Requirement	Dimension	Score	Outcome
I-V	Financial	All from 5-6	Acceptable
	Technical		
	Materials and Naturals Resources		
	Energy		
	Institutional		
VI-VIII	Health and Hygiene	At least one 5-6, (the other two can be lower than 5)	
	Ecological		
	Socio-cultural		

- A city will be recommended for the adaptability of the sanitation system if any of the requirements from I-V obtain a score between 6 and 7 and the other(s) 3 requirement(s) from VI-VII range from 5-6. The option also would be recommended if at least one of the requirements from VI-VIII range from 6-7. In that case, the other requirements can be lower than 5.

Table 9: Evaluation procedure within the IAAF to determine the recommendation of the adaptability

Requirement	Dimension	Score	Score	Score	Outcome
I-V	Financial	All from 5-6	All from 5-6	At least one 6-7	Recommended
	Technical				
	Materials and Naturals Resources				
	Energy				
	Institutional				
VI-VIII	Health and Hygiene	All from 5-6	At least one > 6 (the other two can be lower than 5)	At least one 5-7 (the other two can be lower than 5)	
	Ecological				
	Socio-cultural				

- A city will be highly recommended if at least one of the requirements from I-V are higher than 7 and the requirements from VI-VIII: the three are between 6-7 or at least one them is higher than 7. A city will also be highly recommended if all the requirements from I-V are higher than 7 and at least one of the requirements from VI-VIII are also higher than 7.

Table 10: Evaluation procedure within the IAAF to determine the recommendation of the adaptability

Requirement	Dimension	Score	Score	Outcome
I-V	Financial	At least one > 7	At least one > 7	Highly Recommended
	Technical			
	Materials and Naturals Resources			
	Energy			
	Institutional			
VI-VIII	Health and Hygiene	All three 6-7	At least one > 7 (the other two can be lower than 5)	
	Ecological			
	Socio-cultural			

- A city will be ideal for the adaptability of the sanitation system if all the requirements are higher than 7. The city will also be ideal for the implementation if the requirements I-V are higher than 7 and at least one from VI-VIII is higher than 7 and the other are higher than 5.

Table 11: Evaluation procedure within the IAAF to determine the adaptability of the sanitation system

Requirement	Dimension	Score	Score	Outcome
I-V	Financial	All > 7	All > 7	Ideal
	Technical			
	Materials and Naturals Resources			
	Energy			
	Institutional			
VI-VIII	Health and Hygiene	All > 7	At least one >7. The others higher than 5	
	Ecological			
	Socio-cultural			

2.4.2.7 Quick scan

One crucial shortcoming is that to obtain the final result by means of the IAAF is a complex process which requires a high investment of time and resources. Due to this fact, a supplementary tool is integrated within the IAAF, which is designed to be operated before implementing the formal framework. This tool serves as a quick scan in order to determine if the urban area can be adaptable or not. This quick scan strictly focuses in the feasibility of adapting the sanitation system. Hence, it does not consider if the urban area need the process with regards to the health and hygiene, socio-cultural and ecological dimensions. These latter considerations need to be analysed within the IAAF.

To operate the quick scan there is a need to answer 5 questions by measuring 5 specific indicators:

Q1. Is there the capacity to pay for the implementation and operation of the sanitation system?

- Indicators: Level of welfare of the city + Investment and Funding options (public and/or private).

Q2. Is it technically feasible?

- Indicators: Local serviceability (understood as the capacity to import, distribute, and/or locally obtain the technological components and spare parts necessary to operate the system).

Q3. Is it feasible from a materials and natural resources point of view?

- Indicators: Regular flush water availability.

Q4. Is it feasible from an energetic point of view?

- Indicators: Regular access to electricity.

Q5. Is it institutionally accepted?

- Indicators: Legal acceptability.

The evaluation procedure to determine if the IAAF should be carried out is as it follows:

- If all the indicators are higher than 5, the system has the potential to be implemented. Hence, the IAAF should be carried out. Oppositely, if any of the indicators is less than 5, the sanitation system has the potential to be unsuitable for the area assessed. Therefore, to further analyse the area with the IAAF is not recommended.

2.4.2.8 Limitations and Assumptions

- The indicators within the IAAF are strictly qualitative. There is a need to further research the framework in order to include also quantitative indicators. The limitation that this fact causes is that the evaluation of the indicators is completely subjective which adds uncertainty to the robustness of the data. However, at the current state-of-the-art of the sanitation system it is not possible to carry out a quantitative analysis because there is not enough robust data to perform with regards to many of the technological components of the system. Hence, it was considered that the qualitative evaluation was the only way to evaluate the adaptability of the system.

- The IAAF has been designed in order to analyse the "experts on sanitation" stakeholder group. Even though the inclusion of other stakeholders could be carried out, the inclusion of all the stakeholders is difficult if some technical, ecological, materials or energy indicators are asked because it is possible that they do not have the specific knowledge necessary to assess the indicators. Due to this fact, specific stakeholders could grade specific groups of indicators with respect to their knowledge and preferences. The identification of the indicators which fall under the interest zone of specific stakeholder groups can be carried out following the already existing dimensional division of the indicators. For instance, the farmers could only grade the materials and natural resources, socio-cultural and financial dimension. However, it is recommended that other stakeholders with enough knowledge (like the scientific and technical stakeholder group, representatives of the government and actors directly involved in the decision making process) evaluate all the indicators included in the inventory. The local stakeholders have the possibility to include specific indicators which can play a role in the adaptability of the system in the potential area. However, there is a need to further research and develop the framework in order that all the stakeholders are capable to carry out the evaluation.

- The resources that need to be invested to operate the IAAF and obtain data of quality are high. This is a consequence of a conscious design of the methodology, which wants to tackle the complexity of the decision-making process in order to include all the potential factors that affect the adaptability of the sanitation system in the potential area of implementation. However, it is a shortcoming because it complicates the decision-making process.

- Indicators which are not considered important from a sanitation system viewpoint can become important due to specific local conditions. The inverse process is not likely to produce because if a crucial parameter from a technology viewpoint is not considered crucial from a location viewpoint implies that such technology wise indicators, even though showing a very low performance, can be easily adapted to the local conditions.

2.5 Testing the IAAF

2.5.1 Analysis

The fast-growing economies selected to test the IAAF were China (Central Asia), India (South Asia), Brazil (South America) and South Africa (Africa). Those fast-growing economies were chosen in order to represent different geographic areas of the World which have economies with the highest rates of GDP growth, which in this study is used as an indicator of fast-growing intensity. Hence, China and India are the most important fast-growing economies of Asia, as Brazil is for South America and Durban for South Africa –in terms of GDP growth- (IMF, 2010). Other areas of the World where there are important fast-growing economies were not approached due to a lack of time and resources. For every fast-growing economy selected, 3 different experts representing one different urban area each of them were approached. Hence, in total 12 urban areas were planned to be analysed.

The importance of the technology wise and location wise indicators as well as the values of the location wise indicators were designed to be obtained by means of the second questionnaire embedded in the on-line survey (see section 2.2.2). The experts were also asked to give their technical evaluation about the sanitation system and its key technological components with regards to their adaptability to the cities that they represent. To achieve this objective there was a section to assess the main technological components of the sanitation system with regards to its potential adaptability for adapting to the city that they represent. Secondly, the experts were asked if they would recommend or not the implementation of the sanitation system in their city and also to justify their decision. Finally, they were asked which modifications they would suggest in order to improve the adaptability of the sanitation system in the urban area that they represented. The questionnaire also included a section for comments in every question. The data was used to gain additional insight about the weaknesses and strengths of the sanitation system developed within the SANIRESCH project as well as a reference value to compare the results of implementing the IAAF.

The data with regards to the evaluation of the importance of the location and technology wise indicators was used to elicit the key indicators with regards to the adaptability of the urban area assessed. The main outcome of this step is an inventory of key adaptability indicators. After analysing the list, some additional technology and location wise indicators has been added. The reason to add such indicators is that they assess the performance of specific components of the sanitation system that this study considers necessary to include in the analysis. By doing this, the interactive process of analysis, discussion and selection of the indicators focusing on the sanitation system and the area of implementation between the local actors and stakeholders is replicated. However, none indicator selected by the expert elicitation has been excluded of the final list of indicators.

In this study, the MCDA will serve as a source of data to obtain the values of the performance of the technology wise indicators. With regards to the location wise indicators, the same questionnaire used to elicit the adaptability indicators includes a separate section to collect the performance of the location wise indicators. In this study, the data from the location wise indicators come from the experts on sanitation stakeholder group exclusively.

The values of the technology wise indicators were assessed by one representative of the sanitation system implemented within the SANIRESCH project. This information was obtained by means of the first questionnaire and it is the same data used to operate the MCDA to assess the performance of the system in Germany. It is very important to stress the fact that due to the categorisation process of this MCDA (see section 2.3.7) the values of the technology wise indicators are in comparison to the conventional wastewater system in Hamburg.

This data was supposed to be the main input to implement the Integrated Adaptability Assessment Framework (IAAF) for the case studies. Furthermore, complementary data from specific location wise indicators –population density and average rainfall values- was planned to be obtained from scientific literature.

However, there was a poor response due to the facts discussed in the section 6.1 and eventually it was only possible to get data from two experts representing Sao Paulo (Brazil) and Durban (South Africa). The tables 12 and 13 show the main parameters used to operate the MCDA embedded within the IAAF for Sao Paulo and Durban respectively.

Table 12: Main parameters used to operate the MCDA embedded within the IAAF

Sao Paulo	Number of indicators	Weight of each dimension	Maximum score dimension	Weight of each indicator	Maximum score indicator
Financial	13.0	100.0	500.0	7.7	38.5
Health and Hygiene	9.0	100.0	500.0	11.1	55.6
Technical	18.0	100.0	500.0	5.6	27.8
Socio-cultural	13.0	100.0	500.0	7.7	38.5
Ecological	9.0	100.0	500.0	11.1	55.6
Materials and Nat. Resources	7.0	100.0	500.0	14.3	71.4
Energy	6.0	100.0	500.0	16.7	83.3
Institutional	5.0	100.0	500.0	20.0	100.0
Total	80.0	800.0	4,000.0		

Table 13: Main parameters used to operate the MCDA embedded within the IAAF for Durban

Durban	Number of indicators	Weight of each dimension	Maximum score dimension	Weight of each indicator	Maximum score indicator
Financial	12.0	100.0	500.0	8.3	41.7
Health and Hygiene	9.0	100.0	500.0	11.1	55.6
Technical	15.0	100.0	500.0	6.7	33.3
Socio-cultural	13.0	100.0	500.0	7.7	38.5
Ecological	9.0	100.0	500.0	11.1	55.6
Materials and Nat. Resources	8.0	100.0	500.0	12.5	62.5
Energy	5.0	100.0	500.0	20.0	100.0
Institutional	6.0	100.0	500.0	16.7	83.3
Total	77.0	800.0	4,000.0		

2.5.2 Limitations and assumptions

- Even though the IAAF can include quantitative indicators, the data used to test the IAAF come from a strictly qualitative evaluation of one representative per urban area. The reasons are as it follows:

  1. The testing of the framework focuses on the evaluation of the "expert on sanitation" stakeholder group with regards to the effect of local indicators to the adaptability of the system. Hence, it was considered that the best way to obtain this information was by asking the experts directly their evaluation about the adaptability of the system.

  2. The analysis focuses at a city level and specific data with regards to the elevated set of indicators at city scale implied resources and time which were not available for this study. Therefore, to focus on their qualitative evaluation is a way to solve the impossibility to get quantitative data about the city.

- Only one expert per urban areas was approached due to a lack of time and resources. To increase the number of experts involved as well as to expand the actors and stakeholders in grading the importance of the indicators was not possible due to a lack of time and resources.

- The possibility to carry out semi-structured interviews in depth and/or focus groups with the representatives of the cities was not possible for a lack of resources.

- This study used the previously discussed cut-off (section 2.4.2.3) because it is considered to be an effective and fast way to select the indicators which have a key importance in the adaptability of the system. Therefore, the levels selected are the ones categorised as “high” and “very high”.

- In this study, the indicators which fell under the category “moderate” were analysed thoroughly and some of those indicators were also included in the final elicitation list due to specific interests responding the research questions of this investigation.

- Some indicators the data of which were missing were evaluated according to the literature values and are indicated in the electronic appendices.

Part II: Literature Review

3. Conceptual Background

3.1 Technology transfer

Technology transfer imported from high-income countries is a critical factor for improving technical and infrastructure development in developing and fast-growing economies (Dunmade, 2002). However, to develop and maintain such technologies as well as to obtain equipment and foreign technical know-how is a very expensive process which makes these economies very dependent on foreign technologies (Dunmade, 2002). The problem arises when many of these implementations of foreign technologies dramatically fail (Dunmade, 2002) contributing to an increase of the external debt, harnessing of the environmental conditions and natural resources wasted (Dunmade, 2002). “These failures can be attributed to inadequate pre-investment evaluations of the sustainability of proposed technologies within the local society” (Dunmade, 2002). Therefore, there is a need to enhance the sustainability assessment of foreign technologies (Dunmade, 2002).

3.2 Sustainability

The concept of sustainability proposed by the WECD report (WCED, 1987) is essentially anthropocentric (Ashley, 2009). Furthermore, after more than 20 years of discussion about this concept nobody knows what sustainability really is and it is increasing the viewpoint that a universal concept for sustainability actually does not exist (Ashley, 2009). Oppositely, the voices which claim that sustainability must be assessed in the terms of sustainability of what, of whom, at which costs and how long, are growing fast (Munda, 2008; Ashley, 2009). Furthermore, the reduction of sustainability to four dimensions (economic, environmental, social and technical) is clearly not enough to assess the complexity of real systems (Ashley, 2009) because as Munda (2008) states “the existence of different levels and scales at which a system can be analyzed implies the unavoidable existence of non-equivalent descriptions of it”.

3.3 Sustainability criteria

Sustainability criteria are a tool to assess the sustainability of a system which relies on the evaluation of a set of criteria and indicators target based with regards to the different dimensions of the sustainability (Flores, et al. 2008). Sustainability is context-specific and it is ultimately determined by the needs and opportunities of a specific region (Dunmade, 2002). Hence, Dunmade (2002) divides the indices of sustainability with regards to the import of foreign technologies in two interrelated classes, primary and secondary indicators.

Focusing on technology transfer issues, Dunmade (2002) states that the adaptability is the only primary indicator and the other indicators are derivatives of it. Hence, prior to import a foreign technology, it is strictly necessary to assess if such technology is adaptable to the specific location and society under consideration. Dunmade categorises the indicators in four dimensions: technical sustainability, economic sustainability, environmental sustainability and socio-political sustainability" (Dunmade, 2002). An example of the indicators used by Dunmade (2002) is shown in the figure 7.

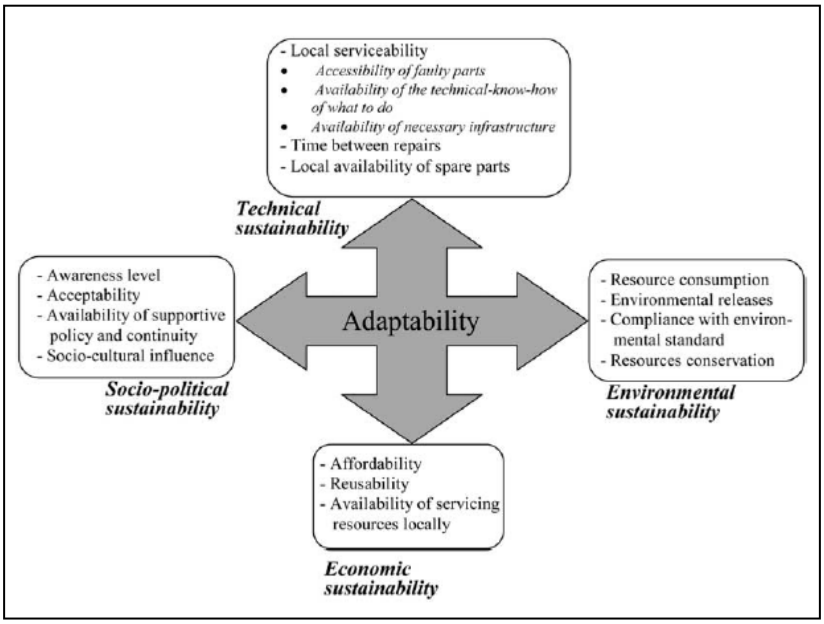

Figure 7: Indices of foreign technology sustainability. Source: (Dunmade, 2002)

3.4 Sustainability criteria for sanitation systems

Water supply and sanitation systems must be appropriate technological solutions "compatible with or readily adaptable to the natural, economic, technical, and social environment of the implementation area" (Balkema, 2003). This "sustainable" sanitation systems should be both effective (providing a real solution) and financially efficient (with the minimum costs) [Balkema, 2003]. Hence, in order to assess the sustainability of a sanitation system it is necessary to evaluate the interaction of the sanitation system with its surrounding environment (Balkema, 2003).

A sanitation system will be adaptable to the local circumstances when "comprises the users of all parts of the system, along with the collection, transport and treatment of human excreta and greywater. It explicitly recognises sanitation as being multi-faceted and includes the social aspect of the sanitation, the economic and logistical side, and the resource and energy management. A sustainable sanitation systems protects and promotes human health, does not contribute to environmental degradation or depletion of resources, is technically and institutionally appropriate, economically viable and socially acceptable" (Bracken, et al. 2005).

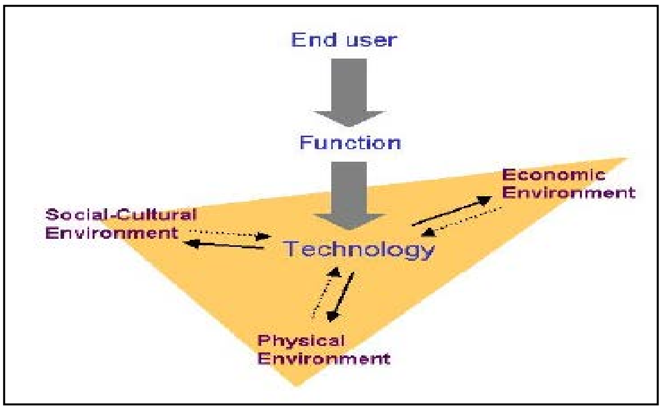

Figure 8: Technology interaction with the surrounding environment. Source: (Balkema, 2003)

Several studies have compiled a list of sustainability criteria and indicators with regards to the assessment of urban water supply and sanitation systems: (Lundin, et al. 1999; Hellström, et al. 2000; Balkema, et al. 2002; Balkema, 2003; Kvarnström, et al. 2004; Bracken, et al. 2005; Palme, et al., 2005; Pierini, 2005; Sahely, et al. 2005; Guio-Torres, 2006; Muga & Mihelcic, 2007; Flores, et al. 2008 and Jones & Silva, 2009).

3.5 Multi-criteria Decision Analysis (MCDA)

3.5.1 The concept

Multi-Criteria Analysis (MCA) provides a flexible tool to deal with qualitative environmental effects of decision-making processes (Munda, et al. 1994) used for multi-dimensional assessments in situations when there are competing evaluation criteria and various conflicting interests (Ness, et al. 2007; Munda, et al. 1994). Even though MCA cannot solve all these conflicts, they can provide a good insight into the nature of these conflicts (Munda, 2008; Munda, et al. 1994) by identifying trade-off between the goals of the decision-making process Ness, et al. 2007). Consequently, MCA "helps the decision maker to learn about the decision problem, to explore the alternatives available as well as the decision outcome and to value judgments about trade-offs between conflicting objectives" (Mysiak, 2005).

According to Munda (2004), Multi-criteria Decision Analysis (MCDA) is capable to face the nature of problems which 'facts are uncertain, values in dispute, stakes high and decisions urgent'' (Funtowicz & Ravetz, 1993). MCDA is a good tool to deal with complex decision problems that require multi-objective optimization of values (Agudelo, 2007) involving a large variety of actors and stakeholders. Ness (2007) defines MCDA as an integrated assessment tool used for supporting decision-making processes based on systems analysis approaches which integrate the different dimensions of sustainability: social, economic, environmental and political value judgements (Munda, et al. 1994). It also assesses different levels and scales at which a system can be analyzed (Munda, 2004) and it is capable to address both the short- and long-term perspectives (Ness, et al. 2007).

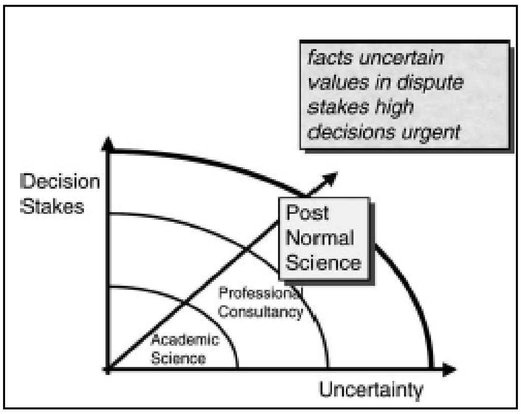

Figure 9: Graphical representation of the Post-Normal Science.
Source: (Munda, 2004)

3.5.2 Structure of the MCDA

The structure of a MCDA consists of the following steps (Munda, et al. 1994):

- Definition and structuring of the problem.
- Generation of alternatives.
- Choice of a set of evaluation criteria.
  Two main problems arise:
  - On one hand, to build the decision model as close as possible to the real-world problem (which will increase the number of evaluation criteria to a level such that its applicability becomes almost impossible).
  - On the other hand, to build a simple and fast decision model using a small number of criteria (which will oversimplify the model used).
- Identification of the preference system of the decision-maker.
- Choice of an aggregation procedure.

As Munda et al. (1994) and Munda (2008) state, the results of a MCDA depends on:

- Available data.
- Structured information.
- Aggregation method.
- Preference of decision-makers.

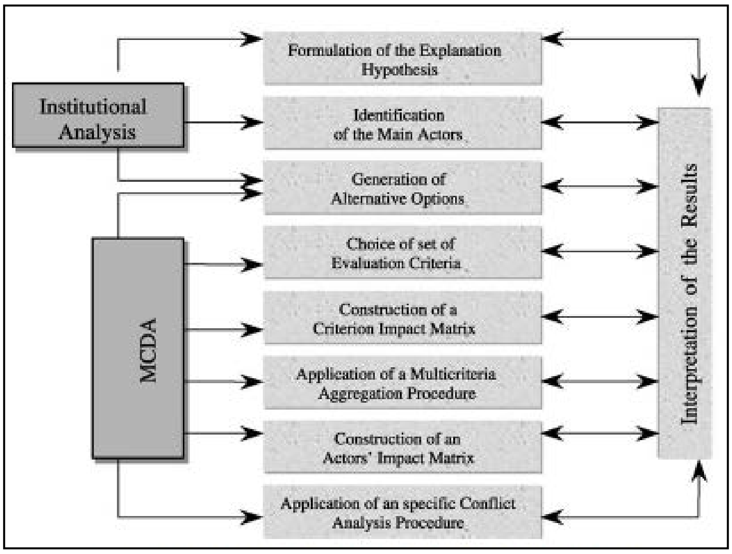

Figure 10: Scheme of the MCDA evaluation process. Source: (Munda, 2004)

3.6 MCDA in urban water and sanitation management

Sustainability in the urban water supply and sanitation sector aims to achieve a "participatory, democratic, holistic and integrated decision making" but urban water management affects a huge range of compartmentalised stakeholder and actors (Hurley, 2008). Agudelo, et al. (2007) state that there is also a huge variety of new sanitation systems but there is a significant lack of information about the performance of these systems. Thus, there is a need of decision making methodologies capable to deal with the complexity of the urban water supply and sanitation sector as well as to adequately assess the new urban sanitation technologies, due to the fact that the conventional assessment frameworks do not fit the characteristics of such technologies anymore (Agudelo, et al. 2007).

It is important to highlight that the significant number of algorithms to solve multiple-criteria decision problems imply both the flexibility and ambiguity of the MCA approach (Mysiak, et al. 2005). Furthermore, this author also points out that different MCA methods will provide the flexibility to accept different types of input data as well as methodological procedures but they will also produce different results. "The use of MCA with regards to water supply and sanitation has been progressively increasing" (Mysiak, et al. 2005) because MCA techniques are more adequate to face the challenges of the new millennium with regards to the water supply and wastewater management: The global water crisis, decentralised systems to close systems, small scale systems for source control to enable reuse and finally the decision between optimising old systems and introducing new ones (Balkema, 2003).

Several studies have used MCDA to assess sanitation systems: (Hellström, et al. 2000; Balkema, et al. 2002; Hiessl & Toussaint, 2003; Mysiak, 2003; van Moeffaert, 2003; Palme, 2005; Netssaf, 2006; de Silva, 2007; Münch & Mels, 2007; Borsuk, et al. 2008; Malisie, 2008; Tanyimboha & Kalungib, 2009; Larsen, et al., 2010; Pearson, et al, 2010).

3.7 Frameworks for urban water management and sanitation assessment

Sustainability cannot be assessed with the traditional approaches: It is a complex process because the criteria and indicators have "disparate and non-commensurate units" (Ashley, 2009). Furthermore, it is only possible to assess the relative sustainability between different technological systems (Ashley, 2009). The challenge of evaluating the relative sustainability of different options "has regularly been met by the development of assessment frameworks as a decision-support tool" (Hurley, et al. 2008). As Hurley, et al. (2008) explain, this is carried out by specialists from different disciplines aiming to enhance the inclusion of the different dimensions of the sustainability into the decision-making processes as well as to expand the range of stakeholders which will understand and participate in the decision problem. As it has been previously discussed, these frameworks should at least cover the economic, environmental and social dimensions. However, there is still a need to take into account other dimensions in order to improve the level of understanding of the system as well as to enhance the decision-making process.

Multi-criteria frameworks to assess the sustainability of water and sanitation system usually consist of a representation of several criteria per each dimension included in the analysis, "the fulfilment of which across all aspects illustrates a more sustainable decision" (Hurley, et al. 2008). If indicators are used, they show the level of fulfilment of the criteria. Hurley, et al. (2008) state that amongst the advantages of such approach are firstly breaking down the complex decision-making into constituent parts and secondly, that the contributory effects of each of these parts affects the overall decision. Furthermore, the authors also point out that multi-criteria frameworks are capable to increase "the role of the stakeholders in the decision-making process, facilitate compromise and provide a means of understanding different professional perspectives" (Hurley, et al. 2008). However, according to Hurley et al. (2008), the main shortcomings of the assessment frameworks are:

- Inadequate in capturing the essence of a problem due to the myriad valid viewpoints and the continually updated knowledge base of the human system involved.
- Time consuming and difficult to use in practice.

- When applied to a complex system involving a variety of actors with different perspectives, the assessment framework typically becomes narrow: it takes no account of the mutable nature of the system, which is itself evolving and dependent on outside influences.

The table 14 shows a review of multi-criteria assessment frameworks for urban water and sanitation management carried out by Tornqvist (2008).

Table 14: Multi-criteria assessment frameworks for urban water and sanitation * All the references are cited by the Tornqvist, et al. (2008). Source: Tornqvist, et al. (2008)

Nr	Name	Reference*
1	Approach toward strategic sanitation	Wright (1997)
2	Ten steps to sustainable infrastructure	Choguill (1996)
3	Sanitation 21 -a framework for sanitation planning in low-income areas	IWA (2006)
4	Household Centered Environmental Sanitation	(EAWAG (2005)
5	Open Wastewater Planning (OWP)	WRS (2007)
6	Terms of Reference (ToR) for planning urban sanitation	ADB /2007b)
7	Gender toolkit	Fong et al (1996)
8	Toolkit for sanitation strategies in low-income urban areas	WUP (2007)
9	Smarter Sanitation -electronic toolkit for planning WWS with the aim of reaching the MDG	ADB (2007a)
10	Model of the planning process of WSS-project in the developing world	Schiller and Dorset (1982)
11	Strategic planning methodology for urban water utilities in low-income countries	Mugabi et al (2007)
12	Framework for developing sustainability criteria for urban infrastructure systems	Sahely et al (2005)
13	Urban Water toolbox	Malmqvist et al (2006)
14	Toolkit for assessing willingness to pay, affordability and political acceptability	DEPA (2002)
15	IWRM toolbox website	GWP (2007)
16	Toolkit for assessing sustainability to urban water systems dependent on groundwater	AISUWRS (2005)
17	SWARD framework	Ashley et al. (2004)

The following multi-criteria based frameworks developed for the assessment of the water management and sanitation in urban areas have been identified in this study: (Hellström, et al. 2000; Balkema; 2003; Hellström, et al. 2004; Kvarnström, et al. 2004; Kvarnström & Petersens, 2004; Ridderstolpe, 2004; Bazzani, 2005; Mysiak, et al. 2005; IWA, 2006; Netssaf, 2006; Agudelo, 2007; Agudelo, et al. 2007; Cornel, et al., 2008; Törnqvist, et al. 2008; Jones & Silva, 2009; Murray, 2009; Murray, et al. 2009).

3.8 The SANIRESCH Project

3.8.1 General remarks

SANIRESCH is a research and demonstration project of an urban ecological sanitation system in the GTZ headquarters in Eschborn (Frankfurt, Germany). During the phase 1 of the project, the hardware of the sanitation system is installed in the GTZ House 1 (2005) within the renovation works of the headquarters and starts operating in 2006 (GTZ, 2009; Werner et al., 2009; Werner et al., 2008; Werner, et al., 2006). Phase 2, which starts on 2009 (Werner et al., 2009), consists of a research project that focuses in the treatment and reuse of the separated fractions collected by means of the system. The other research objectives developed during phase 2 focus on the further development of the technology and its operational concepts (Werner, et al. 2006), user acceptance of the system, environmental and health risks of the final product (especially micropollutants), financial and legal aspects involved in the implementation of the system and the international adaptability of the sanitation system (Werner, et al., 2008; Werner, et al., 2009).

The GTZ House 1 (main edifice) is a multi-storey building which provides space for 650 employees. The sanitation system implemented within SANIRESCH serves approximately 400 users. However the number of users is not known with certainty because the calculation is difficult to estimate (Werner. et al. 2009). Furthermore, the reductions of the water consumption in the GTZ House 1 as well as further scientific research about the implementation aspects of an urban ecological sanitation in Germany are also approached.

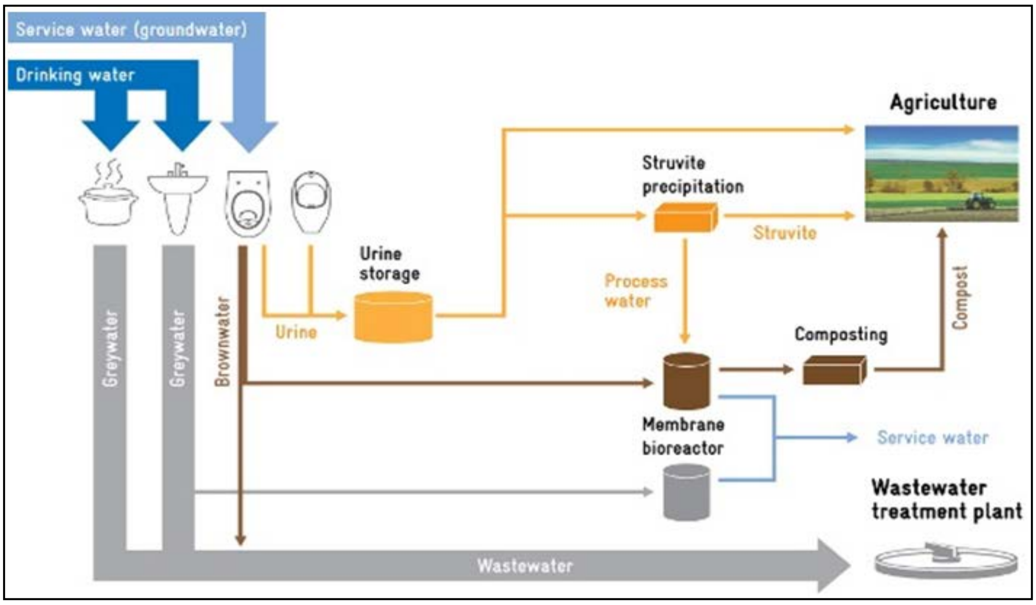

Figure 11: Diagram of the sanitation system implemented within the SANIRESCH project: Phase 1 consisted of the construction of the urine separation, collection and storage system. Phase 2 develops the technologies to treat and reuse the urine, brownwater and greywater collected. Source: (GTZ, 2009)

It is necessary to highlight the state-of-the-art of this project. Whereas the phase 1 is completed, the phase 2 is still developing. According to SANIRESCH (2010_c) the first membrane bioreactor will be installed in February 2011. Due to this fact, Winker (2010_c) states that there is not currently any kind of composting process carried out from the solid fraction of the membrane biological reactors (MBRs). Similarly, the greywater is not treated at the moment within the system but directly directed to the conventional wastewater treatment plant of the area (Winker, 2010_c). In addition, the sanitation system implemented in Eschborn is too small to treat all the excreta of the installations. Due to this fact, part of the excreta collected is directly directed to the conventional wastewater treatment plant of the area (Winker, 2010_c). The application of the urine in the agriculture is limited by the German fertiliser law (Werner, et al., 2009; Werner, et al., 2008). However, there has been applied liquid urine to agricultural fields at a research level by the University of Bonn since March 2010 (Winker, 2010_a). On the other hand, the MAP reactor just started operating in May 2010 but the struvite still has not been applied as solid fertiliser. This is mainly because the process is still being developed and optimised.

3.8.2 Technologies applied

According to Werner et al. (2008) and Werner et al. (2009), the sanitation system develops the following technological concepts to manage the excreta of the GTZ main building.

- **Collection and conveyance**
  The system consists of 23 waterless urinals (Keramag) and 50 urine-diversion (UD) flush toilets (Nomix, Roediger). In addition, there is a separated pipe system for the collection of the urine, brownwater and greywater (Werner, et al., 2008; Werner, et al., 2009). The total amount of urine collected is approximately 120 L per day (Winker, 2010_a).

- **Treatment**
  The urine is treated in two different ways: prolonged storage in plastic tanks in the basement of the building (GTZ, 2009; Werner et al., 2008; Werner, et al., 2009) and struvite (magnesium-ammonium-phosphate, MAP) production as a result of the precipitation of phosphorous and nitrogen by the addition of magnesium oxide (MgO) in the MAP reactor (Winker, 2010_b). The brownwater and the greywater will be treated in two different membrane biological reactors (MBR) [GTZ, 2009].

- **Transport and reuse**
  According to GTZ (2009), the system produces liquid and solid organic fertiliser as well as soil amender. In this way, the urine stored is applied directly to agricultural fields after the storage time (liquid fertiliser) (Winker, 2010_a). The struvite will be used as solid fertiliser. The reclaimed water produced will be used as service water within the system (GTZ, 2009). The liquid permeate from the MBR of the brownwater is suitable to be

reused as irrigation water and it is planned to be infiltrated. The solid fraction will be composted externally and reused as soil amender (Winker, 2010_c). The liquid effluent from the composting process will be added to the MBR of the greywater. In addition, the liquid effluent from the MAP reactor will be added to the MBR of the greywater (GTZ, 2009) . The liquid effluent of this MBR will be used as service water within the system whereas the solid fraction will be added to the composting process and reused as soil amender (GTZ, 2009; Winker, 2010_b; Winker, 2010_c).

3.8.3 Technological components

3.8.3.1 Waterless urinals

According to Werner, et al. (2008) and Werner, et al. (2009), the Keramag waterless urinals, model Centaurus, are made from sanitary porcelain. Initially, they were equipped with a first version of a flat rubber tube which serves as odour seal and sieve made of high-grade steel but they were replaced for an optimised second version (GTZ, 2009). Nevertheless, in both cases the flat tube opens when urine flows in whereas the sieve traps pubic hair which could avoid the opening of the tube (Werner, et al. 2009).

3.8.3.2 Urine-diversion (UD) flush toilets

The Nomix UD flush toilets made by Roediger with also sanitary porcelain have two separate bowls: a conventional bowl for brownwater and paper located at the back, and a bowl for urine which is closed by a movable plug (Roediger, 2001). Each of the bowls is connected to two separated pipe connections (Werner, et al. 2009). Theoretically, the urine is collected undiluted without flush water by means of a valve located below the urinal bowl, which is opened when the user sits down (see figure 12) (Roediger, 2001; Werner et al., 2009; Münch & Winker, 2009).

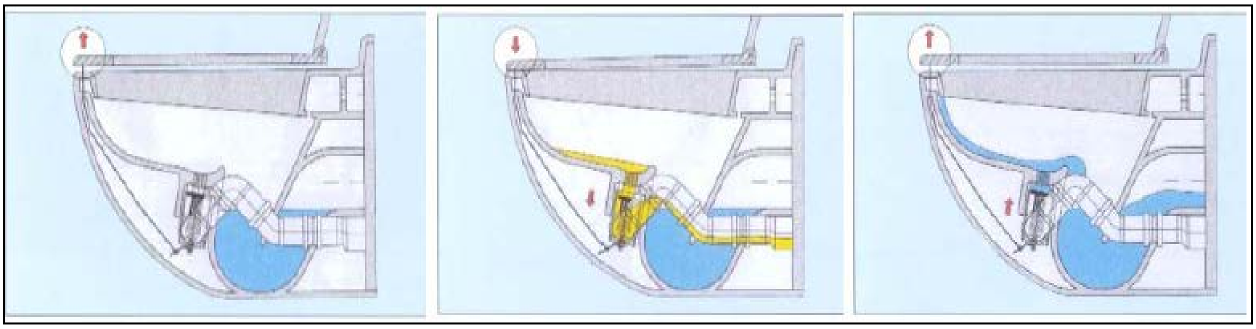

Figure 12: Functioning of the valve in the Nomix toilet: Outlet for urine drainage is closed by a movable plug (left). While the toilet is in use (person sitting), the plug is mechanically opened by a lever. Urine can flow to the front inlet (center). After the user gets up, the toilet can be flushed. The valve of the urine remains closed. Source: (Roediger, 2001)

The faeces are flushed away with water. In addition, there are two different types of flushing buttons depending on the amount of water to flush. The small button, which is meant to clean the urine bowl when the toilet is used to urinate, uses about 1-3L of water. The larger button uses 6 L of water to flush away the faeces (Werner, et al. 2009).

3.8.3.3 Pipe network

Three separated piping systems are implemented for separate urine, brownwater and greywater. The system is connected to the conventional sewerage system in case of malfunctioning, optimisation repairs or bypassing of the urine tanks (Werner, et al. 2009).

3.8.3.4 Urine storage tanks

The urine is stored in 4 polyethylene (PE) tanks of 2.5 m^3 which are located in the basement of the GTZ House 1. The pipe network allows filling each tank separately Werner, et al., 2008; Werner, et al., 2009).

3.8.3.5 Membrane Biological Reactors (MBRs)

Brownwater and greywater can be treated in an activated sludge process combined with a membrane stage, a membrane bioreactor (MBR) (Remy, 2010).

3.8.3.6 MAP reactor

The MAP precipitation reactor facilitates the recovery of phosphorus and part of the nitrogen in the form of solid struvite by means of the addition of magnesium oxide (MgO) (Huber, 2010). Struvite is a high quality slow-release fertiliser (Tettenborn, et al. 2007). The MAP reactor starts operating on May 2010 (Winker 2010_a). The process is at a very initial developing phase.

3.8.3.7 Costs

There are not estimations for the total costs of the implementation of the sanitation system. However, Lazo (2010) has calculated the costs for the phase 1, wich comprises the collection and conveyance system, and the storage tanks. The results are that the average project costs to implement the phase 1 of the sanitation system in the GTZ House 1 are 0,088 € per use (he also calculated the corresponding costs for a conventional sanitation system, 0,071 € per use).

Furthermore, the net present value of the total project costs are also calculated 651,800 €, taking into account that the durability of the technology components are approximately 30 years, the interest rate is 3% and the lifespan of the project are 50 years (Lazo, 2010). Lazo (2010) also calculates the net present value of the total initial investment for the phase 1 of the sanitation system, 222.900 €.

According to Lazo (2010), the most significant part of the initial investment is due to the conveyance system, that is, the pipe network which is equal to 62,5% out of the total investment. In addition, the new sanitation system shows higher operating costs than the conventional system

(13.200 € per year), which are mainly caused by the cleaning personnel and the wastewater fees. With regards to the Phase II of the SANIRESCH project, and due to the fact that the phase II is still in a very initial stage Winker (2010$_d$) states that the only costs available are the investment costs for the MAP reactor, 28.000 €. This figure includes some additional features that are prescindible. Without these extra features, the investment costs could decrease until less than 23.000€ (Winker, 2010$_d$).

3.8.3.8 Operation and maintenance

If operated adequately, the reduction of the water consumption for toilet and urinal flushing is estimated to be 1.200 m^3 per year compared to conventional flush toilets and urinals (Werner, et al. 2009).

- **Waterless urinals**

  The second version of the odour seal was installed because it is easier to clean and prevents more efficiently urine scale formation and internal pubic hair accumulation (Werner, et al. 2009). The waterless urinals are wiped down manually every evening. This is carried out for maintenance personnel of GTZ. In addition, the waterless urinals located in the ground floor are cleaned every hour between 9.00h and 13.00h and subsequently sprayed with a special odour removing cleaning agent for waterless urinals. The sieves and rubber tube seals need to be removed from the urinals at least every two weeks. Then, there is a need to remove the urine scale with a regular toilet cleaner (Werner, et al. 2009). The rubber tube seals have to be replaced about once per year when the sealing mechanism stop working properly. According to Winker (2010$_a$), it is estimated that the waterless urinals are used approximately 160 times a day. In addition, the estimation for the water savings due to the waterless urinals is 640 L per working day.
- **UD flush toilets**

  One of the main drawbacks of the Nomix UD flush toilets is that it is required that the user sits during the use (Lienert & Larsen, 2009; Roediger, 2001). Werner et al. (2009) states that the cleaning routine is the same as for conventional toilets but also that the urine valve requires being soaked overnight with urine scale removing chemicals every month (Blume & Winker, 2010; Werner, et al., 2009). This step is crucial to prevent struvite precipitations which cause clogging of the urine valve and discharge of the urine through the brownwater pipe. The maintenance work is more time consuming than the needed for the conventional. In order to increase the maintenance of the UD flush toilets, it has also been introduced an extra cleaning routine which consists of the addition of a cleaning agent to the toilet 1 time per month from Monday to Friday. The cleaning agent is the same that is used to clean the urine valve (Winker, 2010$_a$).

- **MAP reactor**

  The process is still on an initial developing phase. Currently, the process is being optimised. In this way, different types of filter bags, different doses of MgO and other operational aspects are being tested ($SANIRESCH_a$, 2010). In the beginning of the operation, there was an odour problem (Winker, 2010_c) caused by the MAP reactor, which has been solved by ventilating the reactor's headspace to the roof of the building (through existing vent pipes) ($SANIRESCH_a$, 2010). The yield of the process is currently 5 g of struvite for 1 L of urine. The energy requirements of the process are calculated by Tettenborn, et al. (2007), 30 MJ per m^3.

3.8.3.9 Practical experience and lessons learnt

According to Blume and Winker (2010) and Werner, et al. (2009), the results of GTZ internal survey about the acceptance of the collection system shows that only 5% of the users say the cleanliness of the toilet is higher compared to conventional toilets and 51% say it is worse. Furthermore, 61% of the users flush the toilet more than once after usage, which could be motivated because a large number of users complained about the higher demand for toilet cleaning after defecation and the insufficient strength of the flushing for the faeces if a lot of toilet paper is used. In addition, the reticence to sit on the toilet could be partially overcome by introducing disinfection devices (Blume & Winker, 2010).

According to Blume and Winker (2010) and Werner, et al. (2009), there is a need to further develop the UD flush design because it is not enough to flush away the toilet paper thrown in the urinal bowl. Thus, there is a need to flush at least twice, which neglects the water reduction effect. The amount of flush for the faeces is not enough and often it must be flushed more than once (Blume & Winker, 2010; Werner, et al., 2009).

Another important fact is that the concentration of nitrogen measured in the stored urine (2.8 g/L) is between 2 and 3 times lower than the literature values (Blume, et al., 2010; Winker, 2010a). Blume and Winker (2010) and Werner, et al. (2009) state that the low nitrogen values are caused by loss of ammonia gases through the ventilation system but that it is also possible that the urine is diluted with flush water in the collection tank of the UD flush toilet. Rossi, et al (2009) has calculated the efficiency in the urine recovery of a Nomix toilete in Swizterland, which ranges between 70-75%, giving room to a further improvement of the collection system. The maintenance is essential for the adequate functioning and durability of the collection system as well as to prevent odours. The maintenance personnel must be specifically instructed to carry out the cleaning routines that the collection system requires (Werner, et al., 2009). The waterless urinals are much lower water intensive than the conventional.

Part III: Performance of the system in Germany

4. Performance of the sanitation system in Germany

In this section a MCDA is operated in order to analyse the performance of the sanitation system implemented within the SANIRESCH project in Germany.

Table 15: Summary of the main technological components of the sanitation systems assessed in the MCDA

	SANIRESCH (Eschborn)	**SolarCity (Linz)**	**Lübeck-Flitenbreite (Lübeck)**	**Looloop (pilot, TUHH)**	**Conventional (Hamburg)**
Part A: Collection	UD flush toilets + Waterless urinals + greywater	UD flush toilets (brownwater and urine) + Waterless Urinals (urine) + separated pipes (greywater) + stormwater	Vacuum toilets (urine and faeces) + Rainwater harvesting + Greywater + Biowaste	Flush toilet + Waterless urinal	Flush toilet + any kind of alternative collection system connected to the sewerage system + sewerage system (stormwater + industrial waste)
Part B: Conveyance	Separated pipes (urine + brownwater + greywater)	Separate pipes for urine and brownwater + greywater + stormwater	Vacuum sewerage (urine and faeces) + separated pipes (greywater) + manually (biowaste)	Conventional pipes	Conventional pipes that discharge to the river
Part C: Treatment	Storage + MAP precipitation (urine) + 1st MBR (brownwater) + 2nd MBR (greywater)	Urine storage + Aerobic composting after filtration of the brownwater + greywater (filter bags). Liquid effluent to constructed wetland	Thermal hygienisation + Anaerobic digestion (AD) (**non-operative**) (blackwater and biowaste) + Rainwater harvesting infiltrated (decentralised swales) + Constructed wetlands (Greywater)	Solid separation (excreta) + vermi-composting and/or AD + Fixed bed reactor + MBR + Ultrafiltration + Ozonation	Conventional treatment: Mechanical filtration + primary sedimentation tanks + Aeration tanks + Secondary sedimentation tanks + Phosphates precipitation (iron salts)
Part D: Transport	Struvite + Liquid fertiliser to the reuse zone	Liquid fertiliser + compost + biomass (**non-operative**)	Liquid organic fertiliser to the reuse zone (**non-operative**)	Compost to the reuse zone	Conventional pipes
Part E: Reuse	Liquid fertiliser + Solid fertiliser (struvite) + Soil amender + reclaimed water as service water (flush water) + liquid MBR brownwater	Liquid fertiliser (**non-operative**) + Compost (**non-operative**) + infiltration of the liquid effluent constructed wetland + biomass constructed wetland	Organic fertiliser from the liquid effluent of anaerobic digestion (non-operative) + biogas + recharge of local water resources	Soil amender and or Biogas + Liq./solid Fertiliser + reclaimed water as service water from the liquid effluent as flush water	AD of the sludge + electricity + incineration digested sludge + coarse material (pre-treatment) → ashes as building material + filling sand (construction)

4.1 Results per indicators

In this section the MCDA is operated without considering trade-offs between the technology wise indicators as suggested by Agudelo (2007) and Agudelo, et al. (2007).

4.1.1 Financial indicators

Table 16: Summary of the scores for the financial indicators converted to a scale of 10 (the highest score is marked in **bold** and the lowest with *-the key financial indicators with regards to the adaptability are highlighted in red-)

Financial	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Investment Costs	4.0	3.3*	**5.3**	4.0	**5.3**
Treatment Costs	6.0	**8.0**	**8.0**	2.0*	6.0
Maintenance Costs	**6.0**	4.0*	5.3	4.0*	**6.0**
Replacement Costs	5.3	6.0	6.0	4.7*	**6.7**
Reuse Costs	**8.0**	6.0*	6.0*	**8.0**	**8.0**
Transport costs	6.0*	6.0*	8.0	**10.0**	**10.0**
Direct Benefits	**8.0**	**8.0**	**8.0**	**8.0**	2.0*

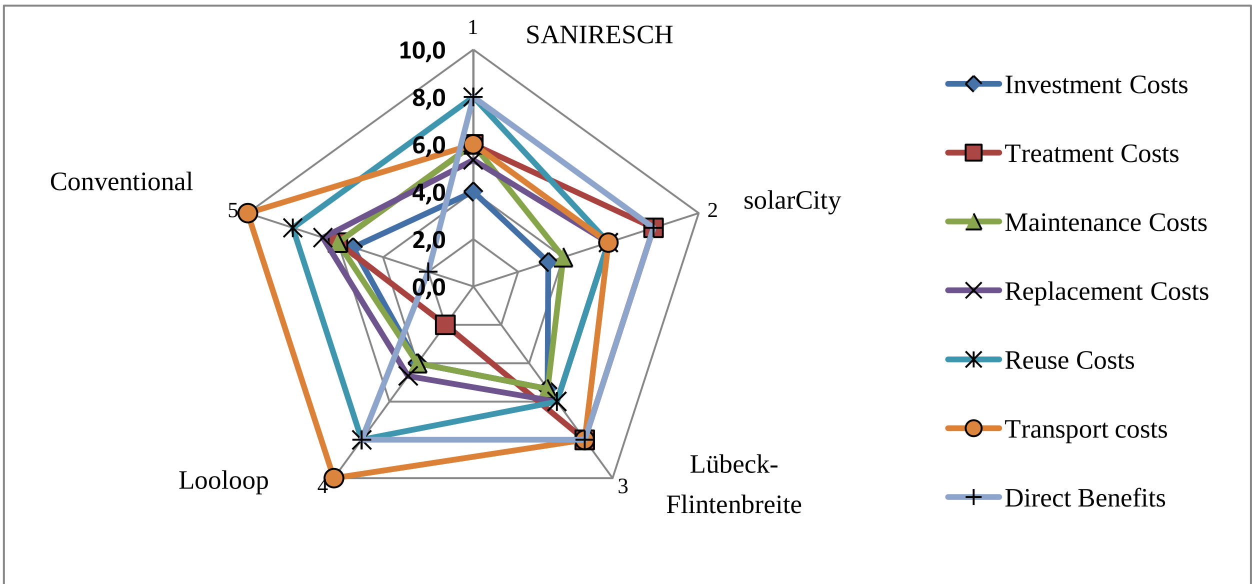

Figure 13: Radial plot displaying the scores of the financial indicators for all the sanitation system assessed in this study

The potential benefits of the system of the sanitation system implemented within the SANIRESCH project are high due to the fact that the system is designed to recover nutrients and organic matter. Hence, there is a production of a final product which has the potential to be sold. Therefore, compared with the conventional system in Hamburg, this sanitation system has higher benefits due to the final product. The reuse costs are considered to be low. This value is equal than the conventional system. However, the reuse costs of the system should be higher than the conventional system because there is a larger amount of final product reused. Hence, the costs derived to reuse the product in the agricultural field should be significantly higher.

As it is shown in the table 16 and figure 13, the overall costs of the sanitation system are high, especially the investment, replacement and maintenance costs. In the case of the maintenance costs, even though the representative of the system evaluated these costs as equal than the conventional system, recent data and discussion with the SANIRESCH project team shows that the costs are higher than the conventional system (Lazo, 2010). The costs of the system are mainly due to the collection, conveyance and treatment costs of the components are considered high due to the state-of-the-art of the system (i.e. the technological components are innovative and they are produced at small scale). The costs are also high due to the high quality of these technological components and the (theoretically) high standards of quality that they provide.

The other innovative systems assessed show relatively high investment costs, being the solarCity the alternative with highest investments costs and the conventional wastewater system in Hamburg and the Lübeck-Flintenbreite the lowest. The treatment costs are clearly dominated by the Looloop system, which show the highest treatment costs. The systems with the lowest values are the solarCity and the Lübeck-Flintenbreite systems, which can be explained because the treatment methods are relatively simple: solarCity carries out compost and storage of urine and Lübeck-Flintenbreite system carries out compost and treat together the blackwater. The maintenance and replacement costs are relatively high in all the systems. The Looloop system shows the highest maintenance and replacement costs. Oppositely, the reuse and the transport costs are relatively low in all the alternatives. The Looloop and the conventional wastewater system show the lowest transport and reuse costs. The Direct Benefits are relatively high in all the alternatives with the exception of the conventional wastewater system, which are significantly lower than the other alternatives.

4.1.2 Health and Hygiene indicators

Table 17: Summary of the scores for the health and hygiene indicators converted to a scale of 10 (the highest score is marked in **bold** and the lowest with *-the key indicators with regards to the adaptability are highlighted in red-)

Health and Hygiene	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Safe Collection	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**
Safe Disposal	**6.0**	**6.0**	**6.0**	**6.0**	4.0*
Exposure to Pathogens	7.3	6.7	6.0*	**10.0**	8.7
Exposure to Hazardous Substances	8.0	8.0	6.0*	**10.0**	7.0
Risk of the Technology (conveyance + collection + reuse)	4.7*	6.7	6.7	**8.7**	6.7

The exposure to both the pathogens and hazardous substances are low (7.3 and 8.0 respectively) for the sanitation system implemented within the SANIRESCH project whereas both the safe collection and disposal show a moderate performance. This is due to the fact that the system is strong with regards to the aspects related to the health and hygiene. Actually, the system was designed in order to have high standards of quality due to the fact that one of the goals of the project is serving as a demonstration of an ecological sanitation implementation in an urban area of a developed country. However, the fact that the system recycles the nutrients and produces a final product creates that the potential risks of the technology are high (4.7). Hence, the main risk focuses in the pollution of the soil. Actually, Benetto (2009) states ecological sanitation systems transfer the pollution to the water (conventional systems) to the soil.

The Looloop system shows the highest scores in all the indicators including the potential risk of the final product because the fraction reused as a soil amender is a small fraction compared to the other systems. The other innovative sanitation systems show also good performance with the exception of the potential risk of the final product due to the same reasons that the sanitation system within the SANIRESCH project. The conventional wastewater system shows relatively high scores in all the indicators, with the exception of the safe disposal, which shows a low performance (4.0). This is due to the fact that the conventional system is an efficient and robust system from a health and hygiene viewpoint. However, the performance of the disposal is low because there is large fraction of hazardous substances and micropollutants that end up in the water.

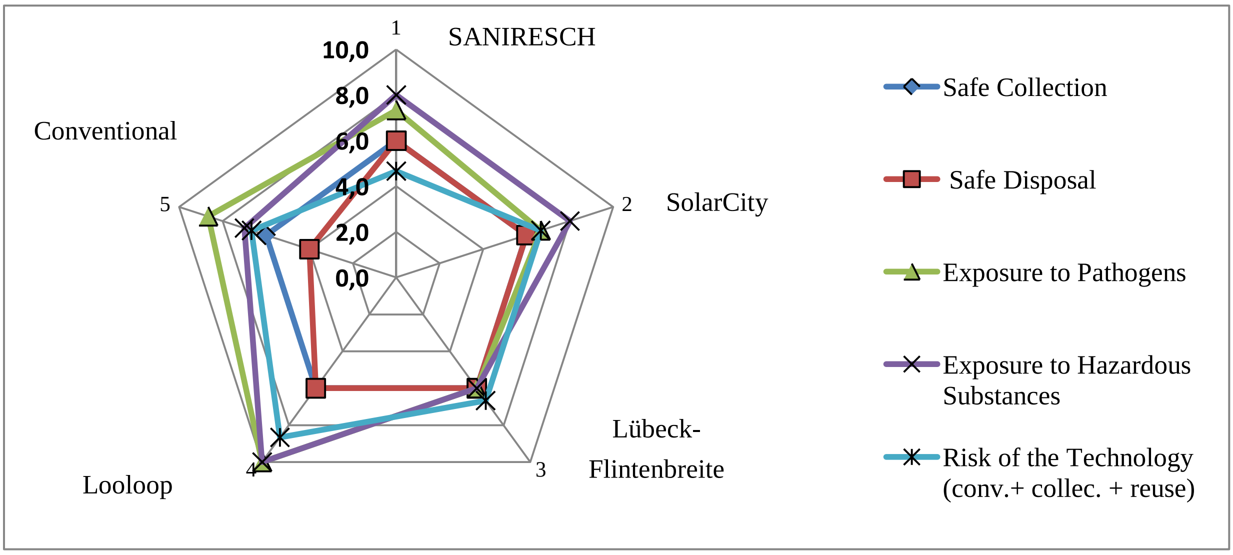

Figure 14: Radial plot displaying the scores of the health and hygiene indicators for all the sanitation systems assessed in this study

4.1.3 Technical indicators

Table 18: Summary of the scores for the technical indicators converted to a scale of 10 (the highest score is marked in **bold** and the lowest with * -the key indicators with regards to the adaptability of the system are highlighted in red-)

Technical	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
System Adaptability (to different types of users)	8.0	2.0*	6.0	6.0	**10.0**
Technical Versatility	**8.0**	4.0*	**8.0**	6.0	4.0*
Scale of the System	**8.0**	**8.0**	4.0*	**8.0**	**8.0**
Complexity	4.4*	5.2	5.6	4.8	**6.0**
Treatment Efficiency	6.0*	6.0*	6.0*	**10.0**	6.0*
Treatment Capacity	**6.0**	**6.0**	**6.0**	4.0*	**6.0**
Durability	6.0*	6.0*	6.0*	6.0	**6.7**
O&M Requirements	5.3	3.3*	4.7	5.3	**6.0**
Robustness	4.0*	5.0	4.0*	5.0	**8.0**
Nuisance	5.6*	6.0	6.4	**8.0**	6.8
Quality final product (efficiency reuse)	8.0	6.0	6.0	**10.0**	4.0

With regards to the sanitation system implemented within the SANIRESCH project it is observed that the quality of the final product, the adaptability of the system, the versatility and the scale of the system show high performance, especially the latter two which are the highest amongst the other alternatives assessed. However, the social adaptability should have a lower result because the UD flush toilets require the men to sit when urinating. The indicators with regards to the complexity of the system, the efficiency, the durability of its technological components, the robustness of the system and the nuisance are the lowest amongst the other alternatives. The high complexity presented is explained by the high standards of quality of the system and the final product produced aimed in the design of the system. It can also be explained for the inherent increase of the complexity that implementing a system which diverts urine and recycle the nutrients, organic matter and wastewater in service water imply. The low values in the other indicators are explained because the state-of-the-art of this system is still in a very initial stage which causes that the system is still in a constant optimising stage. The other indicators show moderate scores implying that the performance is similar than the conventional system.

With regards to the combined results with the rest of the systems assessed in this study, the conventional wastewater system shows the highest performance in these dimensions, with the exception of the technical versatility of the system, which is the lowest amongst the other alternatives. This is due precisely to the inverse process that occurs for the sanitation system within the SANIRESCH project. The conventional system has been developing during the last

150 years and it is a system technically robust. Due to this fact, the other innovative sanitation system show lower results than the conventional system, especially the solarCity system, the Lübeck-Flintenbreite and the system implemented within the SANIRESCH project. However, the Looloop system shows a relative better performance than these other innovative systems with the exception of the treatment capacity, which shows the lowest score, due to the fact that the system is a pilot plant with a minimum treatment capacity.

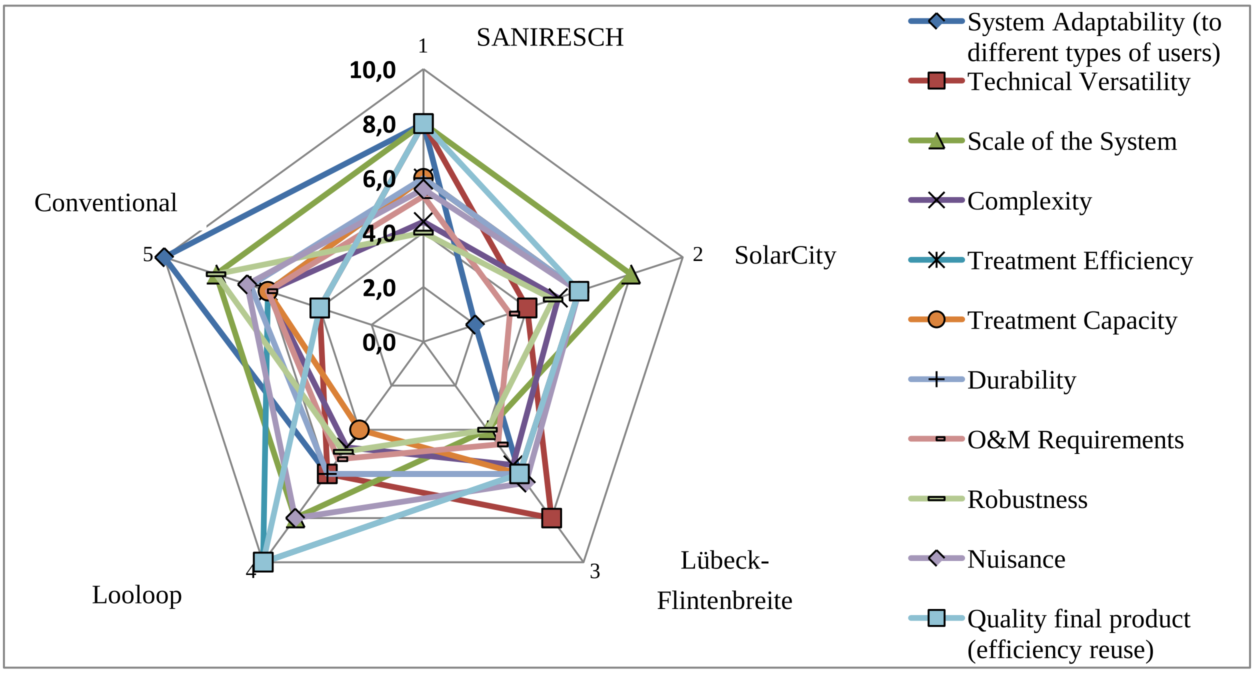

Figure 15: Radial plot displaying the technical indicators for all the sanitation systems assessed

4.1.4 Socio-cultural indicators

Table 19: Summary of the scores for the socio-cultural indicators converted to a scale of 10 (the highest score is marked in **bold** and the lowest with * -the key indicators with regards to the adaptability of the system are highlighted in red-)

Socio-cultural	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Acceptability	6.0	4.0*	5.3	6.7	**8.0**
Appropriateness	5.0*	5.0*	6.0	**8.0**	**8.0**
Aesthetics (Collection)	6.0*	6.0*	**8.0**	6.0*	6.0*
Comfortability	6.0	3.0*	6.5	6.0	**7.0**
Reliability	5.3	**6.0**	5.3	4.7*	5.3

With regards to the sanitation system implemented within the SANIRESCH project, it is observed that the overall performance within this dimension is low, especially for the appropriateness, the reliability and the aesthetics of the collection system. However, it is important to stress the fact that the other innovative systems show similar results with regards to this dimension. This can be justified because these alternative systems are innovative systems which are not known for the society, require a change in the use of the collection component and are in a relatively initial stage of its development. This is completely opposite to the conventional system: The conventional system shows the highest performance in all the socio-cultural indicators.

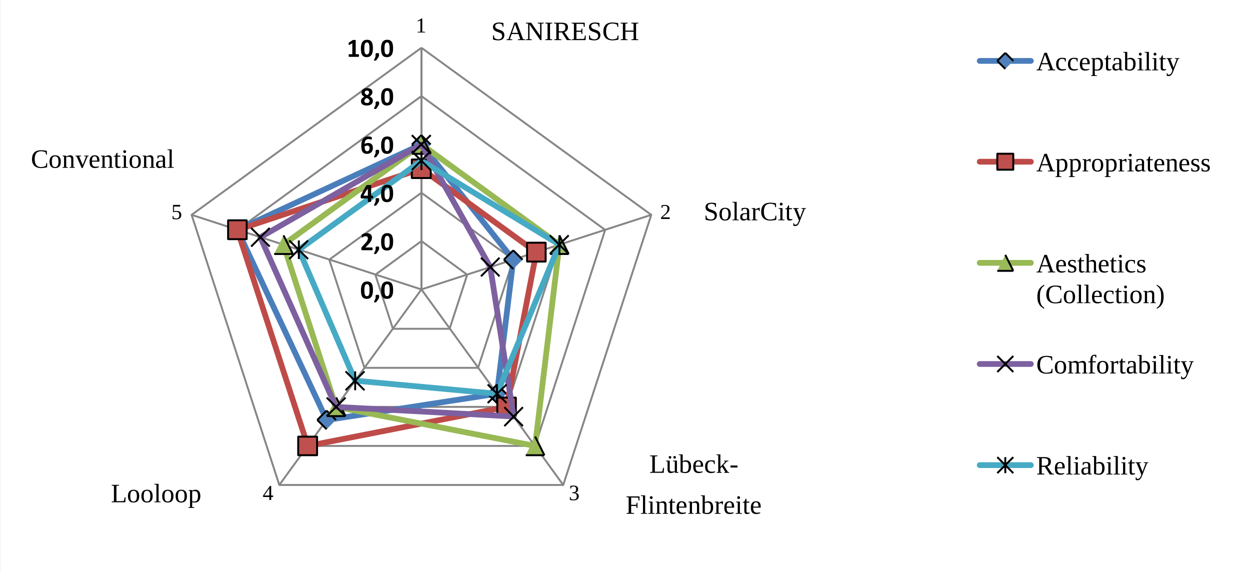

Figure 16: Radial plot displaying the scores of the socio-cultural indicators for the sanitation systems assessed

4.1.5 Ecological indicators

Table 20: Summary of the scores for the ecological indicators converted to a scale of 10 (the highest score is marked in **bold** and the lowest with * -the key indicators with regards to the adaptability are marked with red-)

Ecological	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Potential Greenhouses Gases (GHG) Emissions	5.3*	**6.7**	**6.7**	6.0	**6.7**
Potential Water Pollution	**8.8**	7.2	6.8	**8.8**	4.0*
Potential Eutrophication	**10.0**	6.0	8.0	**10.0**	4.0*
Potential Soil Pollution	4.0*	4.0*	4.0*	4.0*	**10.0**
Final product (Hazardous Substances)	6.0*	6.0*	6.0*	6.0*	**10.0**
Final product (Micropollutants)	4.0*	4.0*	4.0*	4.0*	**10.0**
Organic Matter (Reuse)	**10.0**	8.0	8.0	**10.0**	2.0*

With regards to the sanitation system implemented within the SANIRESCH project, the performance in the indicators related to water pollution and reuse of organic matter is high. This is due to the fact that the system is designed in order to prevent the water pollution caused by the introduction of nutrients and organic matter as well as other hazardous substances in the water as it happens with most of the conventional systems. Oppositely, the indicators assessing the impact of the final product show low scores, which is precisely motivated by the introduction of the reuse in the design of the system and the production of a final product (which in part contains the components which in the conventional are dumped to the water or eliminated). Furthermore, it is necessary to highlight that the contribution to climate change of this technology is moderate but shows the highest score amongst the other systems evaluated, mainly caused by the necessity to transport the final product to the reuse zone. It is also necessary to stress that the indicators related to acidification of water, which is currently a discussion issue within the assessment of the impacts of the ecological sanitation was not included because during the assessment all the experts gave results contradicting recent scientific literature (Benetto, 2009) stating that ecological sanitation shift the impact of eutrophication to acidification.

The other innovative sanitation systems evaluated show similar results than the system implemented within the SANIRESCH project. Oppositely, the conventional wastewater systems show bad performance in the indicators related to the water pollution but high scores in the indicators related to the pollution of the soil and the concentration of pollutants and hazardous substances in the final product. If there is not reuse, there is not the impact due to the reuse. However, the pollution is directed to the water bodies, which are the recipient of the reclaimed water of the conventional system.

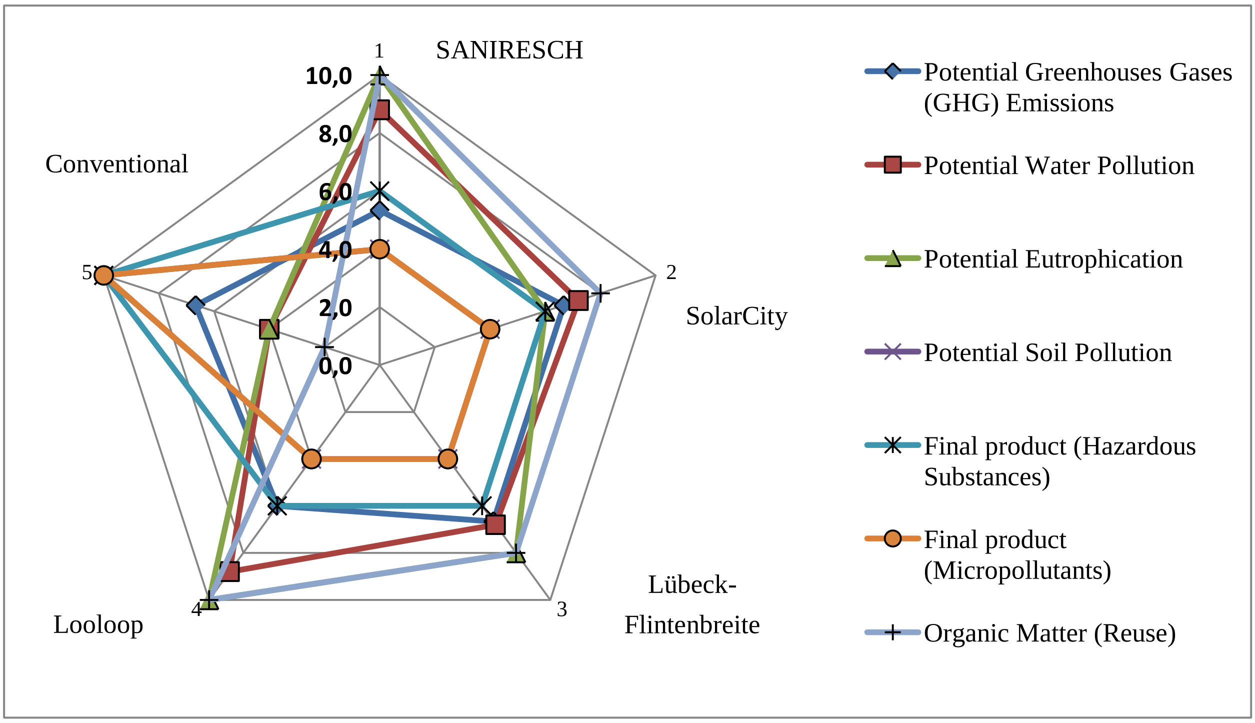

Figure 17: Radial plot displaying the scores of the ecological indicators of the sanitation systems assessed

4.1.6 Materials and Natural Resources indicators

Table 21: Summary of the scores for materials and natural resources converted to a scale of 10 (the highest score is marked in **bold** and the lowest with *-the key indicators with regards to the adaptability are marked in red-)

Materials and Natural Resources	Saniresch	Linz	Lübeck	Looloop	Conventional
Use of Chemicals	7.0	7.0	**8.0**	6.0	5.0*
Water Consumption	8.0	6.0	7.3	**9.3**	3.3*
Collection of Renewable Water Sources	**8.0**	**8.0**	**8.0**	2.0*	4.0
Reuse of Treated Wastewater (reclaimed water)	**10.0**	6.0	6.0	**10.0**	2.0*
Recovery of Nutrients	9.0	**10.0**	**10.0**	**10.0**	2.0*
Raw Materials Use	**6.0**	**6.0**	**6.0**	**6.0**	5.3*
Fossil Fuels Demand (transport)	4.0*	4.0*	4.0*	6.0	**8.0**
Recovery of Organic Matter	8.0	8.0	**10.0**	**10.0**	2.0*

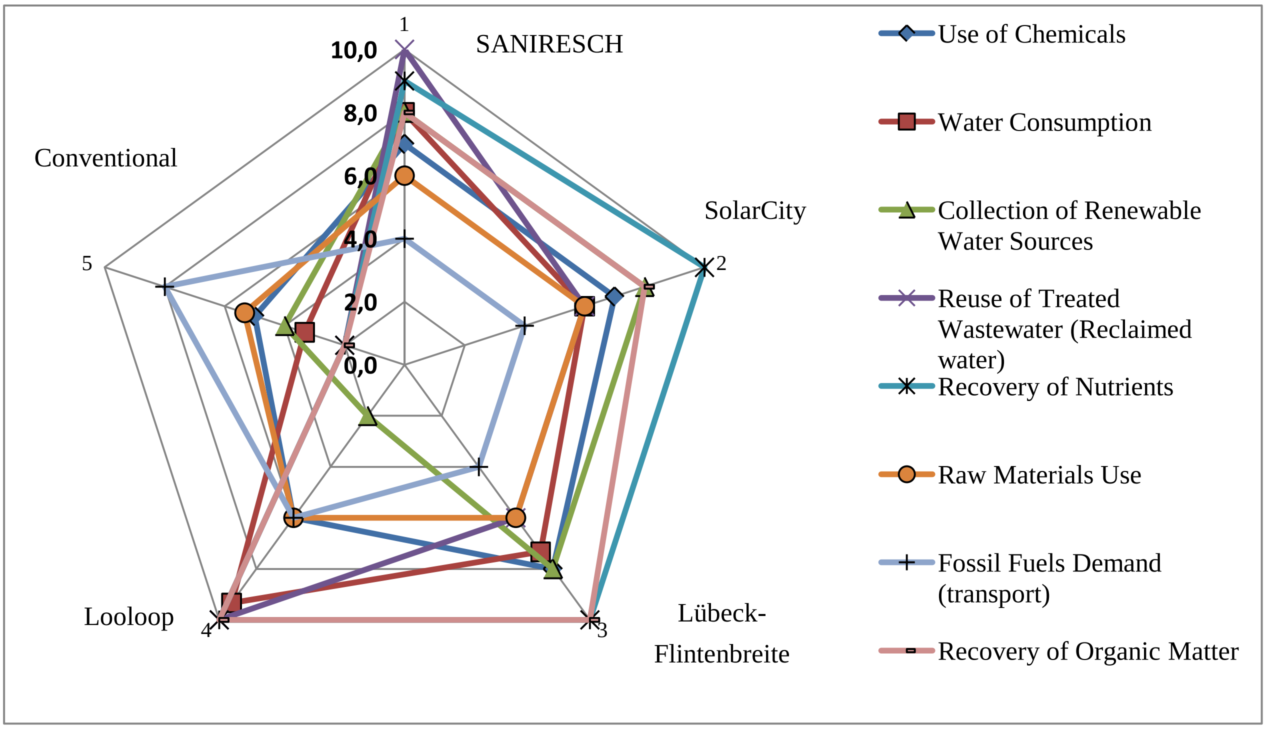

Figure 18: Radial plot displaying the scores of the materials and natural resources indicators for the sanitation systems assessed

With regards to the sanitation system implemented within the SANIRESCH project, the results show a relative good performance in all the indicators evaluated. The scores are very high for the collection of renewable water resources (the system uses the groundwater that has to be pumped up in order to lower the high groundwater level for the underground) (Werner, et al. 2009). Also the use of reclaimed water is very high due to the system reuses the treated wastewater as service water and the consumption of raw materials is lower than the conventional system. The water consumption is considered as low by the representative of the system but this only affects the waterless urinals. Borsuk, et al (2008) and Larsen and Lienert (2007) suggest that the type of UD flush toilets used in the system cannot be considered a water conservative technology. As discussed previously, the indicators related to the recycling of nutrients and organic matter are very high. However, the indicators assessing the consumption of fossil fuels focusing on the transport system show a significant low score (4.0) due to the necessity to transport the final product to the reuse zone. This performance is similar for the solarCity and Lübeck-Flintenbreite systems.

With regards to the other sanitation systems, it is clear that the innovative sanitation systems show a significant higher performance than the conventional wastewater system due to the same reasons discussed for the sanitation system within the SANIRESCH project. This is systematically true in each indicator analysed in the materials and naturals resources dimension with the exception of the fossil fuel consumption for the transport component due to the fact that there is not final product to transport in the conventional system

4.1.7 Energy indicators

Table 22: Summary of the scores for the energy indicators converted to a scale of 10 (the highest score is marked in **bold** and the lowest with *-the key adaptability indicators are marked in red-)

Energy	Saniresch	Linz	Lübeck	Looloop	Conventional
Energy Required	5.7*	5.7*	**6.3**	6.0	6.7
Energy Reused	4.0*	5.0	5.0	**10.0**	6.0
Energy Efficiency	4.0*	6.0	**8.0**	**8.0**	6.0
Energy Generation	4.0	2.0*	8.0	4.0	4.0

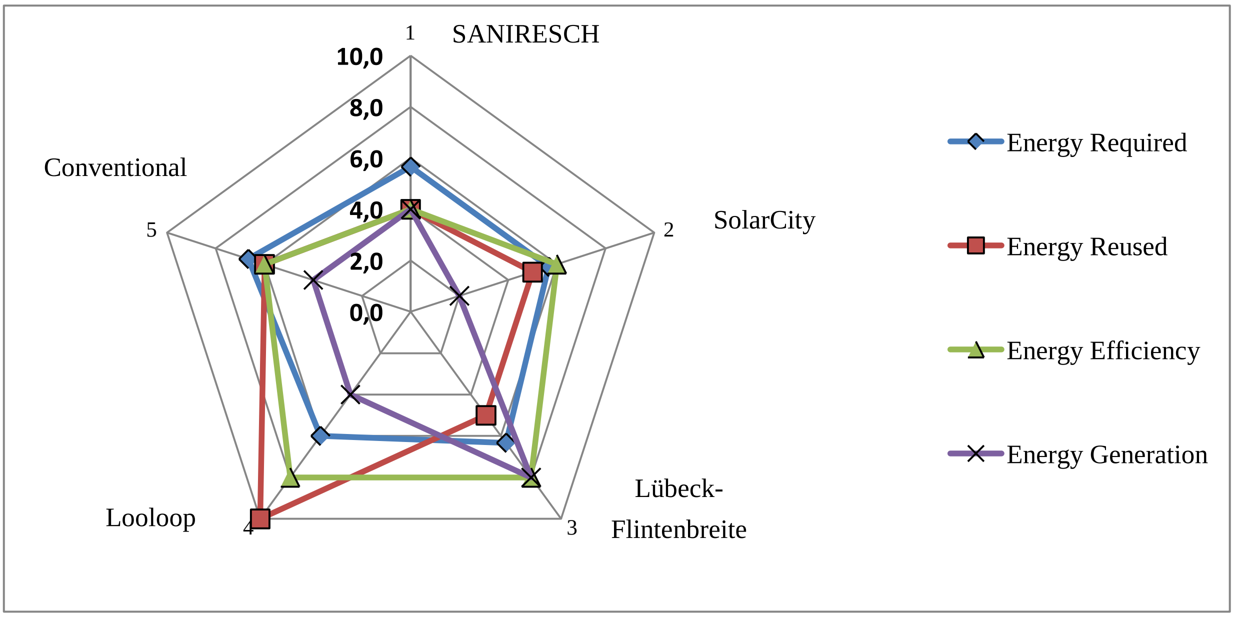

Figure 19: Radial plot displaying the scores of the energy indicators for the sanitation systems assessed

With regards to the sanitation system implemented within the SANIRESCH project, the results shown in the energy dimension are very low, which implies that this system is an energy intensive system. This is due to the fact that the treatment system which facilitates the recovery of nutrients and organic matter as well as the recycling of the wastewater is supported by a high consumption of energy, mainly electricity. The energy required to operate the system and the efficiency in which this energy is consumed show relative low scores when compared with the other alternatives and the conventional wastewater system. A plausible reason for the fact that the Lübeck-Flintenbreite and the conventional system show higher results is that both contemplate the generation of biogas from the brownwater and blackwater respectively (in the case of the Lübeck-Flintenbreite system the blackwater reactor is only operative at a pilot scale). In the case of the solarCity and also again the Lübeck-Flintenbreite systems is that the treatment is simpler. Hence, there is a lower consumption of energy. The Looloop system shows the highest results because also generates energy and shows a high efficiency in the consumption of energy. However, in this case, the fact that it is pilot plant can determine that the values obtained are better than the other alternatives. Hence, it is more logical to consider the results similar than the conventional and the Lübeck-Flintenbreite systems.

4.1.8 Institutional indicators

Table 23: Summary of the institutional scores converted to a scale of 10 (the highest score is marked in **bold** and the lowest with * -the key indicators with regards to the adaptability are highlighted in red-)

Institutional	Saniresch	Linz	Lübeck	Looloop	Conventional
Training Requirements	5,3	3,3*	4,7	5,3	**7,0**
Institutional Acceptance	4,0*	4,0	4,7	4,7	**8,7**
Operational Compliance	4,7*	**6,0**	4,7*	**6,0**	**6,0**

With regards to the sanitation system implemented within the SANIRESCH project it is observed that the performance in this dimension is low. The three indicators show low scores, especially the operational compliance and the institutional acceptance. This situation is similar in the other innovative sanitation systems. However, the Looloop system and the solarCity show a better operational compliance. The conventional wastewater system show the highest performance in this dimension in all the three indicators assessed.

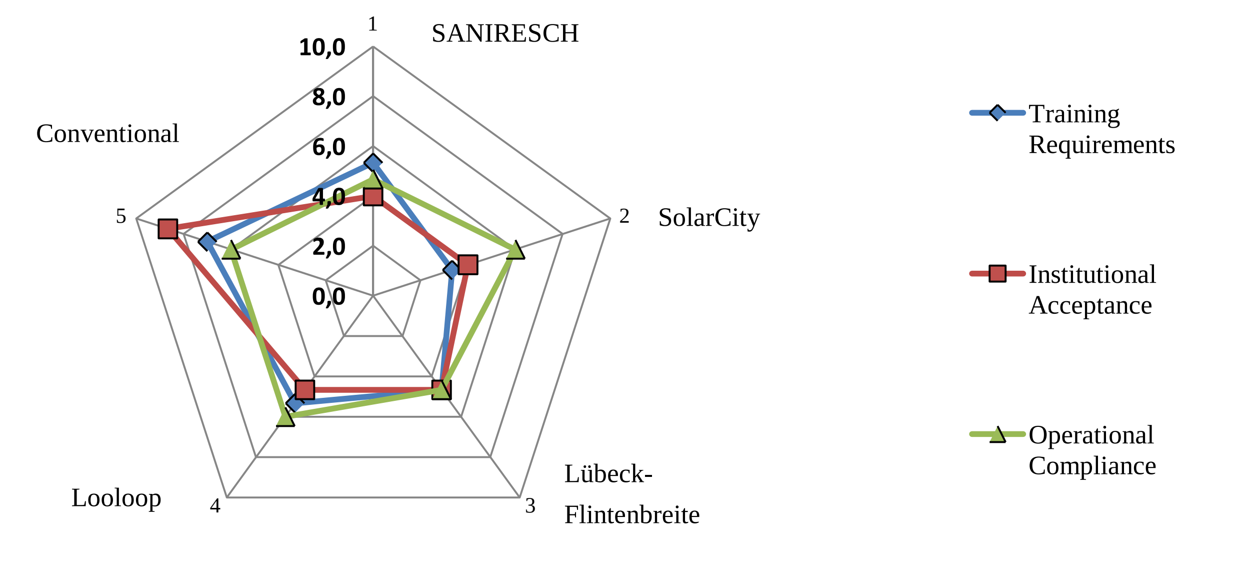

Figure 20: Radial plot displaying the scores of the institutional indicators assessed in this study

4.1.9 Key indicators with regards to the adaptability

The indicators highlighted in red from the tables 16 to 23 will be considered as key indicators due to their performance and score. Two main types of key technology wise indicators are distinguished: indicators with good performance, which are considered as strengths of the system, and indicators with low scores, which are considered as weaknesses. The cut-off applied to identify such indicators is:

- Strengths of the system: The indicators with the highest score amongst all the systems assessed and the indicators with more than 7.0.
- Weaknesses of the system: The indicators with the lowest score amongst all the systems assessed and the indicators with less than 4.0.

The technology wise indicators are also analysed taking into account the evaluation of the importance of the technology wise indicators from the representative of the sanitation system implemented within the SANIRESCH project. Such preferences were asked in a specific section of the questionnaire specifically for the system implemented within the SANIRESCH project. The indicators were also analysed taking into account technology transfer issues and intrinsic characteristic of urban areas of fast-growing economies. In some cases, some indicators which did not pass the cut-off were added because this study considers that they play a key role. The final list of indicators is given below.

- **Financial indicators**

  With regards to the results obtained after operating the MCDA, strengths of the system are: the direct benefits of the system in terms of the reuse of the final product. Main

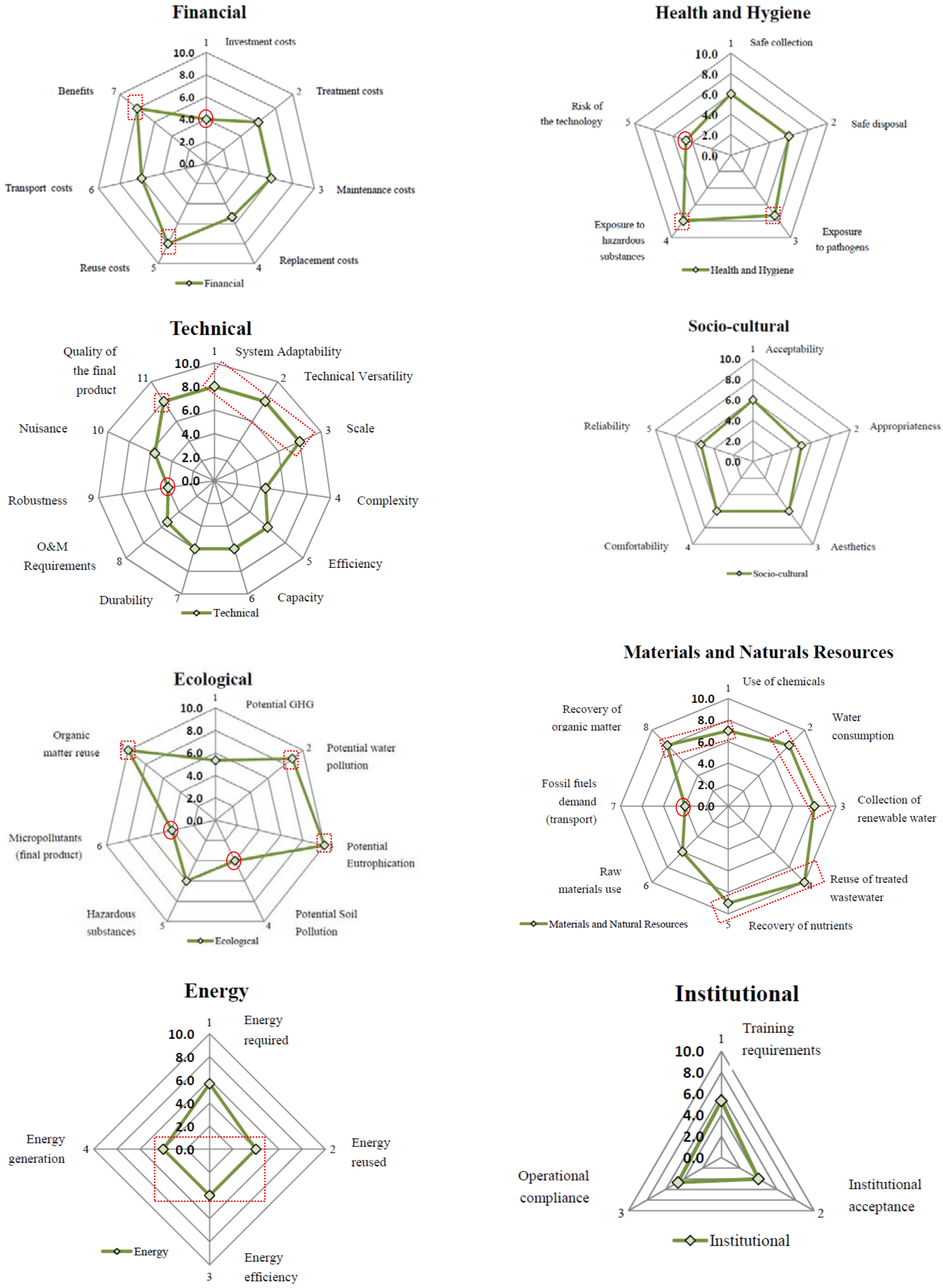

Figure 21: Radial plot displaying the key technology wise indicators with regards to the sanitation system implemented within the SANIRESCH project

weaknesses are: the investment costs, the maintenance costs and the transport costs. In the case of the maintenance costs, even though the results of the MCDA suggest that they are moderate, new data obtained after the analysis indicate that they are high (Lazo, 2010; Winker, 2010_d). The replacement, treatment and reuse costs should also be taken into account in this category.

- **Health and Hygiene indicators**
  Under this dimension, all the indicators are considered to have a crucial role. The main drawback of the technology would be the potential risk of the final product mainly with regards to the reuse. The other indicators are considered as strengths.

- **Technical indicators**
  The adaptability of the system to different users is considered as strength. However, it is necessary to highlight that this system is not convenient for children (Oldenburg, et al. 2009). This is the reason why the score of the solarCity is very low. In this system they faced serious problems with the UD flush toilets because one of the buildings was a school. The treatment capacity also shows a good performance in the MCDA. Finally, the quality of the final product shows a good performance. Main drawbacks of the system with regards to the technical dimension are: the complexity of the system, the efficiency and the robustness of the system (in part because it is a pilot project), the O&M requirements, and the nuisance, which is lower than the conventional system.

- **Socio-cultural indicators**
  The drawbacks of the system with regards to this dimension are: the acceptability of the system, mainly the collection and the reuse component, the appropriateness to the cultural conditions and the aesthetics of the collection component. The comfortability of the system should also be taken into account. There are not strengths with regards to this dimension.

- **Ecological indicators**
  The strengths of the system are: the prevention of both the water pollution and potential eutrophication. The organic matter content in the final product is also considered as an important strength of the system. Main drawbacks are related to the final product: Potential soil pollution and both the hazardous substances and the micropollutants in the final product. The GHG emissions have also to be taken into account, which are mainly related to the transport of the final product to the reuse zone.

- **Materials and Natural Resources indicators**
  The water consumption is regarded as strength of the system, which is reduced mainly due to the waterless urinals. Theoretically, the UD flush toilets should also be water conservative. However, the current state-of-the-art of the technology is that they are not (Borsuk, et al. 2008). Hence, these indicators could also be taken into account like weaknesses of the system, because it requires a minimum water supply at a regular basis to operate the system. Another drawback of the system is the consumption of fossil fuels mainly due to the need to transport the final product until the reuse zone. Strengths of the system are the reuse of treated wastewater, the recovery of nutrients and the recovery of organic matter.

- **Energy indicators**
  The main drawbacks of the system are the energy required to operate the system. Furthermore, the energy efficiency of the system shows a low score. There is no reuse of energy or energy generation, which is also considered as a potential drawback of the system.

- **Institutional indicators**
  The drawbacks of the system are the training requirements, the potential operational compliance of the system as well as the institutional acceptance.

4.2 Components of the sanitation system

If the MCDA is operated taking into account the different components of a sanitation system as Münch and Mels (2007) propose, it is possible to analyse the performance of the components of the sanitation systems.

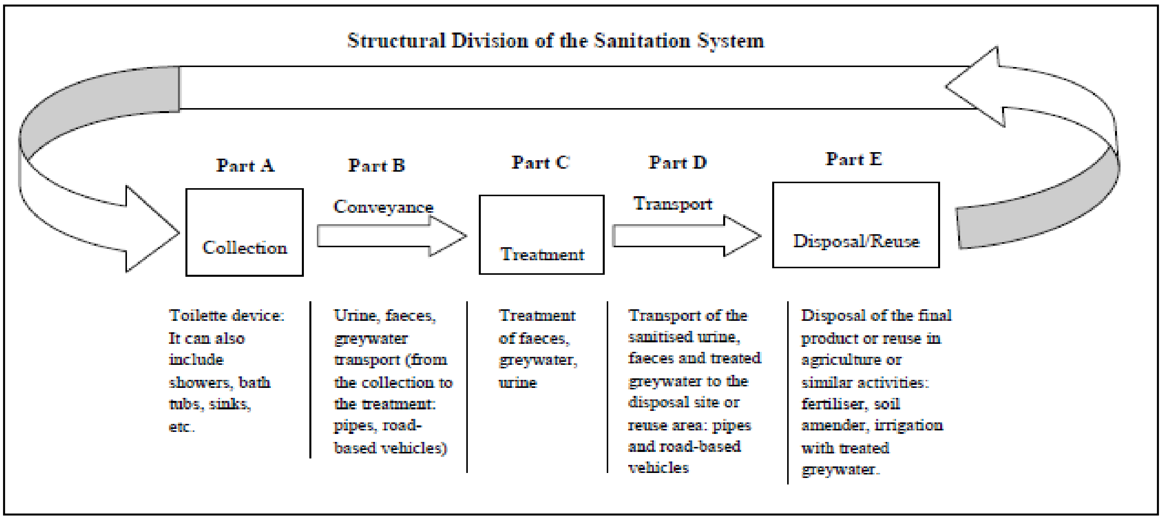

Figure 22: Components of a sanitation system. Source: adapted from Münch & Mels (2007)

Table 24: Summary of the scores for each sanitation system with regards to the different components of the sanitation systems (the highest score is marked in **bold** and the lowest with *)

	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional	Maximum score
Score Part A: Collection	495.0	396.7*	524.0	501.9	**622.1**	888.2
Score Part B: Conveyance	311.4	258.6	293.1	**426.7**	254.4*	526.8
Score Part C: Treatment	607.7	638.9	628.7	**639.1**	603.5*	1103.3
Score Part D: Transport	163.9*	182.7	233.6	253.1	**300.5**	375.7
Score Part: E Reuse	748.1	665.9	690.8	**826.9**	637.5*	1102.7

Table 25: Summary of the scores converted to a scale of 10 with regards to the different components of the sanitation system assessed in this study (the highest score is marked in **bold** and the lowest with *)

	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Part A: Collection	5.6	4.5*	5.9	5.7	**7.0**
Part B: Conveyance	5.9	4.9	5.6	**8.1**	4.8*
Part C: Treatment	5.5*	**5.8**	5.7	**5.8**	5.5*
Part D: Transport	4.4*	4.9	6.2	6.7	**8.0**
Part E: Reuse	6.8	6.0	6.3	**7.5**	5.8*

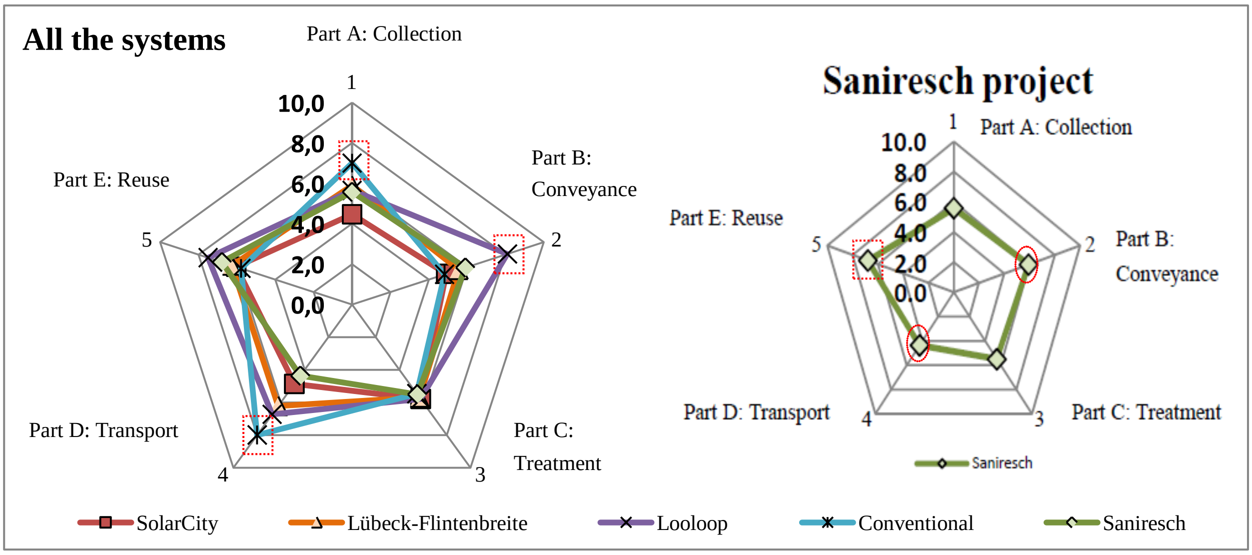

Figure 23: Radial plot displaying the scores converted to a scale of 10 with regards to the components of all the sanitation systems assessed (left) and specifically the sanitation system implemented within the SANIRESCH project (right)

The tables 24-25 and the figure 23 show the dimensional performance at a system level for all the sanitation systems assessed in this study. The figure 24 shows specifically the performance at a system level of the sanitation system implemented within the SANIRESCH project.

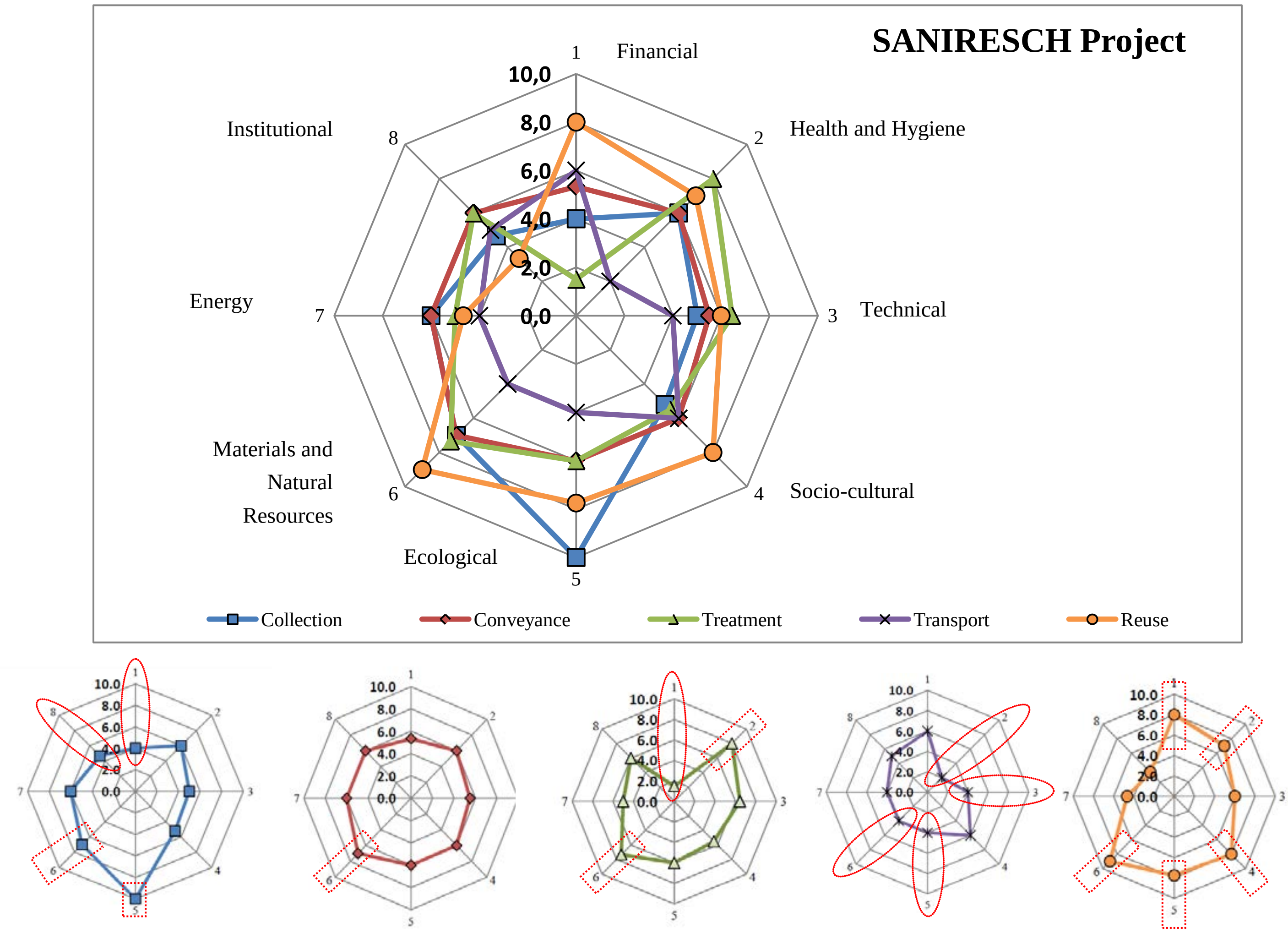

Figure 24: Radial plot of displaying the dimensional analysis at a structural system level specifically for the sanitation system implemented within the SANIRESCH project

4.2.1 Part A: Collection

The part A of the conventional wastewater system (7.0) shows a higher performance than the other systems due to a combination of the lower costs, higher flexibility, technical robustness and both socio-cultural and institutional acceptance of the user interface of this system. The collection system of the solarCity (4.5) shows a very low score. The sanitation system implemented within the SANIRESCH project shows better performance (5.6) than this system. However both systems share the same collection system (i.e. UD flush toilets and waterless urinals). The reasons that could cause this difference in the performance of the user interface is that the solarCity faced serious problems with the collection system which caused the shifting of part of the UD flush toilets to conventional ones (see appendices section I.2) (Oldenburg, et al. 2009). The sanitation system implemented within the SANIRESCH project also detected

Table 26: Summary of the scores for the part A of the sanitation systems with regards to the different dimensions (the highest score is marked in **bold** and the lowest with *)

Part A: Collection	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	4.0	2.7*	4.7	2.7*	**8.7**
Health & Hygiene	6.0	5.0*	6.0	**8.0**	7.0
Technical	5.0	4.0*	5.3	5.7	**7.7**
Socio-Cultural	5.2	3.2*	6.0	6.0	**8.0**
Ecological	**10.0**	8.0	6.0	**10.0**	4.0*
Materials & Natural Resources	7.0	6.0	**7.5**	5.5	4.5*
Energy	6.0*	6.0*	**8.0**	6.0*	**8.0**
Institutional	4.7*	4.7*	4.7*	4.7*	**6.7**

problems with the UD flush toilets and the waterless urinals mainly related to the fact that the system requires higher maintenance needs than the conventional one and specific requirements which need to be carried out in order that the collection component works efficiently (see section 3.8.3.8). However, these problems were detected at an early stage and it has not caused a general rejection of the component and a consequent shift of the collection system as it happened in the solarCity system. Therefore, it is plausible that these differences in the values of the collection component are explained by the problems faced by the solarCity system with the UD flush. Hence, the representative of the solarCity evaluates negatively indicators that there are not categorised so low in the SANIRESCH project.

Furthermore, due to the qualitative nature of the data as well as only one representative has assessed the systems, the personal evaluation of the experts is directly related to the performance of the indicators. Hence, it is plausible that the representative of the solarCity overall evaluates the collection components more negatively than the representative of the sanitation system implemented within the SANIRESCH. However, due to the problems faced in the solarCity with the collection components in the primary school –which suggest that the UD flush toilets should not be implemented in primary schools- the performance of the collection system in the SANIRESCH project shows a better performance. The Looloop system and the Lübeck-Flintenbreite system show higher scores because the collection system has similar characteristics than the conventional, either with regards to the way in which is used (the vacuum system does not require men to sit when urinate and also it can be used by small children) or because it is simply the same than the conventional (the Looloop system uses a conventional toilet as a main collection component for the faecal matter).

The ecological and materials and natural resources dimensions of the sanitation system within the SANIRESCH project show the highest results (see figure 24). This is due to the fact that it is precisely the user interface which facilitates the diversion of the streams and thus the prevention of the water pollution. This component also allows reducing the water consumption (mainly due to the waterless urinals) and it is the first step that facilitates the recovery of the nutrients and organic matter from the excreta. The institutional dimension of the collection system shows a low score due to the fact that it is still a new system which faces a lower institutional acceptability than the conventional system (e.g. in Germany the toilets need to be connected to the conventional wastewater system. To install an alternative collection system there is a need to ask a special permission).

4.2.2 Part B: Conveyance

With regards to the part B, the table 27 and the figure 23 shows that the Looloop system shows the highest performance (8.1) whereas the conventional wastewater system shows the lowest (4.8) but closely followed by the solarCity. This is due to the fact the Looloop system is designed in order to recycle the blackwater as service water to flush the toilets, which produces a high performance of this alternative in the materials and natural resources, ecological, financial and energy dimensions of part B.

Oppositely, the conventional system has the shortcoming of requiring high costs in the conveyance system, as well as high amount of materials and natural resources, energy, and a high repercussion in the ecological related indicators. This is due to the fact that contrary to the other sanitation systems there is a need to transport the excreta collected in the collection component of the system to a centralised wastewater treatment plant. Hence, the values of the conventional system for this dimension are much higher than the other systems.

The sanitation system within the SANIRESCH project (6.0) shows a moderate score with regards to the conveyance system which could be caused that to the high standards of quality integrated in the design of the system (basically the materials of the pipes). Furthermore, the complexity added by the fact of separating the urine creates that the performance of the conveyance system is low.

Table 27: Summary of the scores converted to a scale of 10 for the part B of all the system assessed (the highest score is marked in **bold** and the lowest with *)

Part B: Conveyance	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	5.3	4.0	5.3	**8.0**	3.3*
Health & Hygiene	6.0	8.0	6.0	**10.0**	6.0*
Technical	5.5	4.5*	5.5	**8.0**	5.5
Socio-Cultural	**6.0**	4.0	**6.0**	4.0*	5.0
Ecological	6.0	6.0	6.0	**10.0**	4.0*
Materials & Natural Resources	7.0	6.0	7.0	**8.0**	3.0*
Energy	6.0	6.0	4.0*	**10.0**	8.0
Institutional	6.0	2.0*	4.0	**10.0**	6.0

The table 27 shows that the conveyance system shows higher results in the ecological sanitation systems than the conventional system. This is due to the fact that there is no need to transport the excreta to a central treatment plant, which has a crucial effect in the energetic, materials and natural resources and financial dimension. However, the technical dimension of this system shows similar results than the conventional system mainly due to the addition of technical complexity caused by the fact of transporting separated wastewater streams to the treatment component. The Lübeck-Flintenbreite system shows overall lower scores than the other ecological sanitation systems due to fact that the conveyance system is a vacuum sewage which implies high investment and operating costs, an increase of the technical complexity of the conveyance system and high energetic requirements. The high results shown in the Looloop system could be explained by firstly the effect of the subjectivity of the representative of the system (it was observed that this expert used the categories very high and very low with a significant higher frequency than the other representatives). However, the fact that the Looloop has the potential to be a strictly decentralised system which recycles the wastewater as service water and also that it is pilot plant and it did not face the practical problems related to a real larger scale implementation could explain the higher scores of this system.

With regards to the sanitation system implemented within the SANIRESCH project, the materials and natural resources dimension shows a slightly better performance than the conventional system due to the fact that the conveyance system requires less water resources and there is a general lower consumption in the raw materials due to the level of decentralisation of the system. The other dimensions show an average performance. The financial dimension shows a bad performance because the pipe materials chosen assure high standards of quality and also because there is a need to build separate pipe networks for each wastewater stream separated. This creates that the investment and maintenance costs are high. The overall costs of this component would be similar than the conventional system. The technical complexity should show a lower performance because there is a need to transport separate streams instead of only one and also the fact that the system is implemented in a multi-storey building (there is a need to pump the different streams situated in different plants), which also adds complexity to the conveyance system. The latter is a crucial factor because determines the type of toilet that can be used (urine dry diversion toilets (UDDT) with pumping that can be implemented in multi-storey buildings are not well developed yet).

4.2.3 Part C: Treatment

As it is shown in the table 28 and the figure 23, the part C shows moderate scores in all the systems implying that the performance of the treatment component is similar. This is due to the fact that all the systems require quite complex treatment processes (as the conventional system does) which have a similar aggregated effect. With regards to the ecological sanitation systems, the sanitation system implemented within the SANIRESCH project (5.5) shows the lowest performance, which could be due to the fact that the system is at an initial phase of its developing stage and it is constantly being optimised. This could cause that the general robustness and efficiency of the system is evaluated more negatively by the representative of the system and thus shows lower results than the other systems.

Furthermore, the table 28 shows that there is other slightly differences in the dimensional performance caused by the complexity of the treatments and the final product obtained. Overall, there are shown slightly lower results for the socio-cultural due to the fact that the reliability of the process and the general acceptability is lower than the conventional system. The energy dimension shows a bad performance due to the high energy requirements that the treatment require (which facilitate a final product with relative high standards of quality and which contains nutrients and organic matter). The materials and natural resources dimension as well as the health and hygiene dimensions shows slightly higher scores than the conventional system. This is due to the fact that these systems allows recycling nutrients and organic matter as well as (theoretically) are less water intensive. With regards to the health and hygiene, it prevents at a larger extent the exposure to hazardous substances at the disposal stage than the conventional system. The financial dimension is very low in all the sanitation systems assessed because such relatively complex treatment with the characteristics mentioned previously require high investment costs under the current state-of-the-art of the urban ecological sanitation systems. Hence, the sanitation system implemented within the SANIRESCH project (1.5) shows a very low score in the financial dimension and especially the Looloop system (0.5). The solarCity and the Lübeck-Flintenbreite systems show slightly better performance than the sanitation system implemented within the SANIRESCH project because the treatment is simpler (i.e. do not include MBRs or MAP precipitation in the treatment of the fractions). The institutional dimension of the treatment part of the system implemented within SANIRESCH shows average results.

Table 28: Summary of the scores converted to a scale of 10 for the part C of all the systems assessed (the highest score is marked in **bold** and the lowest with *)

Part C: Treatment	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	1.5	**2.0**	**2.0**	0.5*	1.5
Health & Hygiene	8.0	8.0	6.0*	**10.0**	7.0
Technical	**6.4**	6.2	6.0	5.3*	5.8
Socio-Cultural	5.5*	6.0	6.5	**7.5**	7.0
Ecological	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**
Materials & Natural Resources	**7.3**	7.3	6.7	7.3	5.3*
Energy	5.0*	6.0	**7.5**	**7.5**	5.0*
Institutional	6.0	6.0	4.7	3.3*	**7.3**

4.2.4 Part D: Transport

The system implemented within the SANIRESCH project (4.4) shows a low score because mainly there is a need to transport the liquid stored urine to the reuse zone. The fact that the organic fertiliser is in a liquid form and due to the large volume of urine generated in the system causes that this factor has a significant effect in the overall performance of the part D. However, due to the fact that the representative confused characteristics of the part B with characteristics of the part D (Winker, 2010_b), it can be argued that the performance should be better because the part B of the system is a complex component due to the requirement of separate the streams of the wastewater and the level of development of the state-of-the-art.

Table 29: Summary of the scores converted to a scale of 10 for the part D of all the systems assessed (the highest score is marked in **bold** and the lowest with *)

Part D: Transport	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	6.0*	6.0*	8.0	**10.0**	**10.0**
Health & Hygiene	2.0*	6.0	8.0	**10.0**	8.0
Technical	4.0*	6.0	6.0	**8.0**	**8.0**
Socio-Cultural	**6.0**	6.0	6.0	4.0*	6.0
Ecological	4.0*	8.0	8.0	6.0	8.0
Materials & Natural Resources	4.0*	4.0	4.0	6.0	**8.0**
Energy	4.0*	4.0	4.0	6.0	**8.0**
Institutional	5.0	2.0*	6.0	5.0	**8.0**

The conventional system shows a very high performance because there is not a significant amount of recycled material to transport to the reuse zone [e.g. a small fraction of the wastewater is recycled as sand for construction (HamburgWasser, 2010)]. The Looloop system shows very high results due to the fact that a very significant part of the treatment focuses in re-circulate service water from treated brownwater. Hence, there is only a production of a relatively small volume of soil amender.

4.2.5 Part E: Reuse

Table 30: Summary of the scores converted to a scale of 10 for the part E of all the systems assessed (the highest score is marked in **bold** and the lowest with *)

Part E: Reuse	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	**8.0**	7.0	7.0	**8.0**	5.0*
Health & Hygiene	7.0	7.0	6.0*	**8.0**	7.0
Technical	6.0	5.3*	5.3*	**7.3**	6.7
Socio-Cultural	**8.0**	4.0*	4.0*	**8.0**	6.0
Ecological	**7.8**	6.3	6.5	7.3	6.0*
Materials & Natural Resources	9.0	8.5	9.0	**10.0**	2.0*
Energy	4.7	4.0*	**6.0**	5.3	**6.0**
Institutional	3.3*	4.0	4.0	6.7	**7.3**

The ecological sanitation systems show a better performance in the part E than the conventional systems due to the fact that these systems are designed in order to recover nutrients, organic matter and reuse water. Hence, one inherent characteristic of these systems is the generation of a final product, which usually will be reused within some component related to the agricultural activity. The sanitation system implemented within the SANIRESCH project shows higher results as expected for the solarCity and the Lübeck-Flintenbreite systems because these systems have shown significant problems related to specific parts of the treatment. Hence, the solarCity system could not operate the reuse of the liquid urine due to legal requirements of Austria as well as the soil amender due to technical problems in the composting process. The Lübeck-Flintenbreite system has been operating the blackwater reactor at lab scale due to the fact there is no production of fertiliser from the digestate. The Looloop system (7.5) shows a very high overall performance due to the fact that the expert considered that the reuse carried out within this system was significantly better than the conventional one as there is a total reuse of reclaimed water as service water and there is also the production of fertiliser and soil amender. Furthermore, the pilot plant also generates biogas. The continuous loop of reclaimed wastewater as service water and the generation of energy should be the main reason which cause that the Looloop system has a better performance in the reuse than the other systems.

4.3 Results per Dimension

4.3.1 Dimensions

Table 31: Summary of the scores for each sanitation system with regards to the dimensions: The highest score is marked in **bold** and the lowest with * (maximum best value for each dimension is 500)

Dimensions Equal Weight	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	284.5	261.5	**307.6**	253.8*	**307.6**
Health	320.0	340.0	310.0*	**440.0**	350.0
Technical	282.9	245.4*	282.9	316.2	**324.5**
Socio-cultural	284.5	223.0*	299.9	307.6	**346.1**
Ecological	361.4	323.0	323.0	**369.1**	292.2*
Materials and Natural Resources	371.3	342.7	371.3	**378.4**	199.9*
Energy	250.0*	260.0	320.0	**340.0**	310.0
Institutional	240.7	207.5*	232.4	265.6	**356.9**
Total /4000	2,395.4	2,203.1*	2,447.1	**2,670.7**	2,487.2

Tables 31 and 32 show the results with regard to the aggregation of all the scores of the indicators weighing the dimensions equally (i.e. 1).

Table 32: Summary of the scores for each sanitation system converted to a scale of 10 with regards to the dimensions (the highest score is marked in **bold** and the lowest with *)

Dimension Equal Weight	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	5.7 (2nd)	5.2	**6.2**	5.1*	**6.2**
Health	6.4 (4th)	6.8	6.2*	**8.8**	7.0
Technical	5.7 (3rd)	4.9*	5.7	6.3	**6.5**
Socio-cultural	5.7 (3rd)	4.5*	6.0	6.2	**6.9**
Ecological	7.2 (2nd)	6.5	6.5	**7.4**	5.8*
Materials	7.4 (2nd)	6.9	7.4	**7.6**	4.0*
Energy	5.0* (5th)	5.2	6.4	**6.8**	6.2
Institutional	4.8 (3rd)	4.2*	4.6	5.3	**7.1**
Total	6.0 (4th)	5.5*	6.1	**6.7**	6.2

The financial dimension shows a moderate performance in all the sanitation systems (ranging from 5.1 to 6.2). This result is coherent with the results obtained at the indicators and at the system level. As mentioned previously, all the systems assessed carry out relatively complex treatment processes aiming to achieve a final product with high standards of quality. Furthermore, they have in common that specific technological components require significant investment and maintenance costs. Hence, the ecological sanitation systems require a user interface that facilitates the separation of the excreta in different streams. In addition, these systems also have to invest financial resources in the transport of the final product to the reuse zone and the reuse of the final product itself. The conventional wastewater system requires a high investment in the conveyance component of the system due to the need to send the blackwater to a central wastewater treatment plant.

The health and hygiene dimension show a good performance in all the sanitation systems, especially the Looloop system (8.8), which according the results would be the most desirable system from a health and hygiene viewpoint, and the conventional system (7.0). The reason why there is a significant difference in the performance between the Looloop system and the other ecological sanitation systems can only be explained because the fraction which is reused in the agriculture within the Looloop system is significantly smaller than the other systems. Hence, the potential soil pollution and the derived health effects due to the agricultural reuse of the final product are lower. Another reason previously mentioned is that the way to evaluate qualitatively the factors of the representative of the Looloop system could influence the final score of the Looloop system showing a higher difference than expected. This would be a direct consequence of the limitations of the methodology designed, which are discussed in the section 2.3.9. The conventional system, even though it is not capable to prevent the water pollution as effectively as the other ecological sanitation systems, prevents the soil pollution because simply there is not any kind of agricultural reuse of the final product.

The conventional system (6.5) shows the highest performance in the technical dimension due to the technical robustness of this system. The system is closely followed by the Looloop system (6.3) which had no significant technical problems during the 2.5 years of operation (Braun, 2008; Behrendt, et al., 2009). The solarCity (4.9) shows an especially low performance because the technical problems experimented with the composting filter bags. The main differences observed in these dimensions could be explained by the level of development of the technology. The conventional system has been developing for 150 years, thus the performance is relatively better than the other systems. The Looloop system could show similar results than the conventional system due to the fact that the system is a pilot plant at a very small scale. Hence, this system has not faced the difficulties of implementing the system at a real scale. This could be one of the reasons why the results in this dimension are closer to the conventional and not the other systems, as it could be expected because the level of development of the system is closer to the ecological sanitation systems

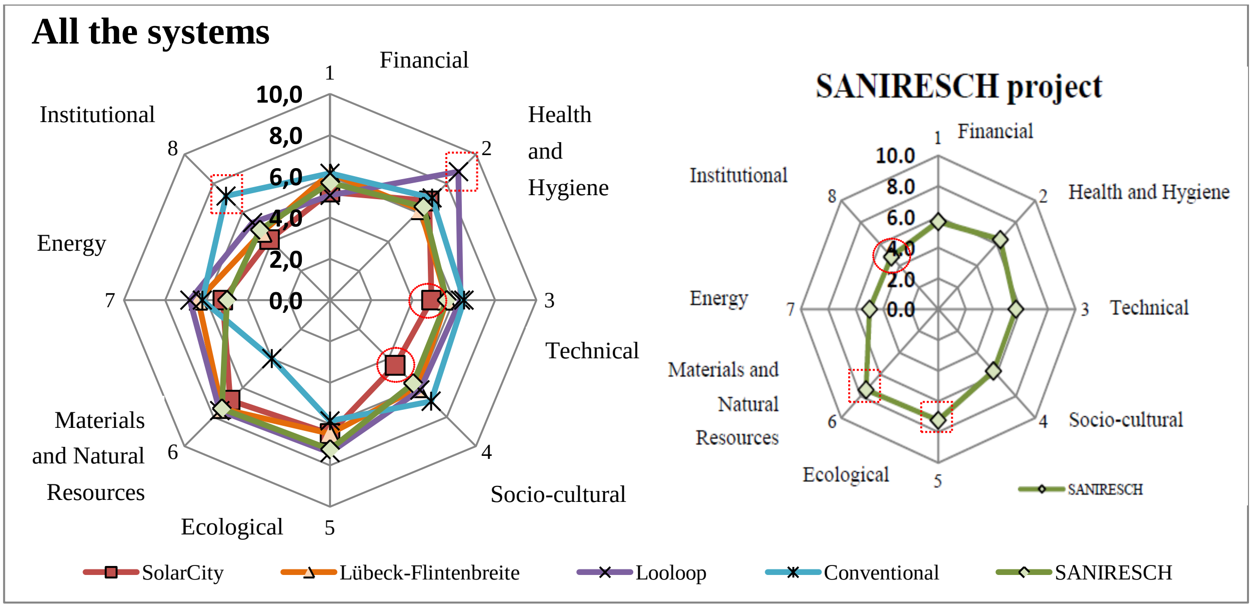

Figure 25: Radial plot displaying the scores converted to a scale of 10 at a dimensional level for all the sanitation systems assessed (left) and specifically for the sanitation system within the SANIRESCH project (right)

The performance of the socio-cultural dimension shows a similar tendency than the technical dimension. The conventional system is the strongest system, which is due to the fact that in Germany as well as other developed countries the people is used and accept this system. The ecological sanitation systems face different difficulties with regards to the socio-cultural dimension. Firstly the user interface, which usually implies basic change in the use in order to facilitate the separation of the streams. Another challenge of this dimension is the acceptability of the final product. Furthermore, the relatively new level of development of the ecological sanitation systems at an urban level causes that usually the level of nuisance and aesthetics could not compete at large extent against the conventional system. This is translated in the lower performance of the ecological sanitation systems for this dimension. However, the high results of the Looloop systems have to be carefully considered as it has been already discussed.

The tendency observed in the technical and socio-cultural dimensions gets inverted for the ecological dimension. Hence, the conventional wastewater system shows the lowest performance due to the fact that it is not capable to prevent the water pollution satisfactorily. The ecological sanitation systems show a better performance than this system. However, this difference gets partly compensated due to the soil pollution with regards to the reuse of the final product, which does not take place in the conventional system. The Looloop system continues showing a significant higher performance than the ecological sanitation systems because the fraction of material reused is lower than these other systems. With regards to the materials and natural resources, the situation is exactly the same. In this case the reason of the higher performance of the ecological sanitation systems is the fact that these systems are designed to recover the nutrients and the organic matter from the excreta as well as also to produce reclaimed water.

The results for the energy dimension should be similar because all the system bases the treatment in high energetic consumption. The reason why the Looloop, the Lübeck-Flintenbreite and the conventional wastewater system shows a better performance could be explained because these systems contemplate the possibility to generate biogas. According to the results, the sanitation system within the SANIRESCH project shows especially bad performance in this dimension due to the high electrical consumption that the treatment system requires (mainly the MAP reactor and the MBRs).

The institutional dimensions show a similar tendency than the socio-cultural dimension. However, in this case the differences between the ecological sanitation systems and the conventional system are more accentuated. This could be explained in the case of the solarCity and the sanitation system within the SANIRESCH project to the fact that the reuse of liquid urine as fertiliser is not allowed under the German law of fertiliser. In general, the ecological sanitation systems show a lower legal acceptability and lower operational compliance due to the fact that these systems are very innovative which still are not only developing the system but as well adapting to the legal requirements.

4.3.2 Aggregation

Taking into account all the factors previously mentioned, it is necessary to stress the fact that all the sanitation systems assessed show a similar average performance range (5.5-6.7). This similarity in the final average score is especially shown by the Lübeck-Flintenbreite system, the conventional system and the sanitation system implemented within the SANIRESCH project.

The Looloop shows a slightly higher performance and the solarCity a slightly lower. The possible reasons of the differences in the final performance of the systems are discussed below.

4.3.2.1 The solarCity system (Linz)

The lowest score (5.5) corresponds to the solarCity. This could be due to the technical problems faced during the treatment (the efficiency of the composting filter units due to clogging and a decrease of the permeability of the filters) and the reuse (the nutrient loop is not closed because it is not institutionally accepted the reuse of urine) (Oldenburg, et al. 2009). Furthermore, the low adaptability of the UD flush toilets to different types of users led to a shift to conventional units in one of the systems of the solarCity. The constructed wetlands worked satisfactorily. Oldenburg, et al (2009) point out that the technological components of this system are not “mature neither fully functional”.

In general, the system is sensitive to improper use due to the UD flush toilets and the waterless urinals. However, an improvement in one dimension causes a decrease in another dimension. In this case, at the current state-of-the-art of the collection technology, to divert urine on-source requires a relatively higher complexity and maintenance requirements of the system, which also is reflected in the price. The most important aspect with regards to the sustainability of the project is the need to optimise the UD flush toilets (Oldenburg, 2009).

4.3.2.2 The Lübeck-Flintenbreite system

This system shows a moderate performance (6.1) very close than the conventional system (6.2) and the system implemented within the SANIRESCH project (6.0). The blackwater reactor is not operative so far (Otterwasser, 2009). Hence, the anaerobic digestion is carried out at lab scale exclusively. The main shortcomings of this system are the investments costs (40% higher than the conventional system) and the energy requirements of the vacuum sewage system (Oldenburg, et al. 2008). The vacuum system is more sensitive than the conventional system but the crucial advantage is the low water consumption of the system.

Furthermore, the system is well accepted by the users due to the fact that the collection component barely implies a change in the use. Furthermore, the fact of being almost a finalised system (only the blackwater reactor is still developing) it increases the robustness of the technical system. Another advantage of the system which could explain the relatively good performance is the high scores in the ecological and materials and natural resources due to the recovery of the nutrients and the prevention of the pollution of the water.

4.3.2.3 The Looloop system

The Looloop system shows the best performance amongst all the alternatives. The fact that the Looloop system shows the highest score can be partly influenced by the fact that it is a pilot plant at a full lab scale which did not face the difficulties of implementing the sanitation system at a real scale. Furthermore, the effect of having a much smaller scale than the other system can also be a significant factor that causes that the results are higher than the other alternatives. Therefore, the comparison with the other alternatives is at least tricky and must be treated carefully.

However, the system could also show higher results than the other systems because firstly the user interface of the system does not suppose any dramatic modification in the behaviour (conventional flush toilets and waterless urinals). Due to the complexity of the treatment process the costs are the highest amongst the alternative. However, this low score in the financial dimension is reflected in high scores in other dimensions, like the materials and natural resources and the ecological. Another drawback is the high energy consumption of the system (Braun, et al. 2008). Another dimension which shows very good results is the materials and natural resources due to the high conservation of water and nutrients. The system is also designed to be compatible with other collection devices, like UD flush toilets. Furthermore, the efficiency of the treatment and the conservation of materials and natural resources can be enhanced by adding complementary recycling of other fractions of wastewater (greywater). Therefore, this theoretical design which is implemented at lab scale shows several strengths. However, they need to be implemented at a larger scale in order to be fully comparable to the other systems.

4.3.2.4 The conventional system

The conventional system shows a strong performance in the financial, technical, socio-cultural and institutional dimensional. The conventional system was used as a reference system to establish the comparison of the indicators. The similar performance in the final aggregated results with the other sanitation systems can be considered a positive sign due to the fact that this system is a very robust and strong system in high-income countries. Hence, the fact that the systems assessed have equivalent results is a good feature.

With regards to the analysis per dimensions and indicators, it should be highlighted that the dimensions where the conventional system is strong the other sanitation systems are weak and vice versa. This suggests that an improvement in all the dimensions of the sustainability is not possible and that the improvement in one dimension causes the decrease in some other dimensions. In the case of the sanitation systems assessed in this study, the improvement in the ecological, materials and natural resources (recycling of nutrients) and energy (in some cases) is compensated by the decrease in the financial and socio-cultural dimension.

4.3.2.5 The sanitation system implemented within the SANIRESCH project

The system implemented within the SANIRESCH project shows average results in most of the dimensions very close to the conventional system with the exception of the ecological and materials and natural resources dimensions, where it shows a high performance. Oppositely, this system shows the lowest results in the energy and institutional dimensions. It also shows a low performance but at a lower scale in the socio-cultural dimension. According to the MCDA results, it can be stressed the fact that this system would be in the same range than the conventional system and the Lübeck-Flintenbreite system.

The system is still in a relatively initial stage of its developing and is being continuously optimised, mainly with regards to the phase 2 but also some specific parts of the phase 1 which decreases the scores of several indicators of the technical dimension. Currently there is not any kind of composting process carried out. The greywater is not treated but directed to the conventional system. Furthermore, part of the excreta collected is directed to the conventional system because there is not enough space to treat it in Eschborn. The reuse of urine is not allowed under the German law but it is currently reused with a special permit.

The main drawbacks of the system are the maintenance requirements and the aesthetics and nuisance, which are considered by the users as lower than the conventional system (Blume & Winker, 2010). The investment and maintenance costs are also high. Finally, a significant shortcoming of the system is the UD flush toilet performance. Due to this, the water consumption is not significantly reduced and the nitrogen is lost by evaporation or dilution (Hochedlinger, et al. 2008).

- **Performance of the UD flush toilets**

  It is also important to highlight that there is a “practical loss from urine separation toilets of nitrogen” (Hochedlinger, et al. 2008). Most of the practical problems in operation were caused as a result of a wrong type of maintenance and/or the incorrect use of the Nomix toilets (Oldenburg, et al. 2009). The flushing of these toilets also causes problems, either because it is too weak (SolarCity, SANIRESCH project) or too strong (solarCity). They also show a low social adaptability, because children have difficulties to operate correctly the system. They also require higher maintenance.

4.3.3 Weights of the dimensions

The table 33 shows the weights given by the representative of each sanitation system to the dimensions. The table 34 shows the final scores per each dimension after considering in the calculation the weights given to the dimensions by the experts representing each system. The weights of the representative of the conventional system were not included because this MCDA focus in the preferences of the representatives of the ecological sanitation alternatives.

Table 33: Weights given by the representatives of the sanitation systems to each dimension. (*) The weights of the conventional system were not included to calculate the final average

	SANIRESCH	Linz	Lübeck-Flintenbreite	Loo-loop	Conventional(*)	Average
Financial	3	2	2	1	3	2
Health & Hygiene	1	1	1	2	3	1.25
Technical	1	3	1	3	2	2
Socio-Cultural	2	3	2	2	2	2.25
Ecological	1	2	1	2	2	1.5
Materials & Natural Resources	1	2	2	1	1	1.5
Energy	2	1	2	1	2	1.5
Institutional	3	3	2	1	1	2.25

Table 34: Summary of the scores converted to a scale of 10 considering the average weight given by the representatives of the systems to each dimension (the highest score is marked in **bold** and the lowest with *)

Dimension	Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional
Financial	5.7	5.2	**6.2**	5.1*	**6.2**
Health	6.4	6.8	6.2*	**8.8**	7.0
Technical	5.7	4.9*	5.7	6.3	**6.5**
Socio-cultural	5.7	4.5*	6.0	6.2	**6.9**
Ecological	7.2	6.5	6.5	**7.4**	5.8*
Materials	7.4	6.9	7.4	**7.6**	4.0*
Energy	5.0*	5.2	6.4	**6.8**	6.2
Institutional	4.8	4.2	4.6*	5.3	**7.1**
Total	5.9	5.3*	6.0	**6.5**	6.3

The inclusion of the weights of the experts modifies the results by slightly decreasing the performance of all the alternatives. Furthermore, the table 35 shows the final scores per dimension of each sanitation system after considering two different scenarios. The scenario 1 approaches to reflect the prioritisation of the dimensions health and hygiene, ecological, materials and natural resources and energy dimension. To do this, such dimensions are weighted as 3 and the rest as 1. The scenario 2 reflects the opposite situation. To accomplish this, the financial, technical, socio-cultural and institutional dimensions are weighed as 3 and the rest as 1. To calculate the score considering the weights of the scenario 1 causes an increase of the performance of all the alternatives but the conventional: the conventional wastewater system (6.0) is moved to the second lowest score very close than the lowest, which corresponds to the solarCity (5.9). Oppositely, the scenario 2 moves the conventional wastewater system (6.4) to the first position, closely followed by the Looloop system (6.2). Within the scenario 2, the performance of all the alternatives decreases except the conventional wastewater system.

Table 35: Summary of the scores for each sanitation system after considering the weights given by the representatives of the systems and two different scenarios (the highest score is marked in **bold** and the lowest with *)

		Saniresch	Linz	Lübeck-Flintenbreite	Looloop	Conventional	Maximum score
Weights all dimensions: 1	Score	2,395.4	2,203.1	2,447.1	2,670.7	2,487.2	4,000
	Scale of 10	6.0	5.5*	6.1	**6.7**	6.2	10
Weights Experts	Score	4,190.7	3,796.0	4,287.5	4,610.9	4,486.5	7,125.0
	Scale of 10	5.9 ↓	5.3*↓	6.0↓	**6.5** ↓	6.3 ↑	10
Weights scenario 1	Score	5,000.8	4,734.5	5,095.6	5,725.8	4,791.5	8,000.0
	Scale of 10	6.3↑	5.9*↑	6.4↑	**7.2** ↑	6.0 ↓	10
Weights scenario 2	Score	4,580.6	4,077.9	4,692.6	4,956.9	5,157.2	8,000.0
	Scale of 10	5.7↓	5.1*↓	5.9↓	6.2 ↓	**6.4** ↑	10

If the weights given by the experts to the dimensions are used to operate the MCDA (instead of considering that the dimensions have an equal weight of 100) a slightly decrease in the total performance of all the ecological sanitation systems is produced. However, the total performance of the conventional system increases. This also occurs when the dimensions classically focused in decision-making processes (i.e. financial, technical, socio-cultural and institutional) are maximised (scenario 2). This is caused because if the decision-making focuses in such dimensions, the conventional system shows higher performance (because precisely the conventional system was designed and developed to maximise these dimensions).

If the scenario 1 is applied, the total performance of the conventional system decreases. However, the total performance of the ecological sanitation systems increases. This is due to the fact that the ecological sanitation systems are designed and being developed to improve these dimensions (ecological, materials and natural resources, health and hygiene and energy). Therefore, these results could suggest that, at least at the current state-of-the-art of the urban sanitation technologies, to maximise one specific dimension of a sanitation system implies to minimise another. Hence, the maximisation of all the dimensions of a sanitation system is not possible but rather a trade-off amongst the dimensions should be found that satisfies the interests of the stakeholders. Furthermore, these results also reflect the change that is necessary for evaluating ecological sanitation systems at least under the current state-of-the-art of the technologies: not prioritising the conventional dimensions but the ecological (eutrophication), the materials and energy intensitivity.

It is necessary to stress that the effect of modifying the weight of the dimensions is lower than expected. However, this is due to the qualitative categorisation process of the MCDA, which only allows a numerical conversion of the preferences from 1 to 5 as well as the conversion of the scores to a scale of 10. Thus, the change in the performance of the indicators when the weight of the dimensions is altered goes to the decimal realm. In a MCDA including quantitative data, the effect of modifying the weights of the dimensions is expected to be higher (due to the fact that the range of the categorisation of the values does not only go from 1 to 5). However, in the case of this MCDA, it is useful to see the trend.

4.4 Limitations

In this section, the limitations identified as a result of operating the MCDA are discussed. The inherent drawbacks of the MCDA are discussed in the section 2.3.9.

4.4.1 MCDA

- The questionnaire included the blank option as possible evaluation of the indicators. Whenever the expert used the option "I do not know" the indicator was eliminated. In the cases that this was not possible (because the indicator was needed to operate the MCDA), the indicator was re-evaluated and a specific score was given. Always that it was possible, such re-evaluation was carried out using the value of one indicator assessed in one of the sanitation systems assessed with the same characteristics. For instance, in the case of the solarCity, there was missing a value from the collection system, this value was taken from the system implemented within the SANIRESCH project because both systems share the same collection component. When this was not possible, the re-evaluation was carried out taking literature values. The evaluation of the experts with the missing data and the re-evaluation is attached in the electronic attachments section 5.

- With regards to the categorisation, to use a scale from 1 to 5 has the limitation that changing the weights in the dimensions is not significantly shown by the final outcome because the variations are within the decimal realm. However, by using a MCDA which combines quantitative and qualitative data this problem gets significantly avoided.

- It is also important to stress the effect of the different scales of the system assessed, which can affect the scores of specific indicators. To avoid this, the alternatives chosen had approximately similar scales and sizes. However, there is the exception of the

Looloop system. The effect of the difference in the scale of the project is reflected in the discussion and has been taken into account as a possible reason for the good performance.

4.4.2 Questionnaires

- The questionnaires were long and complex, and required an effort and strong interest from the representatives of the system to fill it adequately.

Part IV: Testing the IAAF

5. Testing the Framework

5.1 Response

30 experts on sanitation from China, Brazil, India and South Africa were initially approached with the objective to get at least 3 representatives for each of these fast-growing economies, one representative per city. However, the response was very poor and it was only possible to identify 8 experts who were willing to participate in the research and carry out the questionnaire. Notwithstanding, eventually only two experts filled out and sent back the questionnaire: one representative for Sao Paulo (Brazil) and one representative for Durban (South Africa).

The poor response was caused in the first place due to a lack of resources and time, which caused that it was not possible to identify contacts willing and/or motivated enough to collaborate. Due to this fact, instead of three different urban areas per fast-growing economy, only it was possible to have a positive reply from two urban areas per fast-growing economy.

However, the reason why eventually the questionnaire was only carried by two experts is due to a combination of both the complexity of the data required and the length of the questionnaire as well as some crucial drawbacks of the software used to embed the questionnaire in an on-line survey. First of all, it is necessary to stress that the reason to embed the questionnaire in an on-line survey was in order to ease the access to the questionnaire to a set of experts spread all over the World as well as to be able to track the answers and process the data. However, the software had a significant limitation: once started the questionnaire, the expert could not to stop and save the answers and start again in another moment from the same point of the questionnaire. Furthermore, being dependent on the quality of the internet connection to fill the questionnaire complicates the filling process rather than enhancing it, even more in areas where the internet connection might not be very strong. At least two experts faced those difficulties (one finally carried out the questionnaire, the other did not). Other two experts expressed that they were unable to fill out the questionnaire because they did not have enough knowledge to fill the questionnaire about the urban area. Furthermore, by means of the tool to track the answers, 5 experts at least used the link of the questionnaire but they did not even finish the first section (out of 4 sections). In addition, approximately 30% of the experts, even though willing to collaborate in the beginning, they did not to try to fill the questionnaire due to unknown reasons.

Hence, the IAAF will be exemplarily tested for Sao Paulo and Durban.

5.2 Sao Paulo

The final list of technology and location wise indicators selected by the expert on sanitation representing the city of Sao Paulo is attached in the electronic appendices section 6 and also it is displayed in the figure 26.

5.2.1 Analysis at indicator level

The individual interactions of the indicators on the adaptability of the system will be analysed in this section. The technology wise indicators are independent of the area of the implementation. Due to the fact that the values and the effects of these indicators have already been discussed in the section 4.1, this section will mainly focus in the location wise indicators. However, the combined effect of the two types of indicators with regards to the adaptability will be discussed.

5.2.1.1 Financial indicators

As it is shown in the figure 26, the five technology wise indicators selected in the analysis are the investment, maintenance, replacement, operational (treatment) and transport costs. The overall performance is low because the costs of the system are high, especially the investment, replacement and maintenance costs. Such costs, mainly related to the collection, conveyance and treatment components of the system are considered high due to the state-of-the-art of the system (i.e. the technological components are innovative and they are produced at small scale. Thus, the investment costs are high). The costs are also high due to the high quality of these technological components and the (theoretically) high standards of quality that they provide.

The level of welfare of Sao Paulo is high -Sao Paulo is the wealthiest city of South America- (Nolasco, 2010). Furthermore, the costs of access to sanitation in the city are high, which in this framework is considered positive because implies that people is already paying a significant amount in sanitation and that they are financially capable to do it. These two factors combined with moderate possibilities of obtaining external funding or subsidies and potential moderate service fees could compensate the relatively high costs of implementing the system. A negative factor is that the price of the soil amender is low. Furthermore, the price of the chemical fertilisers is moderate. If those two products have a low price in the market, it is difficult that the soil amender and organic fertiliser produced within the system can financially compete against them.

Both the financial feasibility and efficiency of the sanitation system are high. Considering the personal feed-back of the representative and the results of the other financial indicators, this could be due to the combined effect of the high level of welfare of the city, the costs of access to sanitation, the potential service fees and the possibility to save water (which would be carried out by the waterless urinals at the current state-of-the-art of the system –UD flush toilet are not a water conservative technology) (Borsuk, et al. 2008). Hence, the population of Sao Paulo has the financial resources to implement the system and they are already investing large amounts to access to sanitation. Furthermore, the possibility to obtain moderate service fees and mainly the potential saving of water would cause that these two indicators have a high performance.

5.2.1.2 Health and hygiene indicators

The figure 26 shows that the technology wise indicators (safe collection, safe disposal and exposure to pathogens) have an average performance. However it is necessary to stress the fact that all the technology wise indicators with regards to the health and hygiene should be considered to have a good performance because these values are in comparison with the conventional system in Hamburg. Hence, the fact that the system shows average results implies that the standards are the same than the conventional system used as a reference. The other indicators selected, the exposure to hazardous substances, is low because the system avoids the contact with this kind of substances during the life cycle of the technology more efficiently than the conventional system.

The first location wise indicator selected is the need for sanitation improvement, which is high for Sao Paulo even though the coverage of conventional wastewater infrastructure and networks is moderate [“50-75% of the sewage is collected and treated in wastewater treatment plants” (Nolasco, 2010)]. However, if the metropolitan area of Sao Paulo is taken into account (the surrounding cities and slums), there is almost “no treatment of the sewage, which is dumped directly to the nearest river” (Nolasco, 2010). Finally, the availability of sanitation shows a low performance, which implies that actually the access to sanitation in Sao Paulo is high. This is explained because within the IAAF that the metropolitan area of the city has a good access to sanitation is considered as a negative feature because it decreases the need to implement the system from a health and hygiene viewpoint.

5.2.1.3 Technical indicators

The figure 26 shows the indicators considered in the analysis. It is necessary to highlight that the adaptability of the system to different types of user is considered to be high for the representative of the sanitation system, which implies that the performance is better than the conventional system. However, due to the fact that the UD flush toilet requires that men sit to urinate and also that it cannot be adequately used for children, this value should be low. The scale of the system has a good performance due to the fact that the scale of the system is lower than the conventional system. The complexity of the system is considered to be high. This could be due to the fact that firstly there is a diversion of urine and a separation of the excreta in different streams which adds complexity to the collection treatment. The treatment system is designed to meet high standards of quality in the final product. Also the level of recovery of nutrients and recycle of service water cause that the system shows a complexity higher than the conventional system. Hence, this higher complexity is due to the diversion of urine and the treatment designed to recover the nutrient and to use the wastewater as service water. The fact that the system is still developing causes that the robustness of the system is lower than the conventional system, which is a very robust system from a technical viewpoint. Furthermore, the fact that the system separates on-source the excreta in different streams adds O&M requirements to the system and also increases the nuisance, which is also caused by the state-of-the-art of the system and of the diversion of urine in a multi-storey building.

Sao Paulo is an area strong with regards to the performance of the technical indicators. Firstly, both the area available and the scale of implementation are high. This is translated that in Sao Paulo, the seventh largest metropolitan areas of the World (Forstall, et al. 2009) there should be a large number of areas where the system could be implemented implying that there are large number of multi-storey buildings where the system could be implemented. Specifically, Sao Paulo is the financial centre of Brazil, and there should be a significant number of company buildings where the system could be implemented. Another two positive aspects is the local availability of technological components and spare parts which decreases the dependence of Sao Paulo to import the technological components from Germany. Finally, there is availability of technical know-how. Hence, there is local availability of people able to operate, maintain and repair the system. The other indicators selected show a moderate performance.

5.2.1.4 Socio-cultural indicators

With regards to the technology wise indicators selected (acceptability, comfortability and aesthetics), the performance is moderate implying that the performance is equal than the conventional system. However, mainly with regards to the acceptability and comfortability, the values should be lower. This is due to the UD flush toilets. These devices require that men sit when urinating and also have shown specific problems as discussed in the section 3.8 during the operation that causes that the acceptability and the comfortability of the UD flush toilets is lower than the conventional. Furthermore, technical problems faced with the waterless urinals and odour problems should decrease the value of aesthetics when compared to the conventional system (3.8.3.8).

With regards to the location wise indicators, all the indicators related to the acceptability (user, farmer and final product) show a very good performance in Sao Paulo. This is considered a positive feature of the city because implies that the people is willing to use the waterless urinals and UD flush toilets. Furthermore, the acceptability of the final product implies that there is not a strong cultural resistance to use fertilisers and soil amenders produced from excreta. Finally, the fact that the acceptability amongst the farmers is high is also positive with regards to the adaptability of the system because it facilitates the reuse of the final product. The social improvement that the implementation of the system could cause in Sao Paulo is also high, which is also a positive feature for the adaptability of the system. This fact implies that there is a need for a sanitation improvement and that this sanitation improvement could help to improve the socio-cultural conditions of the population of Sao Paulo without access to sanitation. Sao Paulo also shows a high score in the aesthetic standards with regards to the sanitation. This is considered as a positive feature because the sanitation system is designed to achieve high standards of quality. Hence, this feature of the design system which determines many of the characteristics of the system is considered to have a positive effect in the adaptability of the system. On the other hand, there are two negative features of the city that there is a need to highlight. Firstly, the limited rural influence, which implies that the agricultural activities in the city are limited. This has a negative effect because it causes that the final product is transported large distances to be reused, and this fact increases dramatically the price of the final product. In the case of Sao Paulo, this would be an especially negative characteristic because the price of the chemical fertilisers and soil amender is low. Hence, the final product would have serious difficulties to compete against them. Secondly, the population density of the city is very high which is considered a negative feature with regards to the adaptability because even though the scale of the system is considered low, there is a certain need of space to implement the sanitation system, even more if the sanitation system has to be adapted for large areas or large number of users. Hence, the fact of that Sao Paulo is a highly populated area complicates that there is space available in the buildings where the system could be implemented.

5.2.1.5 Ecological indicators

The indicators selected are the potential water pollution and eutrophication which show a very good performance as discussed in the section 4.1. However, the pollution to the soil as well as the amount of hazardous substances and micropollutants in the final product is relatively high.

With regards to the location wise indicators, the soil nutrient depletion is very low, which is considered a negative factor with regards to the adaptability because implies that there is not a need of significant amounts of fertiliser. Hence, it reduces the applicability of the organic fertiliser produced within the system. However, the soil is not rich in organic matter, which is considered a positive because there is a need to apply soil amender. Therefore, at least one of the main final products of the system could be satisfactorily reused in Sao Paulo and it is adequate with regards to the local needs. Another important characteristic of Sao Paulo is that there is a

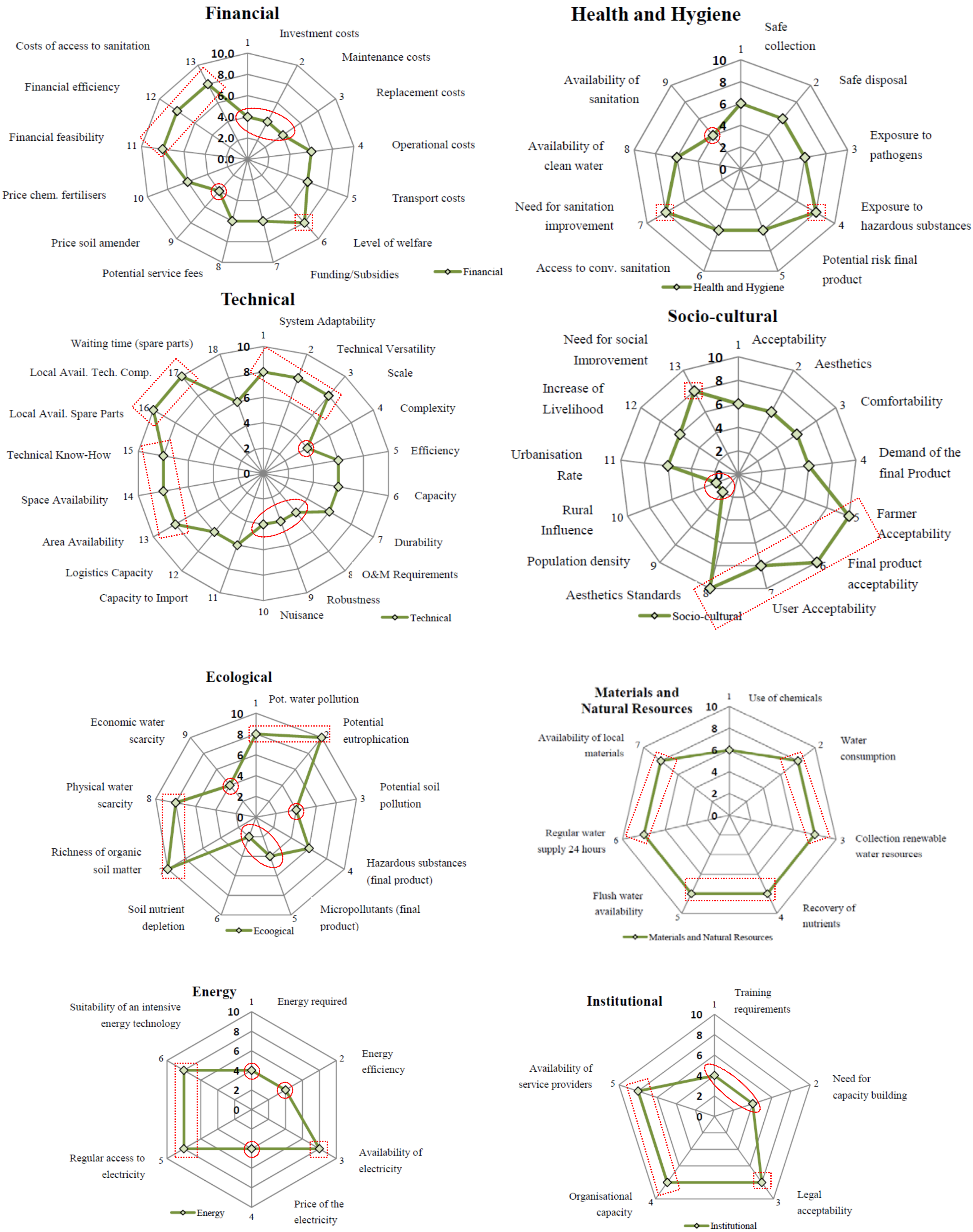

Figure 26: Radial plot of the adaptability indicators included in the IAAF to assess the adaptability of the sanitation system implemented within the SANIRESCH project in Sao Paulo

significant physical water scarcity due to the fact of the enormous pressure on the water resources that 19 million of people create in the environment (Forstall, et al. 2009). This is considered a positive feature with regards to the adaptability because there is a need to implement sanitation systems which are at some extent water conservative. However, there is also a marked economic water scarcity, which is considered negative factor with regards to the adaptability because this implies that even though there could be enough water resources to supply the needs of the sanitation system, there is water scarcity due to human, capital, institutional limits to access the water resources (FAO, 2007). This situation could be produced because considering the metropolitan area of Sao Paulo there is a large number of people that do not have access to water for economical and institutional reasons.

5.2.1.6 Materials and Natural Resources indicators

The first technology wise indicator selected is the use of chemicals, which is moderate. However, this implies that the consumption of chemicals of the system is similar than the conventional system in Hamburg. Therefore, the consumption of chemicals of the system should be considered significant. The water consumption of the system is low mainly due to the waterless urinals. The UD flush toilets are not a water conservative technology, as it has been discussed in the section 4.1. There is a high recovery of nutrients. The representative also selected the collection of renewable water resources and it has been included in the analysis with the performance value of the German system. However, this value should be modified because it depends on the area of implementation and the possibility to obtain water to operate the system.

The indicators within this dimension show very good performances implying that Sao Paulo fulfils satisfactorily the materials and natural resources aspects related to the adaptability of the system. A crucial point is the high availability of flush water availability. Hence, the flush water required to operate the UD flush toilets is satisfied. This is due to the fact that most of the city is connected to a regular water supply (Nolasco, 2010). These factors are vital with regards to the adaptability of the system because without this regular access to flush water the system cannot operate. Furthermore, the availability of local materials is also high, which indicates that the external dependency to obtain the materials needed to operate the system can be adequately satisfied within the city. This is considered as a good feature with regards to the adaptability because contributes to the autonomy of the city and a potential reduction of the costs.

5.2.1.7 Energy indicators

The technology wise indicators show that the system is an energy intensive system which requires a constant source of electricity. The figure 26 shows that with regards to the energy, Sao Paulo shows a high availability and access to electricity which is considered as a positive feature with regards to the adaptability of the system because the system requires a regular access to electricity to operate the conveyance and the treatment component of the system. Due to these factors, the suitability for an energy intensive technology shows also a very good performance. However, the price of the electricity is high, which is considered a negative feature with regards to the adaptability because increases the operation and maintenance costs of the system.

5.2.1.8 Institutional indicators

The figure 26 shows the performance of the indicators for the institutional dimension of Sao Paulo. There is a need to highlight that the performance of the indicators selected by the representative is high. Hence, the legal acceptability of the sanitation system is high. This could be mainly motivated because there is a government effort to adapt water conservative systems (due to the enormous pressure on the water resources). Also, due to the economical strength of the city, there is an institutional effort to implement innovative water sanitation systems (Nolasco, 2010). The fact that the system is accepted from an institutional viewpoint is a very positive feature with regards to the adaptability because facilitates the implementation of the system. Furthermore, the availability of service providers, which also shows a good performance, implies that there are companies which are already working in sanitation related issues. Those could be interested in implement specific parts of the system, like the operation and maintenance of the system or the transport of the final product. Similarly, those service providers could be interested in developing the system in a semi-centralised manner in order to implement the system at larger scale. The organisational capacity of the city is high due to the high standards of living that there is in Sao Paulo and the level of development and organisation of the financial centre of South America. This factor can compensate the need for capacity building that the users of the system as well as specific stakeholders would require if the system is implemented in the city. This need for capacity building, which is considered high, it is considered as a negative feature with regards to the adaptability of the system. However, any innovative sanitation system requires a certain amount of capacity building in order that the local stakeholders are able to integrate, operate and replicate satisfactorily the sanitation system.

5.2.2 Analysis at dimensional level

In this section, the individual effect of the indicators is not considered but their aggregated effect within the same dimension. The advantage of allowing trade-offs amongst the indicators is that it simplifies the analysis and understanding of the results and allows to carry out a faster decision-making which is simpler, comparable and interpretable (van Moeffaert, 2003). However, as a main drawback, the author also states that this aggregation leads to an over-aggregation, over-simplification, which could cause a misinterpretation.

Table 36: Summary of the scores for each dimension with regards to Sao Paulo (maximum value for each dimension is 500 –in **bold** the highest score, *the lowest-)

Sao Paulo	Score	10 scale
Financial	300.0	6.0*
Technical	333.3	6.7
Materials and Nat. Resources	385.7	**7.7**
Energy	300.0	6.0*
Institutional	320.0	6.4
Health and Hygiene	311.1	6.2
Ecological	311.1	6.2
Socio-cultural	330.8	6.6
Total	2,592.0	6.5

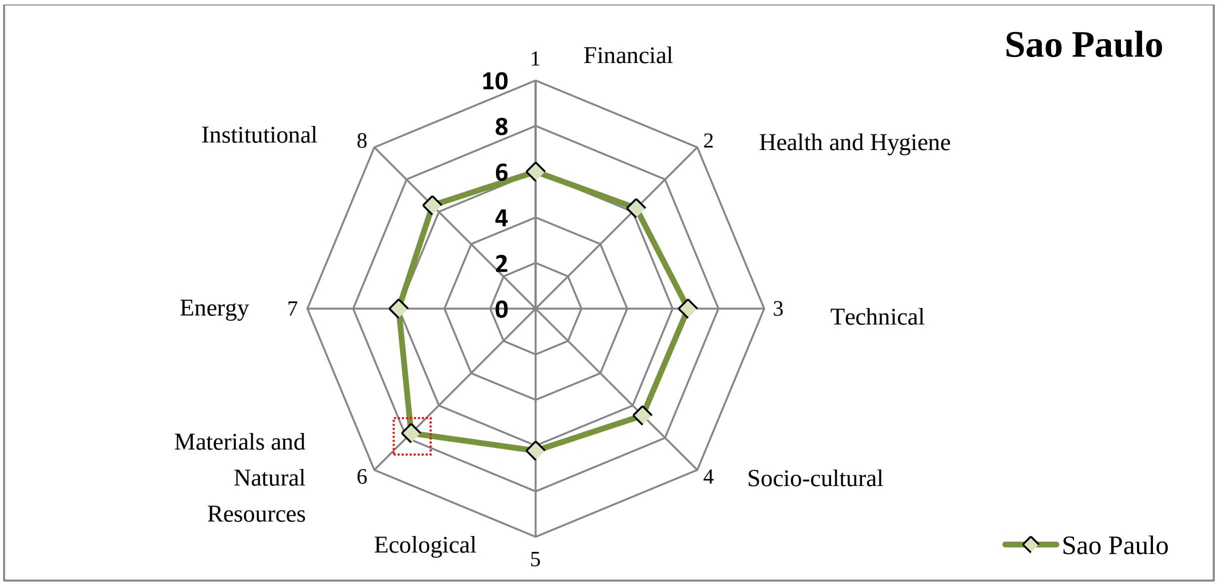

Figure 27: Radial plot displaying the adaptability of the sanitation system implemented within the SANIRESCH project in Sao Paulo considering trade-offs between the indicators

In the table 36 and figure 27 is shown that all the dimensions have an average performance ranging the values from 6.0 (Financial and Energy) to 7.7 (Materials and Natural Resources). The causes of such performance cannot be identified as in the indicators analysis (see section 4.1). However, it is necessary to highlight that the fact that the dimensions show an above moderate performance is considered a positive feature with regards to the adaptability because it implies that when the indicators are aggregated the number of indicators with a positive effect to the adaptability of the system in Sao Paulo has more influence that the indicators with a negative effect. This is the case in all the dimensions, especially in the technical and the materials and natural resources dimensions. However, to identify the specific factors it is necessary to carry out the indicators analysis.

5.2.3 Expert's feed-back

As it has been already mentioned, the questionnaire included a final section where the experts were asked to give their personal evaluation about the sanitation system implemented within the SANIRESCH project. The comments of the experts about the questionnaire and the methodology (dimensions, indicators and specific factors to take into account) are also included in this section.

1. With regards to the suitability of the technological components for Sao Paulo, the expert states that the UD flush toilets, the waterless urinals and the PE tanks have a positive effect. The MAP reactors and the 2 MBRs are irrelevant according to the expert. However, the expert added in the comments section of this question that he believed that the reactors are very important, but that he assigned as irrelevant due to the necessity to evaluate other kinds of biological, physical and chemical treatments. Finally, the reuse of the final product to the agriculture aimed in the design process of the sanitation system is considered positive.

2. The expert would recommend the implementation of the system in Sao Paulo. The reasons provided are that there is not an easy solution to solve the sanitation issue in Sao Paulo. The city has to import water from water basins far from the city (more than 200 Km). Due to this fact, there are incentives of water conservation in the city. For instance, it is compulsory to install rainwater harvesting devices in large buildings. Furthermore, in Sao Paulo most of the sewage is collected (from 50% and 75% is treated in several large wastewater treatment plants). However, in the surrounding cities (the Great Sao Paulo), most of the sewage is not treated. Also in the peri-urban areas several million have their sewage dumped in the nearest river without any kind of collection pipeline and treatment. The expert also states that Sao Paulo is the wealthiest city in Latin America, and thus it should look for innovative solutions that go beyond the conventional waterborne systems. Systems capable to save water at buildings (like the waterless urinals) can have a significant impact on water savings. Also the reuse of water at household or community level such as greywater is a reasonable accepted solution. However, space for agricultural activities in the city is complicated. Probably the urine and faeces should be exported to other places nearby.

3. With regards to the modifications, he stresses that the costs of the system are very important if the system has to be implemented at larger scale (e.g. for large cities like Sao Paulo). If very small scale is considered, then this point does not make any difference. However, to have an impact in such a large human agglomeration (one of the largest in the world) the upgrade for a real big scale is a crucial point.

As the expert states, there is a need to save water in Sao Paulo due to the enormous pressure of the population on the water resources of the zone. However, the UD flush toilets are not considered a water conservative technology with regards to the current state-of-the-art of these devices (Borsuk, et al. 2008). Due to this fact, if the goal is to reduce substantially the water consumption and due to the high availability of energy that there is in Sao Paulo, a vacuum toilet instead of the UD flush toilet combined with waterless urinals would be a better solution. However, the main drawback of this system is that there would not be diversion of urine which would prevent the production of N-based fertiliser specifically from urine. This situation would not be dramatic from the financial viewpoint due to the moderate price of the chemical fertilisers and the low price of the soil amender as well as the large distances that the final product need to be transported to be reused. These factors cause that the final product cannot compete from a financial viewpoint. Then, the treatment would have to be completely modified and focused to the composting process of the blackwater. The process could generate biogas but due to the characteristics of Sao Paulo it does not appear to be a very desirable option. An alternative option would be to use vacuum source separation toilet (Oldenburg, et al. 2007; Otterpohl, 2010). However, the performance of these toilets has not been good until the moment (Otterpohl, 2010). Hence, these devices are not robust enough and there is still a need to further develop the system. Another alternative would be to use the vacuum without separating the urine but to apply new concepts in the composting process of the excreta, like the Terra Preta sanitation (Otterpohl, 2010).

Focusing on the need for a sanitation improvement, the system implemented within the SANIRESCH project can provide access to sanitation for the areas of Sao Paulo which are not currently connected to the grid. Due to the relative high level of welfare of the city and the funding and subsidies available the implementation of the system could be desirable from a health and hygiene and financial viewpoint at a small scale. However, as the expert points out, if the system needs to be implemented at large scale, the lifecycle costs of the system must be reduced. Notwithstanding, this appears not to be the tendency of the system and according to Lazo (2010) the costs of the system do not significantly reduce with an increase of the scale under the current conditions. However, the costs are reduced when the numbers of daily uses of the system increase (Lazo, 2010). Therefore, the sanitation system should be implemented as an intermediate solution at small scale which comprises the ecological sanitation principles but that it is not adequate for a large scale implementation at long term.

5.3 Durban

The final list of indicators selected by the expert on sanitation representing the city of Durban is attached in the electronic attachments, section 7. The final adaptability indicators are also displayed in the figure 28.

5.3.1 Analysis at indicator level

5.3.1.1 Financial indicators

The technology wise indicators selected by the representative of Durban are the same than for Sao Paulo (investment, maintenance, replacement and treatment costs, see section 5.2.1.1) which have an overall low performance due to the high costs to implement and operate the system (see section 4.1). In this case, the analysis did not include the transport costs.

Durban shows a high level of welfare, which added to the moderate funding and subsidies possibilities, potential service fees and price of the water, can compensate the high costs of the sanitation system as discussed in the section 5.2.1.1. However, it is important to highlight that both the prices of the chemical fertiliser and the soil amender are very low, which complicates the financial feasibility and efficiency of the final product produced within the system as previously discussed in the section 5.2.1.1.

5.3.1.2 Health and hygiene indicators

The technology wise indicators selected by the expert are the safe collection and safe disposal, the exposure to pathogens and potential risk of the final product. As it has been discussed for Sao Paulo (see section 5.2.1.2), these indicators show a good performance with the exception of the risk of the final product which is high. In this case, the expert did not consider the exposure to hazardous substances but the exposure to pathogens as a crucial factor to take into account.

The regular access to conventional sanitation is low, which is considered as a positive feature with regards to the adaptability because there is a need to improve the sanitation coverage of the city. Hence, the implementation of the system could enhance the access to sanitation in the city. This factor is strictly correlated to the high need for a sanitation improvement in Durban, which is in part consequence of the reduced access to conventional sanitation. The results for the availability of clean water and the availability of sanitation are very high. However, this data is significantly higher than the values expected and contradictory with the values of the access to sanitation and need for a sanitation improvement. The data was included in the IAAF but the final calculation of the dimension was also performed without considering these results. The performance of the dimension without considering these two contradictory values is reduced (5.3) due to the fact that the availability of clean water is considered a positive feature with regards to the adaptability of the sanitation system because implies that the water available to operate the water is hygienically safe. However, if the availability of sanitation is very high the need to implement the system from a health and hygiene viewpoint is reduced significantly due to the fact that it is considered a negative feature with regards to the adaptability.

5.3.1.3 Technical indicators

The technology wise indicators selected are the system adaptability to different types of users, the technical versatility, the complexity, treatment efficiency, the durability and the O&M requirements. These indicators are the same than Sao Paulo with the difference that in this case the scale of the system has not been included in the analysis. The values and effect of the technology wise indicators have already been discussed in the section 5.2.1.3.

All the technical indicators focusing on Durban show a moderate performance. Firstly, the indicators related with the capacity to import and distribute the technological components of the system as well as the capacity to obtain imported spare parts indicate that Durban is capable to obtain imported products and distribute them satisfactorily. This is considered as a positive feature with regards to the adaptability because some of the parts of the system, specifically the UD flush toilets need to be imported from Germany because the market of these products is not very developed. Another positive characteristic is the local availability of both spare parts and technological components of the system which reduces the dependency to the exterior and reduces the investment and operating costs. Furthermore, the availability of technical know-how also shows a moderate performance which is considered as a positive feature with regards to the adaptability because implies that there are people who can operate, maintain and repair the system. Finally, the level of decentralisation of the sanitation system is high, which also is a positive feature because it implies that there are decentralised systems already implemented and operating in Durban.

5.3.1.4 Socio-cultural indicators

The technology wise indicators selected by the representative of Durban are the same than for Sao Paulo. The discussion of these indicators with regards to the adaptability is found in the section 5.2.1.4. Furthermore, the expert of Durban also includes the reliability of the system, which shows a low performance which indicates that the system is less reliable than the conventional wastewater system in Hamburg due to the lower level of development of the technological components of the system and also due to the higher complexity of the system (diversion of urine, recycle of nutrients and recovery of water as service water).

With regards to the location wise indicators, it is observed that the farmer and user acceptability are low. This indicates that there is a cultural resistance to use the system which probably could be caused by the UD flush toilets. This is considered as a negative feature with regards to the adaptability. This is regarded as a significant shortcoming of Durban with regards to the adaptability of the system due to the fact that the user interface of the system requires a change in the way the toilet is used. Hence, there is a need that the user accepts these changes in order that the system works efficiently. The farmers are not willing to reuse the final product in the agriculture, which could be motivated due to socio-cultural barriers as well as that the price of chemical fertiliser and soil amenders are very low. The population density of the city is relatively high which is considered as a negative feature with regards to the adaptability as it has been discussed in the section 5.2.1.4. Furthermore, the increase of the livelihood related to the implementation of the system is low indicating that it is not expected that the system contributes to an increase of the social welfare in Durban. Oppositely, the social acceptability of the final product show a good performance, implying that there is not a strong social opposition with regards to the reuse of nutrients from excreta to the agriculture. This is regarded as a positive feature with regards to the adaptability of the system because there would be the possibility to have a market for the final product.

5.3.1.5 Ecological indicators

In the case of Durban, the technology wise indicators assessed are the water pollution, the potential soil pollution and the quality of the final product, which have been already discussed in the section 5.2.1.5.

The freshwater quality of the water is low in Durban which is considered as a negative feature with regards to the adaptability because the system requires a source of water to operate. Hence, if the quality is bad, the system adds an extra pressure to the fraction of water of good quality. The food scarcity shows a very high score, which is considered as a positive feature with regards to the adaptability because it indicates that there is a need to improve the production of food, which can be enhanced by the production of soil amender and fertilisers as a result of operating the system. Both the richness of soil organic matter and the physical water scarcity show a moderate value. The moderate richness of the soil and the significant food scarcity could be enhanced by the recovery of organic matter from the excreta which could be used to enhance the richness of the soil. This is considered as a positive feature with regards to the adaptability because it justifies the implementation from an ecological viewpoint.

5.3.1.6 Materials and Natural Resources indicators

The technology wise indicators analysed are the same than in the case of Sao Paulo and their effect have also been discussed in the section 5.2.1.6. The representative of Durban also selected the reuse of treated wastewater. This technology wise indicator shows a very good performance due to the fact that the treated wastewater within the system is reused as service water.

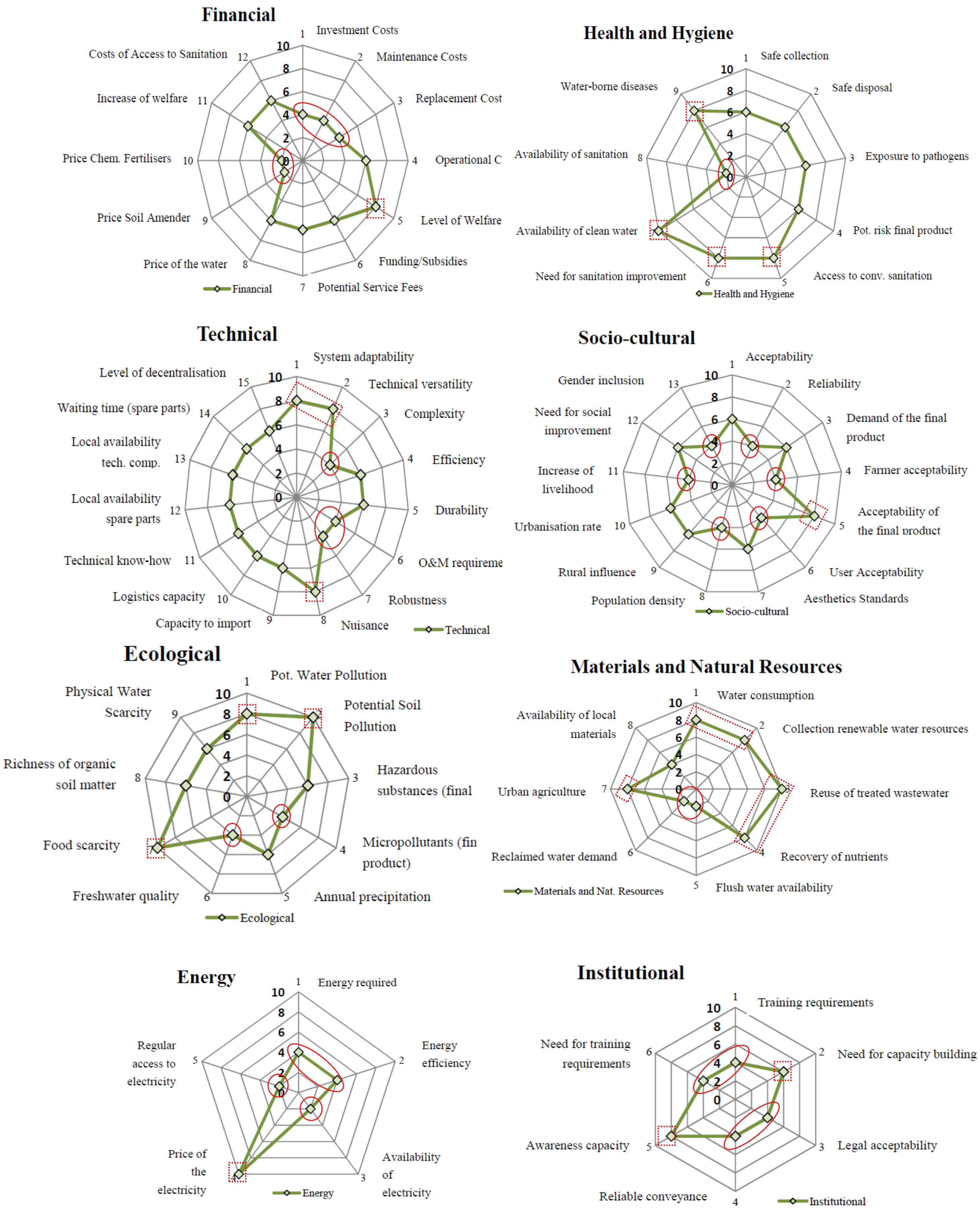

Figure 28: Radial plot of the adaptability criteria included in the IAAF to assess the adaptability of the sanitation system implemented within the SANIRESCH project in Durban

It is very important to stress that the flush water availability in Durban is very low. This factor is crucial with regards to the adaptability of the system because without flush water the UD flush toilets cannot be operated. This low availability of flush water causes that the system could be only implemented in the areas of the city where a regular supply of water can be assured. Even though the value is very low, it should not be considered as if there is not flush water in Durban but as the availability of flush water is very scarce and difficult to obtain. On the other hand, the fact that urban agriculture is practised in Durban could be a source of demand for organic fertilisers, soil amender and reclaimed water, which is considered a positive feature with regards to the adaptability. Finally, the availability of local materials shows a low score implying that the materials required to implement, operate and maintain the system must be imported, which is a negative feature because eventually increases the costs and the suitability of the system.

5.3.1.7 Energy indicators

The indicators selected are the energy required and the energy efficiency (technology wise). The technology wise indicators with regards to the energy dimension analysed in the case of Durban are the same than for Sao Paulo and the values and effects of these indicators have already been discussed in the section 5.2.1.7.

With regards to the location wise indicators, it is necessary to highlight that the availability and regular access to electricity have a very low score, which indicates that there could be serious complications to adapt the system because it needs a constant source of electricity. Furthermore, the amount of electricity that the system needs to operate is high and constant. Hence, Durban shows a crucial shortcoming with regards to the adaptability: it cannot provide the requirements of electricity at a regular basis. However, the price of the electricity is very low, which is considered as a positive feature with regards to the adaptability because in those areas where it is possible to have a constant source of electricity, the costs of this electricity will not be high.

5.3.1.8 Institutional indicators

The indicators elicited by the expert representing Durban are the same than for Sao Paulo with regards to the technology wise indicators and the values and effects have already been discussed in the section 5.2.1.8.

The need for training requirements to use adequately the system is high, which even though is considered as a negative feature with regards to the adaptability, it is normal that a new system requires certain training for the users and operating personnel. The awareness capacity of the study area is high, which could compensate the high training requirements related to the sanitation system in the sense that Durban is capable to train them efficiently. A negative factor is the legal acceptability of the system which is low, which complicates the reuse of the final product in the agriculture. The lack of a reliable conveyance system is considered as a positive feature because it facilitates the implementation of a decentralised system with an autonomous conveyance system.

5.3.2 Analysis at dimensional level

Table 37: Final outcome of the MCDA embedded within the IAAF for Durban considering trade-offs amongst the indicators

Durban	Score	10 scale
Financial	250.0	5.0
Health and Hygiene	333.3	**6.7**
Technical	300.0	6.0
Socio-cultural	261.5	5.2
Ecological	333.3	**6.7**
Materials and Nat. Resources	312.5	6.3
Energy	220.0	4.4*
Institutional	283.3	5.7
Total	2,260.7	5.7

The results of operating the MCDA are aggregated to produce a final outcome showing the performance of each dimension with regards to the adaptability of the sanitation system implemented within the SANIRESCH project in Durban, which is shown in the table 37 and the figure 29.

Durban shows a low performance in the energy dimension as a consequence of a low availability of electricity which complicates the operation of the process due to the fact that the system needs a regular source of electricity. Furthermore, the electricity requirements are high. Therefore, this dimension will determine the adaptability of the system in Durban. The materials and natural resources dimension show an average performance. However, the analysis of the indicators has highlighted the impossibility to provide a regular and constant flush water supply, which limits the implementation of the system to the areas where the flush water can be provided. Hence, this dimension will also strongly determine the adaptability of the system in the city. The health and hygiene and the ecological dimension show above average results, which is a positive feature with regards to the adaptability because it implies there it is desirable from the health and hygiene and ecological viewpoint that the system is implemented.

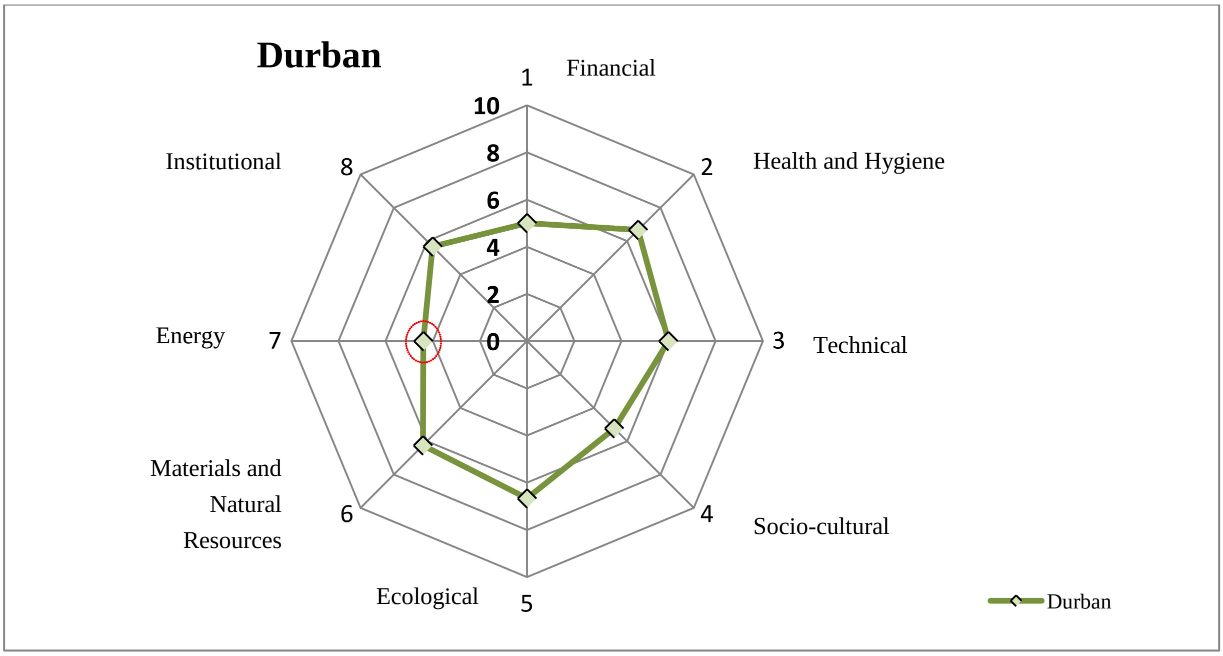

Figure 29: Radial plot displaying the adaptability of the sanitation system implemented within the SANIRESCH project in Durban considering trade-offs between the indicators

5.3.3 Expert's feed-back

1. The expert stressed the fact that there is a need to include in the financial dimension the life cycle costs of the system. However, the lifecycle costs were not included in order to analyse the separated contribution of the different technological components and components of the sanitation system to the costs of the system.
2. The expert considered in the evaluation of the importance of the indicators that the potential health risk of the reuse of the final product was irrelevant in Durban. He added in the comments of this question that the reuse at this stage is a research question and there is a need to discover why the reuse is not practised in Durban. This is an important factor with regards to the adaptability of the system because it points out that currently the reuse within the sanitation is not practised in Durban. Hence, the implementation of the system looses one of its main strengths, which is the recovery of nutrients and organic matter. This affects negatively the adaptability of the system because causes that the system is less efficient and useful.
3. With regards to the technological components of the sanitation system, the expert considers that the UD flush toilets, the waterless urinals, the MAP reactor and the reuse to the agriculture of the final product have a positive effect in the adaptability of the system to Durban. The PE tanks and the MBRs are irrelevant and they would not play any significant role. However, the analysis of the indicators has highlighted that the UD flush toilets complicate the adaptability of the system in Durban because they require a constant flush water supply. Hence, the limited availability of flush water limits the

implementation of the system only in those areas or situations where the flush water can be regularly supplied. This drawback affecting the adaptability is caused by the UD flush toilets. Furthermore, the MBRs are not irrelevant for Durban because this technological component is responsible of part of the high consumption of energy, which is precisely one the factors that threatens the adaptability of the system in Durban. Similarly than the flush water, the treatment limits the adaptability of the system to those areas where electricity can be provided at a regular basis.

4. The expert would recommend the implementation of the system in Durban, but only to some specific places, not like a general solution because there are zones that should not be implemented. The expert stressed the fact that different areas of the city are more appropriate for different systems. In this way, there is no a single solution at Durban scale.

5.4 Recommendation of the adaptability within the IAAF

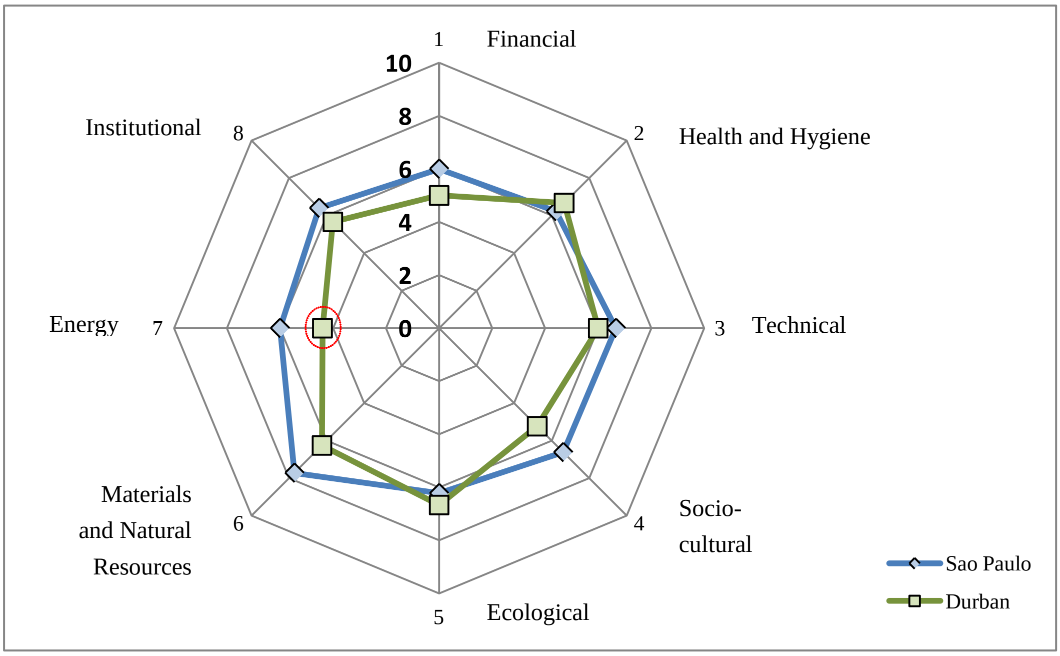

Figure 30: Radial plot of the displaying the adaptability of the sanitation system implemented within the SANIRESCH project in the two case studies

The figure 30 shows the superposition of the aggregated performance of the indicators for the two case studies used to test the framework.

The evaluation procedure proposed within the IAAF indicates that the sanitation system would be highly recommended in Sao Paulo. This is due to the fact that at least one of the requirements I-V is higher than 7 (the materials and naturals resources) and the three requirements VI-VII are from 6-7, indicating that the system is desirable from the health and hygiene, ecological and socio-cultural viewpoint.

However, this conclusion cannot be stated without uncertainty due to the fact that the scale of the analysis need to be reduced because it is not possible assess the adaptability for the whole are of Sao Paulo because there are too many local factors that can vary the outcome. Hence, there could be some specific situations which cause that the system is not recommended at all in Sao Paulo (e.g. in a new primary school built in a slum area). Furthermore, the fact that the data to evaluate the adaptability come from a strictly qualitative evaluation of only one representative add a significant share of uncertainty in the results as it has been discussed in the section 2.4.2.8. Therefore, the results should interpreted as an indication that that Sao Paulo shows a high potential in the adaptability of the system, as it has been discussed in the section 5.2 and now it is indicated again with the final evaluation step of the framework. To carry out further research and investment of human capital and resources to assess in which specific areas of Sao Paulo the system could be successfully implemented would be highly appropriate.

Oppositely, the IAAF results show that the system is not suitable to be implemented in Durban due to the fact that one of the requirements I-V, (the energy V) is lower than 5. One point necessary to highlight which is not reflected in the final evaluation of the IAAF is that the flush water availability is very low in Durban, and this is considered a crucial negative feature because the system needs a regular source of flush water. The reason why it is not reflected in the final aggregation is because the fact to aggregate the indicators within the materials and natural resources compensate the negative effect of this indicator. It is precisely due to these trade-offs amongst indicators that the analysis of the data within the IAAF should be carried out at strictly both the dimensional and indicators level. Hence, the analysis of the indicators indicates that the adaptability of the system would not be recommended either from the materials and natural resources dimension due to the lack of flush water.

Notwithstanding, similarly than in the case of Sao Paulo, this results should be considered as an indication that Durban shows crucial drawbacks that would complicate the implementation of the system at a city level. However, this does not imply that there are some specific situations (e.g. if the flush water is provided by a collection container and the electricity by means of an electricity generator) where the adaptability of the system in Durban could be acceptable. Another point is that if to operate an energy intensive system by means of an electricity generator is appropriate and/or sustainable.

5.5 Quick-scan

The quick scan is meant to save human resources and investment of capital due to the assessment of the adaptability by means of the IAAF is a process that requires a high investment of time and resources. The results of the quick scan are shown in the figure 31 and are coherent with the results after implementing the IAAF.

There are strong indications that suggest that Durban should not be an adequate place where the sanitation system within the SANIRESCH project would be recommended to apply due to the very low scores in the flush water availability and energy availability and the very low score in the legal acceptability. Therefore, to implement the IAAF as a tool to assess the adaptability of the sanitation system within the SANIRESCH project would not be recommended.

Oppositely, Sao Paulo would be a place where the IAAF would be recommended to carry out because there are strong indications that suggest that the system has a high potential to be successfully implemented at a city level: high performance in all the indicators with the exception of the investment and funding options which shows a moderate performance.

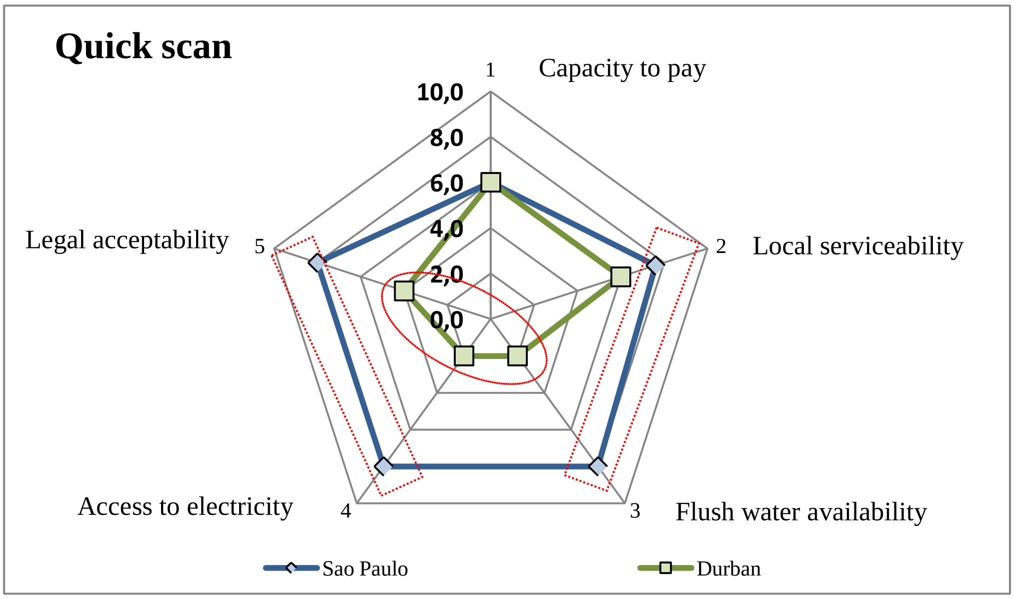

Figure 31: Radial plot displaying the results of the quick scan to assess the adaptability of the sanitation system implemented within the SANIRESCH project in the two case studies

6. Final remarks and Lessons learnt

6.1 Questionnaires

- A questionnaire is not a good tool to collect data with regards to complex set of indicators because there is a limitation in the communication between the participant and the designer of the questionnaire which adds a dramatic complexity factor to the collection of the data. The quality of the data would have been significantly improved if instead of questionnaires, focus groups combined with personal semi-structured interviews would have been used to collect the data (which allows direct interaction with the participants). Hence, the doubts and difficulties faced by the experts would have been solved and the feed-back would have been more robust and less uncertain. However, in this research this was not possible due to the high investment of time and resources that this approach requires.

- To use a questionnaire embedded in the software "sureveyguizmo$_{TM}$" (and by extension, the use of online surveys with similar characteristics) it is not recommended as an option when the complexity of the data to fill and the time to carry out the questionnaire are high (i.e. 30 minutes). The fact of not being able to control crucial design parameters (e.g. to be able to stop the on-line survey and continue in another moment) and also the fact of being completely dependent on filling the survey on-line significantly increases the complexity of the data collection and determines the quality of the feed-back (e.g. the experts are not able to think the answers). In the case of using a questionnaire, it is recommended to embed the questionnaire in a word document or excel data sheet. In this way, there is not any kind of dependence to the internet connection and also it gives more freedom to the participant. To include these simple considerations is expected to increase considerably the response and the quality of the data obtained.

- The questionnaire to assess the performance of the sanitation systems in Germany was long and complex to fill, which in addition to the drawbacks of the categorisation process caused that 2 of the 7 experts initially willing to collaborate did not eventually participated in the research. Hence, these two experts (and also the expert representing the conventional system) expressed that the questionnaire was too long and the fact of comparing their sanitation system with an ideal representation of either a conventional sanitation system (innovative systems) or an ecological sanitation system (the conventional system) caused that the data was not robust because allowed to the participants to choose the system which could enhance better the performance of their system. This observation has been identified as an important drawback of the MCDA methodology which needs to be improved in future research.

- The IAAF questionnaire was also long and complex. The representative of Durban expressed that the questionnaire was complex to carry out because “there were too many questions, each of them with different attributes”. He was not positive about if his reply was very consistent as he could not have time to think about the answers because the software used to create the electronic survey did not allow saving the answers. Even though to show the complexity of the assessment of the adaptability was a methodological decision (it was decided to include as much indicators as possible in the inventory in order to identify the maximum number of factors which could have a key role in the adaptability of the system), it is clear that this decision increases dramatically the complexity of the questionnaire. In future research, it is recommended to improve the structure and design of the questionnaire or to reduce the complexity of the questions in order to enhance the filling process to the participants.

6.2 MCDA

- The data used in the MCDA should combine qualitative and quantitative indicators which increases the quality of the data and the robustness of the results. However, this is not possible until there is robust quantitative data with regards to the performance of the different technological components of the sanitation assessed in this study.

- The number of experts interviewed representing the systems and the same city needs to be increased in order to give robustness to the data. Furthermore, all the stakeholders involved in the implementation of the system in the potential area of implementation should also be included.

- To identify motivated stakeholders with a high level of interest in the research is a crucial step to have data of high quality.

- A sensitivity analysis could be carried out in order to identify indicators which play a role in the performance of the sanitation system.

6.3 IAAF

- The IAAF and the methodology of this study have been designed to alleviate the drawbacks caused by the state-of-the-art of the sanitation system and the general lack of data of crucial components of the system. Hence, the analysis has focused in the "expert on sanitation" stakeholder group because at this stage of the development of the system, they are the only ones with enough knowledge to give an evaluation of the system and its adaptability. The viewpoint of other important stakeholders is not included in this analysis. However, the IAAF has been designed in order to include the preferences and values of the rest of stakeholders and actors involved in the decision-making.

- In future research or real case application of the IAAF, it is recommended to operate again a MCDA to obtain updated and robust values of the technology wise indicators. This is necessary due to the following reasons: Firstly, the data with regards to the sanitation system implemented within the SANIRESCH project comes exclusively from the qualitative evaluation of one expert responsible of the operation of the system in Eschborn. Secondly, it is also recommended that such MCDA is carried out between other stakeholders (e.g. users, operating personnel, etc.) in order to include their preferences. In addition, the MCDA carried out in this study is exclusively qualitative due to the fact that the current state-of-the-art of the technology is not developed enough to have quantitative robust data from the different components of the system, especially the phase 2 of the SANIRESCH project, which involves basically the treatment of the separated fractions and the reuse.

- Specific key indicators which were not selected by the two experts were included in the analysis because this investigation wanted to assess the performance of such parameters in the implementation area. However, in a real case implementation, the elicitation process of the key adaptability criteria should include a final step where the stakeholders negotiate which indicators will be selected to carry out the decision-making process.

- Missing values identified in the data were substituted by values according to Literature values at the best of the knowledge of this research.

- A drawback of the IAFF is that if only the aggregated results are taken into account the effect of crucial indicators can be compensated by other indicators within the same dimension (as it is shown in the section 5.4 and 5.5). The solution to this problem is to assess the adaptability at both the aggregated and non-aggregated level in order to be able to identify such trade-offs that can compensate the effect of crucial indicators. However, to carry out such analysis implies to invest a significant amount of resources and time. A solution to this problem included within the IAAF is to carry out the quick-scan analysis, which only focuses in the crucial indicators that determine the adaptability of the system focusing exclusively in the requirement to implement the components of the sanitation system.

- The values of the technology wise indicators are in reference to the conventional wastewater system in Hamburg. Therefore, if the value is moderate implies that the performance is equal than the conventional system. In some cases, the fact of having a performance equal than the conventional system can be considered as a positive feature and another times as negative. The IAAF does not distinguish this. Hence, an average value is considered as if the performance for these indicators was average. This needs to be solved by the substitution of the technology wise indicators by values evaluating strictly the performance of the sanitation system and not a comparison with the conventional system.

- The analysis has been carried out at city level because initially it was considered that this was an adequate scale to assess the adaptability of the system. However, it is necessary to decrease the scale of analysis with regards to future research. Hence, it should be approached not cities of fast-growing economies but specific areas within cities of fast-growing economies (e.g. districts). The adaptability can dramatically change in parts of the same city (Bracken, et al., 2008) due to the complexity of the urban settlements. In fast-growing economies, where the differences among the people in the same city are huge, this factor has even a stronger effect. Hence, what is convenient for a part of the city might not be convenient for another part because for instance, within the same city some districts have characteristics of high-income countries and other low-income characteristics. The same situation happens with other characteristics not directly related to the financial dimension. For instance, a part of the city can be adequately connected to the grid and thus have 24h reliable water supply and other parts of the same city not. Similarly, parts of the city inhabited for specific ethnic and cultural groups can influence the adaptability of the system at a socio-cultural level.

6.4 Potential Improvements

The improvement of the system is a complex step which falls out of the scope of this research. However, during this study there have been identified some potential areas of improvement.

The main shortcomings identified with regards to the adaptability to fast-growing economies is the UD flush toilets (which require a regular access to flush water) and the high complexity of the system (which produce that the system is very energy intensive and also increase the lifecycle costs of the system). In order to alleviate these factors, the system could be modified as it follows.

6.4.1 UD flush toilets

- To include any type of rainwater harvesting device in order to collect water could decrease the dependency of an external water supply of the system. This modification would be useful for areas with moderate water scarcity (as an alternative source of water) and also in areas where there is no regular flush water. In this case, the implementation of the system could require an alternative flush water source, as a water container which would provide the flush water. The water harvested could be used to fill this container and be part of the flush water of the system.

- In areas where there is a severe water scarcity, the UD flush toilets could be exchanged by vacuum toilets. However, this would imply not separating urine and depend more upon a regular supply of electricity (the system would be more energy intensive than the current one). Another possibility would be to switch to vacuum source separation toilets (the system would be more energy intensive but the urine could be separated). This type of toilet collects urine and a small, concentrated amount of brownwater (faeces with about 1 L of flush water) [Münch & Winker, 2009)].

6.4.2 Treatment

The main goal would be to reduce the complexity and dependency on energy of the system. The modification of the treatment step has a direct consequence in the final product and at the same time is dependent to the collection component of the system.

- If the system includes UD flush toilets and waterless urinals as the components of the collection system (or a vacuum source separation toilet is used as a replacement for the UD flush toilets) the MAP reactor is considered to be an adequate option to treat the urine diverted. However, a shortcoming is the need to add MgO to obtain the struvite. In this way potential synergies with industries which produce MgO as a waste, like desalination plants could decrease significantly the costs of the process.

- However, if the potential area of implementation has problems of access and/or availability of energy, a treatment less energy intensive would be to store the urine, as it is already carried out within the system. The main shortcomings related to the storage of the urine is the need to transport large volumes of the final product after the required storage time, which requires a significant investment of financial resources and materials (fossil fuels to transport the liquid fertilizer).

- Another alternative could be to lacto-ferment the urine fraction. This process is an innovative way to treat the urine fraction which consists in the addition of finely sliced wood material (80%), a microbial mix (10%) and ground charcoal powder (10%) to and existing amount of soil (10%) (Gensch, 2010). Specific shortcomings of this treatment are that it is a very innovative process, the high demand of land and a regular watering of the composting material. The access to charcoal could not be considered a significant shortcoming due to the fact that fast-growing economies are considered to have at least moderate capacity to import material and/or moderate local availability of materials.

- The treatment of the faecal matter could be carried out differently consuming less energy by implementing new ways to compost the brownwater. Hence, to carry out the "innovative" Terra Preta sanitation process to the brownwater fraction (Factura et al., 2010) could reduce the dependency on electricity of the system. A significant advantage of this system is that it does not strictly require separating urine and it can be carried out composting both the urine and the faecal matter collectively or the faecal matter exclusively. Hence the collection component could be a source separating system (UD flush toilet or vacuum), a vacuum system or even a conventional flush toilet depending on the specific requirements of the area of implementation. The shortcomings are the same than the case of the urine composting.

Another point to take into account in order to reduce the complexity of the system and the energetic requirements is to shift the management of the system to a semi-decentralised level. In this way, the collection of the separated fraction could be done on source but the treatment could be carried out on-plant by sanitation service provider companies at a medium-scale level. These companies would be responsible to collect the separated fractions on-source and transport them to the treatment plant. This could be a good option that allows shifting the responsibility to treat the separated fractions and reuse the final product to private companies with a commercial interest in carrying out the process.

However, as it has been previously pointed out, the best collection and treatment process will be context specific and thus will depend on the needs and preferences of the local stakeholders and actors involved in the decision making process and the characteristics of the potential area of implementation.

7. Conclusions

7.1 Adaptability of the system

- More sustainable sanitation systems imply more complex user collection systems (with more responsibilities, maintenance requirements and higher investment costs, at least within the current state-of-the-art of the urban sanitation). It should not be expected to use sanitation systems with lower water consumption, recycling of nutrients and organic matter, using locally available and environmental friendly materials without compromising other dimensions like the financial, socio-cultural or energy. Therefore, at least at the current state-of-the-art of the urban sanitation technologies, it can be concluded that to maximise one specific dimension of the sustainability of a sanitation system implies to minimise another. Hence, the maximisation of all the dimensions of a sanitation system is not possible but rather a trade-off amongst the dimensions should be found that satisfies the interests of the local stakeholders. Therefore, the aim should be to find a sanitation system adequate to a specific area of implementation. A system would be adequate to a specific area when such area "needs" the dimensions where the system shows a good performance and can deal with the dimensions which show a bad performance.

- To assess the adaptability of the sanitation system in urban areas of fast-growing economies there is a need to reduce the scale to a level lower than the city level. Hence, in different areas of the same urban area, the sanitation can be (or not) adaptable.

- The framework can only serve as an aid in the decision making process (identify the weaknesses and strengths of the city with regards to the adaptability of the sanitation system, manage and visualize information as well as to facilitate discussion).

- The collection of the data is a crucial part of the MCDA and the IAAF, and their quality influences the whole decision making process in both situations. For that reason the data acquisition is a fundamental step in the assessment of sanitation assessment technologies.

- After testing the IAAF, it is concluded that potential areas where the sanitation system will be adaptable are those urban areas of fast-growing economies which are able to:
  - -Pay for the system.
  - -Maintain and operate the system from a technical viewpoint.
  - -Provide a regular availability of flush water.
  - -Provide a regular availability of electricity.

-Assure institutional acceptability of both the operation of the system and the reuse of the final product.

Moreover, the implementation of the system must meet on of these three requirements in the potential area of implementation:

-It is socially desirable.
-It is desirable from health and hygiene viewpoint.
-It is desirable from an ecological viewpoint.

- The main limitations of this study are the time and resources constraint, the need to reduce the scale of the analysis and the incapacity to assess the adaptability of a system which still is at a developing stage. Furthermore, the quality of the data processed has been affected by the use of strictly qualitative indicators, the use of a reduced number of experts and the shortcomings of carrying out only questionnaires.

7.2 Objectives of the research

- The MCDA analysis indicates that the sanitation system within the SANIRESCH project shows a moderate performance similar than the other innovation sanitation systems assessed and the conventional sanitation system in Hamburg. However, there are two things to take into account:

  1. The dimensions which show a good performance in the sanitation system assessed in this study (materials and natural resources and ecological) are the dimensions which show a bad performance in the conventional.

  2. The results must be considered carefully and rather as an indication than as a normative result due to the shortcomings of the methodology and the current state-of-the-art of the system.

- The IAAF suggests that, at least at a city level, the system has a high potential to be successfully implemented in Sao Paulo. Oppositely, in Durban the system has low probabilities to be successfully implemented.

- The weaknesses and strengths of the urban sanitation system with regards to its adaptability in urban areas of fast-growing economies as well as the potential factors of urban areas of fast-growing economies that can play a role in the adaptability of the system are shown in the table 38.

Table 38: Key indicators with regards to the adaptability of the system in fast-growing economies (the performance of the indicators in bold must be at least moderate in order that the adaptability of the system is accepted)

	Technology wise indicators		**Location wise indicators**
	Strengths	Weaknesses	Potential factors
Financial	- Potential benefits	- Investment costs - Maintenance costs - Replacement costs - Treatment costs Alternative: lifecycle costs (aggregation)	**-Level of welfare of the city** **-Funding and Subsidies (private and public)** -Potential service fees -Price of the water -Price of the soil amender -Price of the chemical fertilizers -Costs of access to sanitation Alternative: financial feasibility (aggregation)
Health and Hygiene	- Safe collection - Safe disposal - Exposure to pathogens	- Risk of the final product	- Access to conventional sanitation - Need for sanitation improvement - Availability of clean water - Availability of sanitation - Incidence of water-borne diseases
Technical	- Scale	- Adaptability - Versatility - Complexity - Capacity - Efficiency - Durability - O & M requirements - Robustness - Nuisance	**- Capacity to import technological components and spare parts** - Availability of technical know-how **- Local availability of technological components and spare parts** - Area and space availability
Socio-cultural	- Aesthetics		- Demand of the final product - Acceptability (Use, farmer and final product) - Aesthetics standards - Rural influence - Increase of livelihood -Urbanisation rate - Population density - Need for social improvement

	Technology wise indicators		Location wise indicators
	Strengths	Weaknesses	Key effect
Ecological	- Potential Water pollution - Potential eutrophication	- Soil pollution - Hazardous substances & Micropollutants (final product)	- Freshwater quality - Food scarcity - Soil nutrient depletion - Richness of soil organic matter - Physical water scarcity - Economical water scarcity
Materials and Nat. Resources	- Water consumption - Recovery of nutrients and organic matter - Reuse of treated wastewater	- Water consumption - Collection of water renewable resources	**- Flush water availability (access and 24h supply)** - Availability of local materials - Urban agriculture
Energy		- Energy consumption - Energy efficiency	**- Availability of electricity (access and 24h supply)** - Price of the electricity
Institutional		- Training requirements	- Need for training requirements **- Legal acceptability** - Awareness capacity - Service providers availability

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Appendices

I. Alternatives

In this section the main characteristics of the different sanitation systems assessed in the multicriteria decision analysis (MCDA) are described.

I.1 Ecological housing estate in Flintenbreite, Lübeck, Germany

I.1.1 General remarks

This sanitation system is implemented in an ecological settlement situated in Lübeck (Germany). In the settlement, which covers 5.4 ha, there are 117 apartments in twin houses, terraced houses and a central building with 4 flats up to 380 inhabitants (Oldenburg, et al., 2008; Otterwasser, 2009). It was designed and constructed between 1995 and 1999. Since 2000, the integrated sanitation system concept is being operated except the blackwater reactor, which is currently not operative (Otterwasser, 2009). According to Oldenburg, et al. (2008), initially it was designed for 117 units but it was interrupted at 30 units in 2000. The settlement is not connected to the public wastewater system and the wastewater is collected and treated in an internal cycle.

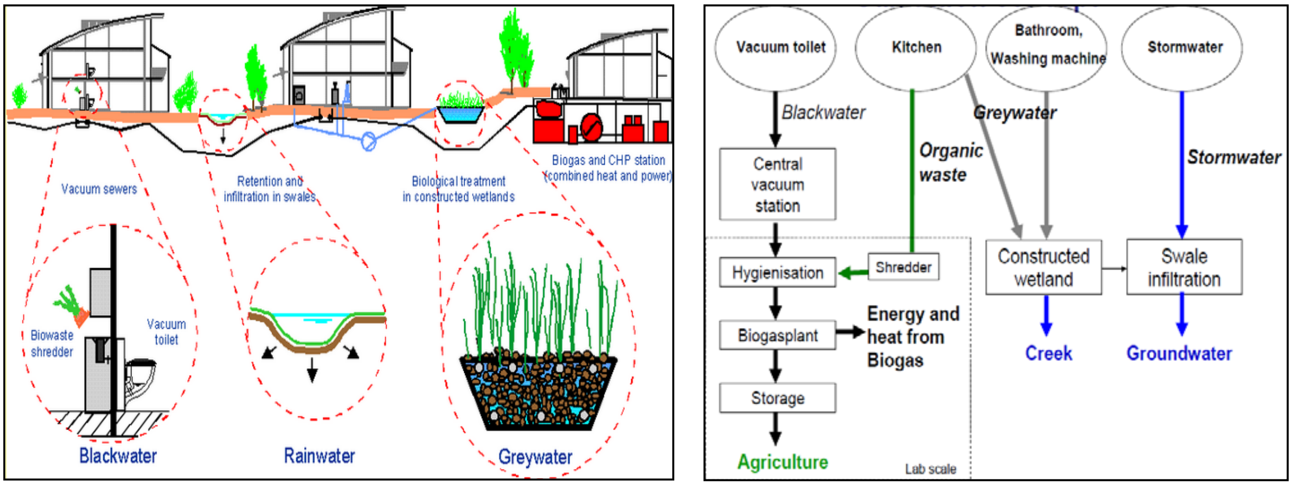

Figure 32: The three main sanitation systems implemented in the Flintenbreite-Lübeck (left) and a diagram of the applied sanitation components. Source: (Otterwasser, 2007) -left- and (Oldenburg, et al. 2008) -right-.

I.1.2 Technologies applied

The sanitation concept is shown in the figure 32. According to Otterwasser (2009) and GTZ (2005) the main characteristics of the Lübeck-Flintenbreite system are:

- **Collection and Conveyance**

  The sanitation system collects three separated fractions: urine and faeces (blackwater), rainwater and greywater. The rainwater is collected in small gutters from the roofs of the buildings and adjacent sealed areas The faeces and urine (blackwater) are not separated but collected in a vacuum toilet and transported collectively via a vacuum sewerage system (Otterpohl, 2002) with a very low water consumption (0.7-1.2 L per flush) to a central anaerobic digester. The biowaste from the kitchen is first collected at household level and transported manually to a conditioning plant where it is crushed separately to be subsequently mixed together with the blackwater. The greywater (wastewater from the kitchen and the bathroom) is transported by gravity pipes to a sedimentation tank.

- **Treatment**
  The rainwater collected is subsequently infiltrated to the groundwater in decentralised swales. The mixing of the low diluted blackwater and the shredded biowaste is first treated by thermal hygienisation (pasteurisation) and then followed by an anaerobic digestion (Wendland, 2008). The digested anaerobic sludge is stabilised by prolonged storage in order to produce an organic fertiliser. It is necessary to stress the fact that the anaerobic treatment is carried out at a lab scale and it is not currently operative (Oldenburg, et al. 2008). After a preliminary sedimentation, the greywater is fed in intervals to a vertical flown filter constructed wetland. The treatment plant operates partially due to the fact that the settlement is not fully inhabited.

- **Transport and Reuse**
  The organic fertiliser produced as a liquid effluent of the anaerobic digestion will be collected and used by farming cooperative. The biogas is a source of energy which can be used as a power and heat generation for the households in a combined heat and power unit (CHP). The treated greywater is directed to a nearby receiving water body, partially infiltrating on route. The stormwater is infiltrated and led back to the natural water cycle as groundwater.

I.1.3 Costs

The costs of the sanitation system cannot be verified in detail because the system is not fully operational. Notwithstanding, the estimated total investment costs of the integrated sanitation system are 600.000 € (Otterwasser, 2009; GTZ, 2005). That is 40% higher than the conventional wastewater system. However, the estimated operation costs are 25% lower than the conventional system. It is necessary to also take into account the additional energy demand of the vacuum system [45 KWh a year per inhabitant (Oldenburg, 2008)]. According to Otterpohl (2002), the infrastructure for the settlement including the sanitation system has been pre-financed by a bank and is operated by a private company where the owners of the buildings have the right to vote on decisions. Parts of the investments are covered by this connection fee. The fees for wastewater and organic waste charged cover operation, interest rates on addition investment and rehabilitation of the system.

I.1.4 Operation and maintenance

The production of blackwater is 5.0 l per inhabitant per day (Wendland, 2008). The low water consumption for the flushing of the toilettes leads to a drinking water consumption of less than 80 l per inhabitant per day in the housing estate -127 l per inhabitant per day- (Oldenburg, et al., 2008). The sanitation system is operated and maintained by external technical staff from the operation company (Otterwasser, 2009). The professional maintenance of the plants and education of the users and technical staff are indispensable (Otterpohl, et al. 2002). According to Oldenburg, et al. (2008), it is necessary to take into account that the vacuum system can be blocked by misuse. In addition, the control tubes can be clogged with fibres. The flush button is accident-sensitive which can lead a lower water reduction values and higher energy consumption levels. The pipes need to be cleaned with acid after 6 years of operation to remove blockades caused by the hardness precipitation. Finally, the toilet valves showed higher lifetime than expected. The material and energy intensity of the sanitation system is less than the half of the conventional system (Otterpohl, 2002).

I.1.5 Lessons learnt and practical experience

According to Otterwasser (2009):

- There is a high acceptance of the sanitation system amongst the inhabitants of the settlement. The vacuum system causes no loss of comfort and a significant reduction of water consumption.
- The risk of clocking can be effectively minimised by posing the pipes 0.8 m under the earth level (frost protected) and by user adequate user behaviour.
- The quantity of air and water needs to be adjusted by the operating personnel to optimise the use of the system. The system requires a certain level of technical know-how and experience to have an adequate performance.

According to Oldenburg, et al. (2008):

- There is a need to treat the exhausted air with a biofilter.
- The PE-pipes for the vacuum pipes require no steel or galvanised steel pipes due to the fact that the cleaning may hurt the inner surface and increases the possibility of corrosion.

I.2 Urban urine diversion and greywater treatment system, Linz, Austria

I.2.1 General remarks

According to Oldenburg, et al. (2009), this pilot ecological sanitation system is built as a part of an innovative urban area planning project named SolarCity (IWA, 2008) which has a large number of ecological features and is located in the southern part of Linz (Austria). The sanitation system holds 270 pupils in a primary a school with an integrated childcare facility (system 1) and 250 inhabitants in 88 flats (system 2). The total number of population equivalents is 460. This settlement was planned and constructed between 1998 and 2004. In 2006, the sanitation system started to operate and currently is still ongoing.

In the project area there are different types of buildings (single housed and flats), lakes, a creek, and the biggest joint biotope structure in Upper Austria (Oldenburg, et al. 2009).

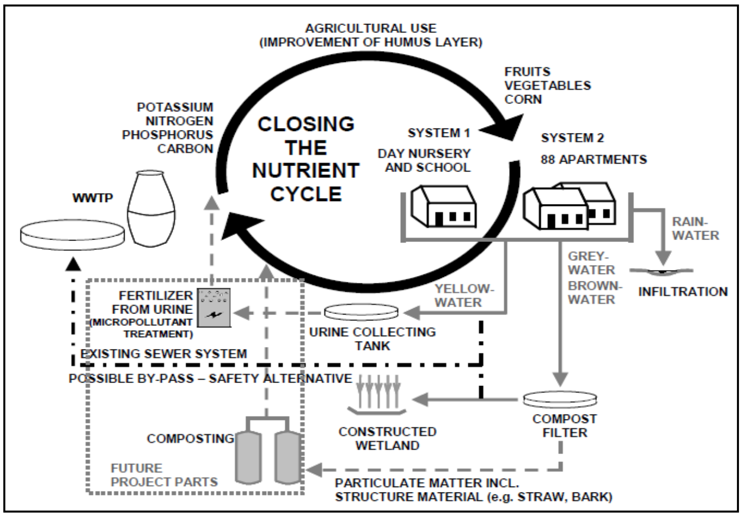

Figure 33: The sanitation system of the solarCity Linz. Source: (Hochedlinger, et al. 2008)

I.2.2 Technologies applied

The main processes carried out by this sanitation system are urine diversion, compost filters and constructed wetlands (Oldenburg, et al. 2009).

- **Collection and Conveyance**

  According to Oldenburg, et al. (2009), in the system 1 there are 12 urine-diversion (UD) flush toilets of the model "No-mix". There are also 20 waterless urinals supplied by Hellbrok. In the system 2 there are 115 UD flush toilets and also 2 separate pipe networks for urine and other wastewater.

- **Treatment and Transport**

  According to Oldenburg, et al. (2009), in the system 1, the urine is stored in 2 fibreglass tanks (total volume 3 m^3). There are also two 1 m^3 compost filters for the pre-treatment of the mixed brownwater and greywater (solids removal). Subsequently, the filtered mixture is stored and dewatered. The filter units, made of stainless steel, serve as a container for the filter bag, which is filled with organic structure material (straw). The mixture is pre-treated in the filter bag by aerobic composting and drains through the structure material. The filtrate is pumped at intermittent batches to the constructed wetlands. The constructed wetland treats the filtrate from the compost filters. In the system 2 there are 6 fibreglass tanks for urine collection and storage (total volume 4.5

m^3), 2 compost filters for pre-treatment of the combined brownwater and greywater (solids removal) and 2 constructed wetlands for the treatment of the filtrate from the compost filters. The constructed wetlands are of the sub-surface vertical flow type, and are planted with reed. It is important to highlight that this sanitation system can discharge any of the separated wastewater fraction to the existing conventional wastewater system, which is useful in case of malfunctions or optimisation works. The stormwater is infiltrated by means of ditches (infiltrations depressions) on-site (Hochedlinger, et al. 2008).

- **Reuse**
  According to Oldenburg, et al. (2009), currently the nutrients loop is not closed because the reuse of the urine as a fertiliser in agriculture is not carried out due to specific regulatory system of Austria. In addition, the composting process of the compost filter material is not functional due to optimisation works. In the future, it is expected that the nutrients are recycled within the sanitation system through urine reuse, the compost and the biomass from the constructed wetlands and the treated brownwater and greywater is infiltrated.

I.2.3 Costs

According Oldenburg, et al. (2009), the total costs of the solarCity project, which are totally covered by an Austrian public service, are 2.3 Million € in 2008. These costs cover investment, operation, maintenance and research sponsorship (Oldenburg, et al. 2009). The construction costs are 1.7 Million € whereas the sponsorship of research is 0.5 Million €. The operation and maintenance costs are 100.000 € from 2006 and 2008.

The inhabitants of the settlement connected to the sanitation system are paying the conventional wastewater fees, which is a combination of the number of toilets and water consumption. [E.g. a family (4 persons) with 160 m^3 per year (EUR 0.32 per m^3) and one toilet (EUR 112 per year and toilet) has to pay yearly fees of EUR 160 per year (plus 10% tax). All inhabitants of solarCity involved in this Ecosan project pay the same fees as users of conventional toilets (Oldenburg, et al. 2009)].

I.2.4 Operation and Maintenance

The construction of all parts of the sanitation system and the information for the user were carried out by the non-profit residential cooperatives. The maintenance of the sanitation system is carried out by technical staff of the public service company that funds the solarCity project (Oldenburg, et al. 2009).

- **UD flush toilets**

  The operation and maintenance routine is very similar to the one described for the sanitation system used within the SANIRESCH project. The main difference is that in this case the maintenance is carried out by the household owners. Furthermore, there is annual inspection of the UD flush toilets carried out by the service provider (Oldenburg, et al. 2009). It is also important to highlight that there is a "practical loss from urine separation toilets of nitrogen" (Hochedlinger, et al. 2008).

- **Waterless urinals**

  The waterless urinals are made of ceramics and use a biodegradable liquid with lower density than water and urine which works as a sealant liquid in the odour trap (Oldenburg, et al. 2009). In addition, these types of waterless urinals have a special surface that prevents sticking of a urine film that could cause odours. However, the reliability of these devices strongly depends on regular maintenance. According to Oldenburg, et al. (2009), the urinals at the school are cleaned at a daily basis by the maintenance personnel of the schools and the odour traps of the waterless urinals need to be exchanged after one to two years.

- **Urine Storage Tanks**

  According to Oldenburg, et al. (2009), due to the regulatory restrictions, the storage tanks are not used and the diverted urine is discharged in the urine storage tanks. If the urine storage tanks are used, there is a need to empty the content once a month by pumping the urine with a vacuum truck, which also could transport the urine to a nearby agricultural field.

- **Constructed Wetlands**

  According to Oldenburg, et al. (2009), the technical components of the treatment facilities are controlled by remote systems installed at a wastewater treatment plant 2 Km away.

- **Composting filter units**

  According to Oldenburg, et al. (2009), the compost filters are not currently operative because they are at a trial stage. However, it is planned to operate them intermittently. That is, when the first filter unit is full, the inflow will be connected to the second while the first is dewatered. The dehydration process continues until is transported to another room where it can be lifted. Bulking material should be added at least once a week. The containers from the storage rooms will be collected once or twice per year and then post-composted.

I.2.5 Lessons learnt and practical experience

According to Oldenburg, et al. (2009) and Hochedlinger, et al. (2008) the entire sanitation system is sensitive to improper use and maintenance of the UD flush toilets, which can produce blocking of the pipes, inefficient separation of the nutrients and sequestration of the nutrients and odour problems. Most of the practical problems in operation were caused as a result of a wrong type of maintenance and/or the incorrect use of the Nomix toilets. In addition, the flushing strength of the UD flush toilets sometimes is too weak which causes that the solids (faeces and toilet paper) are not completely flushed. Thus, it is often necessary to flush twice, which avoids reducing the water consumption of the sanitation system. However, it has also been reported that some other times is too strong and causes that flushing water splashes over the toilet seat. On the other hand, the UD flush toilets require special maintenance work. Another aspect necessary to highlight is that the UD toilets are too large for small children and therefore not suitable for primary schools. Thus, a small child cannot sit adequately which means that the faeces can fall in the urine bowl, which causes odour problems if the faeces are not flushed completely. This and other problems related to the maintenance requirements of the UD flush toilets lead to the shift to conventional toilets in the system 1 after two years of operation. The waterless urinals are working well with neither blockages nor odour problems occurring. Due to the strong link between the efficient functioning of the system and the use and maintenance of the UD flush toilets, there is a need to increase awareness and carry out education campaigns to use adequately the system.

The performance of the compost filter has not been satisfactory due to clogging of the filter bags and a decreasing of the permeability of the filter (Hochedlinger, et al. 2008). Further research is needed to improve the efficiency and functioning of the process. However, the performance of the constructed wetlands is very satisfactory. The technologies components applied in this sanitation system are neither fully mature nor functional. There is a need to optimise the Nomix toilet design, which currently is not suitable for the system 1.

I.3 The Looloop Process

I.3.1 General remarks

As Braun et al. (2008) state, Hamburg University of Technology (TUHH) and a private German company, Intaqua AG, have investigated a pilot technology process aiming to reuse urine as toilet flushing water: “the loop processing of toilet wastewater generating concentrated and thoroughly treated liquid and solid fertilizers plus soil conditioners”. The Looloop pilot technology has been designed, built and operated at TUHH, where a pilot plant for 20 population equivalents has been running for approximately 2.5 years (Braun, et al. 2008).

I.3.2 Technologies applied

- **Collection and Conveyance**
  The pilot plant at TUHH works with a conventional flush toilet and also a waterless urinal. The flush water is untreated tap water (Braun, et al. 2008).
- **Treatment**
  As Braun, et al. (2008) explain the treatment of the excreta first follows a separation of solids step. Subsequently, the solid fraction is vermi-composted (smaller units) or treated by anaerobic digestion at a larger scale. Behrendt et al. (2009) states that the resulting liquid fraction is treated by means of a biological treatment process by means of the following processes:

  - Ureolysis/equalization tank (Fixed-bed reactor)
  - Biological oxidation comprising nitrification of the liquids (MBR).
  - In both cases, the permeate is subsequently treated by means of:
    - Ultra-filtration.
    - Ozonisation.

- **Transport and Reuse**
  On one hand, from the solid fraction two main products can be produced depending on the treatment path, either compost which will be used as soil amender or biogas. On the other hand, the liquid fraction is completely reused as service water within the system (flush water) (Braun, et al. 2008). Furthermore, fertiliser is produced from the raw material produced after the treatment process of the liquid fraction. The authors also state that after the treatment of the liquid fraction, "a clear, colour and odourless flushing water, which is sensually indistinguishable from normal tap water" is produced.

Figure 34: Technical pilot plant. Source: (Braun, et al. 2008)

I.3.3 Operation and maintenance

The main drawback mentioned by Braun, et al. (2008) is the high energy consumption. Furthermore, the authors state that during the operation period no major process disturbances were observed.

I.3.4 Sustainability of the system

The experimental set of technologies is an integrated sanitation system which strongest point is the maximum conservation of natural resources, mainly nutrients and water. The final products are soil amender (compost), a fertilizer raw material and also biogas (optionally) (Braun, et al. 2008). The authors also claim that in combination with "the groundwater-loop process (a loop processing of grey water via a groundwater passage), even safe water self-sufficient settling becomes possible if 10 to 25 L of water per person and day can be renewed from local resources (rain, groundwater, river, lake, sea)" (Braun, et al. 2008). The Looloop system could eliminate domestic wastewater. It is also necessary to highlight that the system can be used in combination with other ecological sanitation devices in order to maximise the recycling of nutrients. In this way, Braun, et al. (2008) state that the Looloop system can be used with UD flush toilets. In addition, the Looloop system can be used in combination with an "external grey water reuse (irrigation, landscaping, industrial process water, etc.)" or an "indirect internal (after a passage through an artificial or natural groundwater body) reuse of grey water to drinking water).

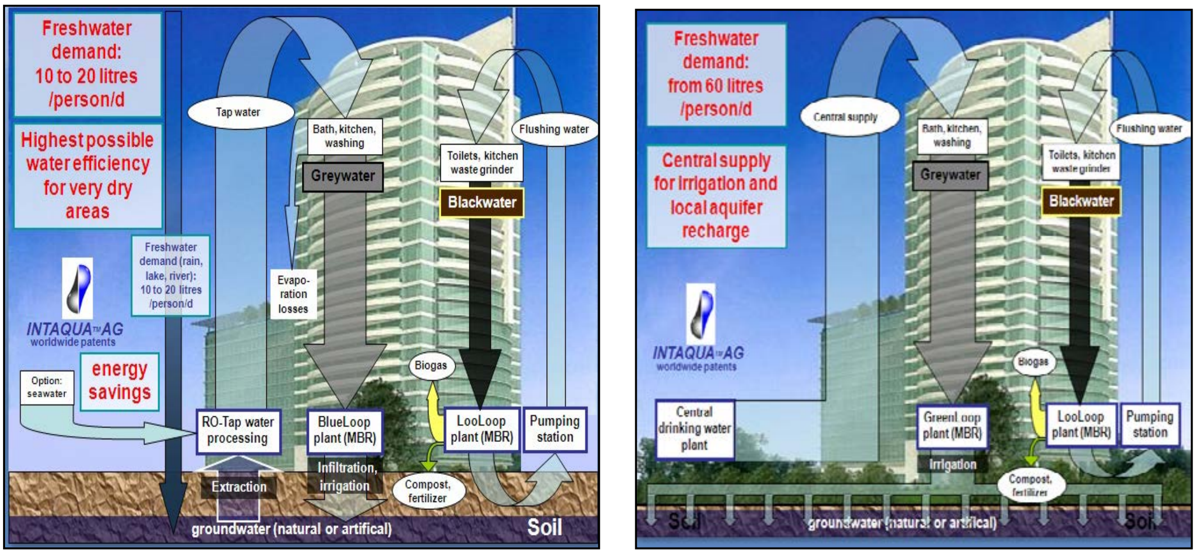

Figure 35: Black water loop and central supply with ground water recharge (left) and Black water loop and local water autarky (right). Source: (Otterpohl, 2009)

I.4 The conventional wastewater system of Hamburg

I.4.1 General remarks

The end-of-pipe technology is a linear system based in a wastewater treatment plant at the end of the sewage which purifies a mixture of rainwater and domestic, commercial and industrial wastewater in different treatment steps (Lindner, 2007). The treatment usually includes a combination of physical, biological and chemical processes to ensure the compliance with stringent effluent standards (DWA, 2008 cited in Remy, 2010). The main product of this sanitation system is the sludge, which can be reused in different ways depending on the composition. (Lindner, 2007).

Günner (2008) states that the city of Hamburg owns the largest drinking water supply and wastewater company in Germany, Hamburg *Wasser* treats the wastewater for 2.1 Million people in the metropolitan area of Hamburg and adjacent communities. According to HamburgWasser (2010), the central wastewater treatment plant *Köhlbrandhöft-Dradenau*, which was built in 1995, was initially located exclusively in *Köhlbrandhöft*. Nevertheless, in 1988, it was built an additional advanced biological treatment in *Dradenau*. Both plants are connected through a 2-3 Km pipe line. In absence of rain, there is an average flow to the sewage network of 4-5 m^3/s of wastewater. Heavy precipitation can increase the wastewater flux up to 19 m^3per second. On an annual basis, 150 Million m^3 of wastewater are cleaned (HamburgWasser, 2010).

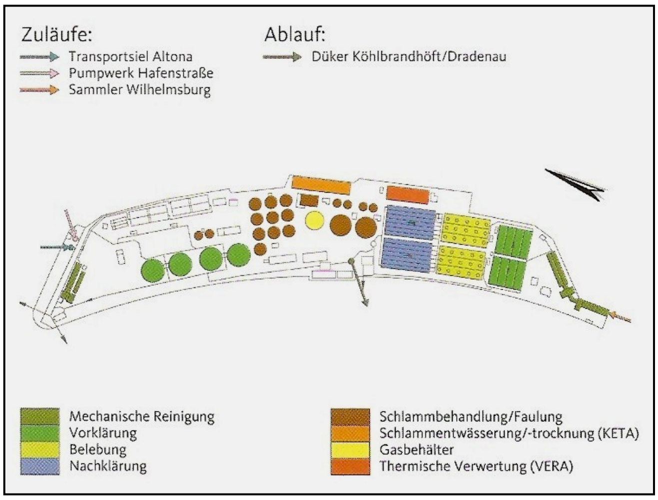

Figure 36: Schematic representation of the wastewater treatment plant of Hamburg. Source: (HamburgWasser, 2009)

I.4.2 Technologies applied

- **Collection and Conveyance**

  Any kind of collection device is adequate to the conventional system. The crucial step is that this collection device is connected to a sewage system. According to Gunner (2008), the length of the sewage system is 5.400 Km, the diameter of which ranges from 250mm to 3.700 mm. The conveyance system needs 209 pumping stations (Günner, 2008). The conventional wastewater treatment system collects human excreta, industrial waste (usually pre-treated on-plant) and stormwater.

- **Treatment**

  450.000 m^3 of wastewater are cleaned everyday in the wastewater treatment plant *Köhlbrandhöft-Dradenau*, which has a load size of 2.9 million population equivalents (HamburgWasser, 2010).

  Similar than other conventional wastewater treatment plants, there is a first step of mechanical treatment of the wastewater, which takes place in the sewage treatment plant *Köhlbrandhöft* (HamburgWasser, 2010). During this first stage the coarse material is removed (approximately about 7.000 tonnes per year, which is subsequently drained and incinerated altogether with the sludge). There is also a grid removal and sand trap stage where the sand is separated (which will be washed and re-used mostly as filling sand in construction). Subsequently, the remaining solids are separated from the waste water in the primary sedimentation tanks. After this, between 20-30% of the pollutants are removed (HamburgWasser, 2010).

  The secondary treatment is carried out in *Dradenau*, after the wastewater is pumped through 2.3 km long connecting line at 80 me of depth (HamburgWasser, 2009; HamburgWasser, 2010). In the aeration tanks, the oxygen required to degrade the organic matter and the ammonia is currently supplied by large surface aerators which require high energy costs. However, since autumn 2008, these aerators are gradually replaced by a pressure ventilation system, which are lower energy intensive. Subsequently, there is a secondary clarifier treatment step (HamburgWasser, 2010).

  The tertiary treatment consists basically in the precipitation of phosphate by the addition of iron salts from biological treatment (HamburgWasser, 2009). After this step, the water effluent is introduced to the river. The legally prescribed limits are exceeded in some cases significantly. The sludge produced contains 30% of the nitrogen from the biological treatment (HamburgWasser, 2010).

- **Transport and Reuse**

  The amount of sludge removed is approximately 3.700 m^3 out of the 450.000 m^3 wastewater treated (HamburgWasser, 2010). This sludge is treated by anaerobic digestion. 90.000 m3 of biogas is daily produced, which is used for generation of electricity (HamburgWasser, 2009; HamburgWasser, 2010). Annually, 45.000 tons of sludge is treated. Subsequently, the sludge is dewatered and dried by means of a centrifugation process and heat respectively (HamburgWasser, 2010).

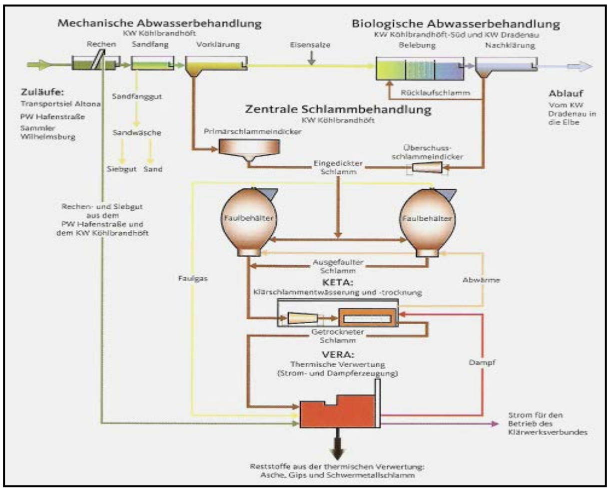

Figure 37: Schematic diagram of the treatment step processes of the wastewater treatment plant of Hamburg. Source: (HamburgWasser, 2009)

The final stage of the wastewater treatment process is the incineration of the dried sludge altogether with the coarse material removed in the screening process. 65 tons of ashes are produced, which are subsequently melted and used as building material (HamburgWasser, 2010). From the flue gas cleaning are produced 9 tons of added gypsum, which are also in the building industry (HamburgWasser, 2010).

HamburgWasser (2010) states that the process treats annually 150 Million m^3 of wastewater producing 1.6 Million m^3 of sludge which by means of an anaerobic digestion, drying and thermal recovery produces 450 tons of landfill waste. However, the heavy metals still need to be disposed as hazardous waste (HamburgWasser, 2010).