Master's Thesis

An innovative greywater treatment system for urban areas – International transferability of a German approach, installed in GIZ's headquarters in Eschborn

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ABSTRACT

In its German headquarters in Eschborn, GIZ installed a greywater treatment system within the research project SANIRESCH. It is based on membrane bioreactor (MBR) technology designed by HUBER SE. Greywater is domestic wastewater excluding toilet water, therefore easily recyclable. Within this work the international transferability of this technology was investigated.

Greywater characteristics and legal foundations were obtained by literature study. Different treatment methods were compared and an investigation of existing MBR projects was conducted. The SANIRESCH plant was described and evaluated according to its economic aspects in comparison to a standard application in a hotel. By means of a utility analysis, based on the fundamentals of sustainable sanitation, the potential for international transferability was assessed to detect the crucial issues.

In summary, MBR technology for greywater treatment provides an excellent cleaning performance with minimal space requirement, but relatively high energy demand. For office buildings, an economic benefit is rarely achieved, caused by an unfavourable water balance. While residential buildings show beneficial water balance and reimbursement is attainable. Concerning worldwide transferability, environmental aspects based on water scarcity as an indicator criterion, 32 countries were assessed. Due to water shortage, poor water quality, high population density and high urbanisation rate, the MENA region was identified as hotspot.

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ABBREVIATIONS

AHP	Analytical hierarchy process
AFS	Filterable Substances
BMBF	Bundesministerium für Bildung und Forschung - Federal Ministry of Education and Research
BOD_x	Biochemical Oxygen Demand used within x days
B_{TS}	Sludge load in kg COD/kg TS*d
CBA	Cost benefit analysis
cf.	Compare
CFU	Colony forming units
COD	Chemical Oxygen Demand
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
EC	Electrical conductivity
E. coli	Escherichia coli
e. g.	For example
EPI	Environmental performance index
EU	European Union
fbr	Fachvereinigung Betriebs- und Regenwassernutzung (German Association for Water Reuse and Rainwater Harvesting) e. V.
GIS	Geographic information systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
l	Litre
l/(c*d)	Litres per capita per day
l/d	Litres per day
MBR	Membrane bioreactor
MADM	Multi attributive decision method
MAUT	Multi attribute utility theory
MCDA	Multi criteria decision analysis
MENA	Middle East & North Africa
MODM	Multi objective decision method
N_{total}	Total nitrogen
n. a.	Not available
O_2	Oxygen
OECD	Organisation for economic co-operation and development
P_{total}	Total phosphorus
Pcs.	pieces
PE	Polyethylene
PES	Polyethersulfone
RWTH Aachen	Rheinisch-Westfaelische Technische Hochschule Aachen

SANIRESCH	Sanitär Recycling Eschborn (research project)
SBR	Sequencing batch reactor
SS	Suspended solids
T	Temperature
THM	Technische Hochschule Mittelhessen – University of Applied Sciences
TN_b	Total nitrogen bound
TrinkwV	Trinkwasserverordnung - drinking water ordinance
TS	Total solids
WQI	Water quality index

1 INTRODUCTION

In regions of the world, where low availability of water causes significant problems, the sustainable use of water resources is a fundamental task. Due to increasing water demand, global structural shifts, and climate change, investments particularly in water saving techniques and improved water management systems are vital developments in those areas. A solution to these challenges is offered by greywater reuse, with multiple use of water in the household (fbr, 2011). Wastewater treatment techniques, which result in an enhanced removal of a wide range of contaminants, enable the implementation of such an approach. In particular, the industry works actively on water reuse projects, not only for economic reasons, but also from the perspective of an environmental responsibility (Van der Bruggen, 2010).

Greywater is a part of domestic wastewater which is produced during personal hygiene routines such as showering, bathing or hand-washing. In addition, washing machine, dishwasher and kitchen sink water also generates greywater. It is faecal free, and low polluted wastewater (DIN EN 12056-1, 2000). Every single household within a given region, and with an equal cultural background, produces similar amounts of greywater with a similar quality every day, regardless of weather conditions.

In order to "lead by example", the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH installed a greywater treatment system within the research project SANIRESCH in its headquarters located in Eschborn, Germany (Winker & Saadoun, 2011). The aim is to showcase the potential of such systems for urban areas in both, developed and developing countries. The system is based on the technology of membrane bioreactor (MBR), a method which provides a very good cleaning capacity and effective removal of contaminants (Mallevialle et al., 1996), developed by company HUBER SE. After MBR treatment, the purified water fulfils the regulations of the EU directive 2006/7/EG for bathing water quality. The water is then called process water. It can be used optimally for irrigation, toilet flushing or laundry.

This technology firstly reduces the water consumption and secondly substitutes drinking water in applications where drinking water quality is not required. Reuse of treated greywater as process water contributes to the protection of the water resources and exerts a positive influence on the water balance as well as on the environment. Additionally, drinking water demand is reduced by greywater recycling, and the negative effects of the drinking water extraction and distribution processes (e.g. energy and chemical requirement, drop in the groundwater level, consumption peaks) can be minimised as well. Finally, the production of wastewater and discharge into the sewer system is reduced and consequently also the water pollution (fbr, 2005).

An important aspect within the research project and also for GIZ is to investigate the worldwide transferability of such a decentralised wastewater substream treatment. The pivotal question in this context is whether membrane bioreactor treatment of greywater is a meaningful and feasible application in emerging and developing countries, as they are often affected by water shortage and problems of freshwater supply and discharge.

Generally, this study tried to find answers on the following questions that refer to technical issues of membrane bioreactor technology:

- Is the membrane bioreactor technology a feasible system to recycle greywater?
- What is the advantage of greywater treatment via MBR technology?
- What is the quality like of MBR treated purified greywater?

Furthermore an assessment of the treatment system was made, in order to see the differences between the utilisation of the technology in a research project and in a serial application. For this purpose, economical parameters were roughly estimated in order to get an insight into the costs. This task triggered the following queries:

- When does it make sense to separate wastewater streams and reuse it after treatment?
- Is MBR treatment economically feasible?

After the clarification of technological and economic issues, the investigation of international transferability of a MBR greywater treatment plant took place. Following questions were investigated and assessed:

- What are the criteria of international transferability of greywater treatment via membrane bioreactor?
- Which regions in the world are the hotspots to implement greywater treatment plants?
- What are possible applications for greywater treatment in developing and emerging countries?

In connection with all the afore mentioned questions, three hypotheses were formulated according to assignment:

Hypothesis 1: The greywater treatment plant, which is in used in Eschborn, represents a research facility that is convenient in order to collect data in regard of the reliability of greywater treatment. According to economic calculations, the SANIRESCH plant is not reliable for drawing comparisons, due to its pilot character. Simplified system designs for "normal users" are available on the market. These systems provide high saving potential in water balance and economic feasibility.

Hypothesis 2: The MBR technology provides the most advanced form of greywater treatment. The technology can only work efficiently, reasonable and reliable, if it is implemented in an urban environment with good infrastructure and in building units with a high production of greywater (e. g. office buildings, hotels, hospitals, etc.).

Hypothesis 3: The method of using an ultrafiltration membrane bioreactor system is applicable in extreme areas and can be very well used when there are high quality requirements for permeate. The hotspot regions of meaningful applications are arid areas with high urbanisation rate.

2 MATERIALS AND METHODS

2.1 LITERATURE STUDY

In the initial phase of this work a literature study took place to get an overview of greywater characteristics, like volume, ingredients and chronological sequence. The reason behind this approach was to find out the average daily quantities of freshwater used and the amounts of different types of wastewater such as greywater and blackwater (drain from toilets) produced in Germany. With this information insight of water consumption and potential options of greywater reuse was obtained. Additionally, a summary of legal foundations for water recycling was collected. Furthermore, a comparison of different treatment technologies was carried out to get an overview of diverse treatment methods and to extract typical membrane bioreactor characteristics compared with other technologies.

2.1.1 DEFINITION OF DOMESTIC PARTIAL WATER FLOWS

A multiple use of water in the household is the aspiration of greywater recycling. To create a uniform understanding of the indications of the domestic water flow, the terms must be defined. The chart in Figure 1 gives a visual impression of water flow in a building. In sanitary engineering, there are common specific water terms and this is described in the following paragraph.

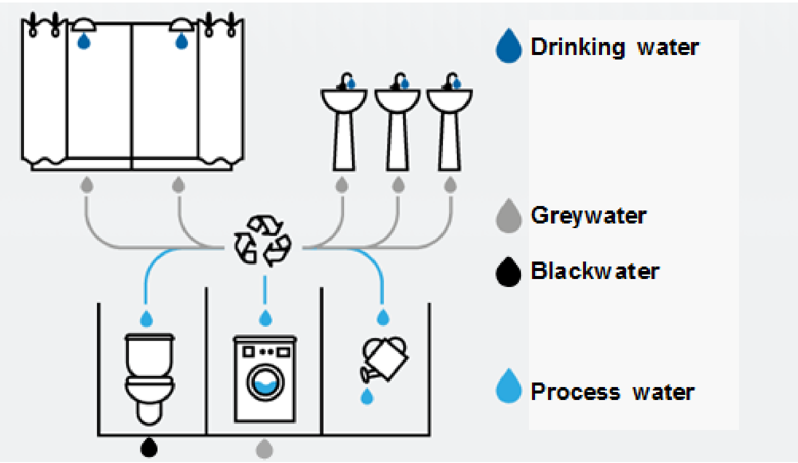


Figure 1: Domestic partial water flows; (ewu aqua, 2011, modified)

Drinking water is defined according to the drinking water ordinance (TrinkwV) §3 as water used in its original state or after treatment, intended for drinking, cooking, preparing food and drinks, or in particular to the following other domestic purposes: personal care and - cleaning, cleaning of objects intended to come into contact with food, cleaning of objects, which are intended not only temporarily in contact with the human body. This applies regardless of the origin of the water, its physical state and regardless of the way of deployment (by public uilities, by tanker trucks, in bottles or other containers). With respect to the quality of water intended for human consumption, water regulations define several requirements (TrinkwV, 2011):

- Water for human consumption must be free of pathogens, edible and pure.
- In the water for human consumption, pathogens within the meaning of § 2, No. 1 of the Infection Protection Act must not be included in concentrations that can be responsible for human health damages (microbiological requirements).
- In the water for human consumption it must not contain chemicals in concentrations that can cause damage to human health. Concentrations of chemicals that contaminate the water intended for human consumption or affect its quality adversely should be kept low, in compliance with the generally accepted rules of technology at a reasonable cost, taking into account the circumstances (chemical requirements).

Greywater is part of domestic wastewater without wastewater from toilets (blackwater). The European standard DIN EN 12056-1 (2000) defines greywater as faecal-free, low polluted wastewater. It is the outflow of bath and shower trays, washbasins, sinks and washing machines and may also contain high-strength kitchen wastewater. For greywater reuse, however, only the low-loaded wastewater from shower, bath and hand basin is usually used for treatment.

Blackwater is according to ISO 6107-7:2006-05 (2006) in the urban water management context domestic sewage water with feacal solids, but without greywater. Therefore, wastewater from toilets is called blackwater and has a urine and/or feacal load.

DIN4045, (2003) specifies process water as "commercial, industrial, agricultural or similar purposes serving water with different quality requirements, where drinking water quality can be included." This means that process water can be used anywhere, where water quality is not necessarily required. In connection with greywater recycling it means household and industrial uses which do not necessarily need drinking water quality, such as water for toilet flushing, for irrigation or for cleaning purposes and for laundry wash. However, process water must be sufficient on the operation, depending on the scope, national and international requirements in hygienic, chemical and physical terms.

2.1.2 CHARACTERISTICS OF GREYWATER

In 2007 the mean value of per-capita consumption of fresh water in households and small enterprises in Germany was 122 l/d (Statistisches Bundesamt, 2009). The installed sanitary facilities in households and the habits of users are vital factors influencing the quantity of drinking water consumption and greywater production. The average fresh water use in modern buildings or in edifices with renovated sanitary equipment is 100 l/(c*d). The greywater accumulation aggregates 70 l/(c*d) and is taken as a basis in Figure 2. The chart shows that the amount of greywater corresponds to the demand of process water of approximately 48 l/(c*d). Toilet flushing averages out at 25 to 35 l/(c*d) and lies clearly below the available amount of process water (fbr, 2005).

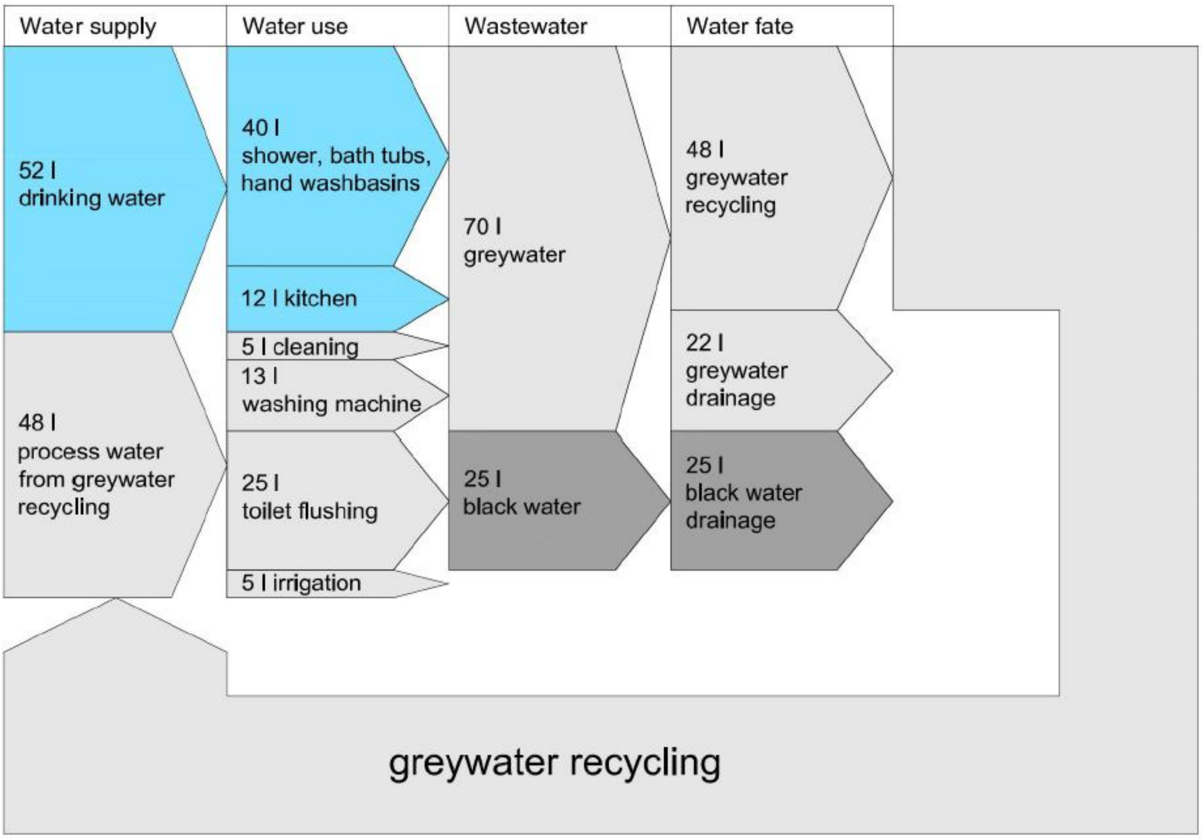


Figure 2: Partial water flows in buildings with modern sanitary equipment; (Mehlhart, 2001)

To get an overview of chronological sequence of water use, the typical water consumption pattern in a hotel building over one day is shown in Figure 3. In a hotel in Jordan which is equipped with a greywater treatment plant, it was monitored on 6 April 2010. It can be characterised by two peaks of fresh water consumption/greywater production in the morning and in the evening. It is obvious that the demand of water for toilet flushing can be provided easily by volume of recycled greywater, furthermore there is still a huge potential for additional use of service water, e.g. for irrigation or cleaning purposes (Rothenberger et al., 2011).

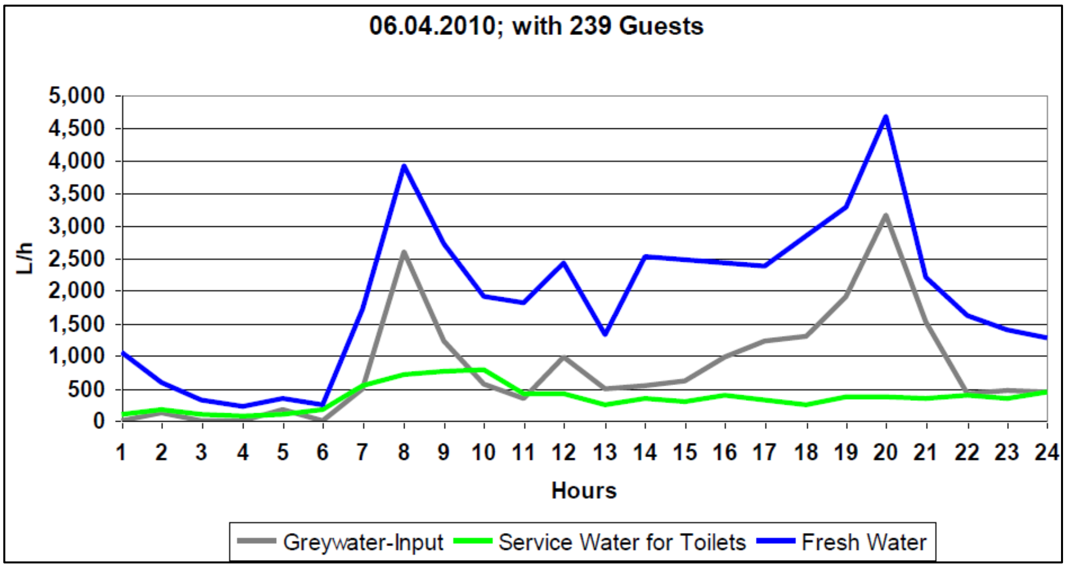


Figure 3: **Water consumption pattern for freshwater (blue), greywater (grey) and service water (green) over one day, in a Jordanian hotel; (Rothenberger et al., 2011)**

To characterise the greywater stream, the volumes and ingredients in comparison to urine and faeces can be identified in the following illustration (Figure 4). In the first row of the diagram the volumes of different wastewater streams are segmented in greywater (grey), urine (yellow) and faeces (brown). The second row shows nutrient ingredients of the fractions, including nitrogen (N), phosphorous (P) and potassium (K). The organic matter is presented in the last row by amount of chemical oxygen demand (COD) in different sewage water shares. Greywater constitutes a high volume and comprises a low level of nutrients compared with excreta. All other partial sewage flows require a greater effort of recycling preparation, therefore greywater is very well suited for the treatment and reuse. Another advantage is the high volume in comparison to the other wastewater flows (Lange & Otterpohl, 2000).

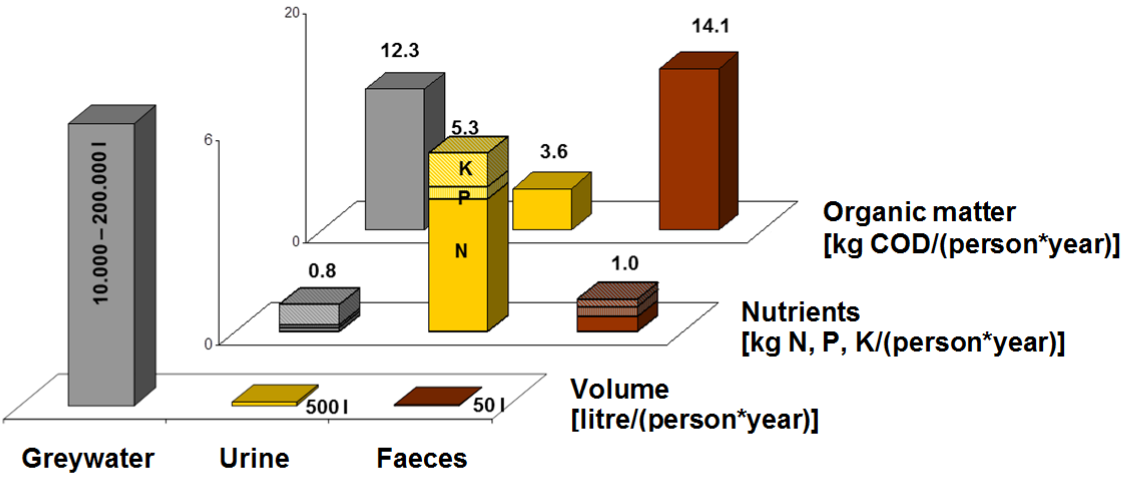


Figure 4: **Sewage ingredients of greywater (grey), urine (yellow) and faeces (brown); (Lange & Otterpohl, 2000)**

The organic substances included in greywater and measured by means of biological oxygen demand (BOD) or chemical oxygen demand (COD) originate mainly from detergents, skin grease, hair and skin and dandruff particles. In relation to the source area of greywater there are differences in the composition of ingredients, shown in a detailed overview in Table 1. The lowest contamination can be achieved, if only greywater from bath tubs, showers and hand wash basin is collected. Higher loads of organic substances and nutrients can be detected if washing machine outlet and kitchen drain is taken into consideration. The influence of regional drinking water quality, such as value of total nitrogen caused by nitrate concentrations exists. Phosphate values are dependent on the use of pipe preventers and dishwashing soap (fbr, 2005).

For greywater the ratio of COD:BOD_5 can reach values of 4:1. Compared to municipal wastewater (COD:BOD_5 ratio 2:1), this value is very high (Jefferson et al., 2000). This suggests that greywater contains a high volume of compounds which are not or not easy biodegradable. Due to the use of toiletries e.g. shower gel, shampoo and tooth paste, this is particularly the case in bathroom drains. BOD_5 values from the kitchen outlets show the highest values because of the high organic load.

Table 1: Overview of characteristic greywater ingredients, depending on its origin; (fbr, 2005)

		from bath tubs, showers and hand washbasins (measured after the sendimentation tank	from bath tubs, showers, hand washbasins **and** washing machine (including baby diapers)	from bathtubs, showers, hand washbasins, washing machine **and** kitchen
COD	[mg/l]	150 – 400 Ø 225	250 – 430	400 – 700 Ø 535
BOD_5	[mg/l]	85 – 200 Ø 111	125 – 250	250 – 550 Ø 360
AFS	[mg/l]	30 – 70 Ø 40	n/a	n/a
P_{total} A)	[mg/l]	0,5 – 4 Ø 1,5	n/a	3 – 8 Ø 5,4
N_{total} A)	[mg/l]	4 – 16 Ø 10	n/a	10 – 17 Ø 13
pH	[-]	7,5 – 8,2	n/a	6,9 – 8

A) Values may vary depending on the regional drinking water quality, e.g. higher nitrate content or addition of phosphate to prevent corrosion of pipes. Additional significant phosphate concentrations may result from dishwashers.

A comparison of different greywater streams using a microbiological load of typical household greywater is presented in Table 2. The amount of total and faecal coliforms (*E.coli*) in household wastewater is at least a 10-fold magnitude higher than in greywater. For greywater that is produced only from personal hygiene use there is a 100-fold lower contamination of bacteria measurable (Nolde, 1995). This fact makes the greywater flow from the bathroom interesting for treatment and reuse.

Table 2: Microbiological load of greywater from typicall housholds; (fbr, 2005)

Parameter	Unit	Greywater from bath tubs, showers and hand washbasins	Greywater from bath tubs, showers, hand washbasins **and** washing machine (including baby diapers)	Greywater from bath tubs, showers, hand washbasins, washing machine **and** kitchen	Household wastewater including faeces
Total coliform bacteria	1/ml	$10^1 – 10^5$ median: 10^5	$10^2 – 10^6$	$10^2 – 10^6$	$10^4 – 10^7$
Faecal coliform bacteria (*E. coli*)	1/ml	$10^1 – 10^5$ median: 10^4	$10^1 – 10^5$	$10^2 – 10^6$	$10^4 – 10^7$

2.1.3 REUSE OF GREYWATER

From the various sources available (sewage water, greywater and rainwater), which could cover the demand for an inner household’s water reuse, greywater is the most appropriate option. The availability of rainwater that could be collected from roof drainage, which has in general a low load, depends on the weather. In many regions of the world rainfall is usually limited and, due to climatic conditions not consistent (Paris, 2009b). In contrast, in every household greywater occurs regularly, but in-house installations for separate collection and treatment are necessary, to make it available for reuse.

In principle, there are many possibilities of water recycling, which enable a sustainable handling of water resources. In many places, purified wastewater is used for agricultural irrigation. Water saving techniques in industrial production are widespread due to the monetary benefits. A common practice is, to collect the relevant process water separately and prepare it specifically for reuse. For the reduction of drinking water consumption it is also useful in the urban context, to use water several times. Any use, both in the building as well as outside, requires a defined process water quality to avoid health risks. The usual inner-urban applications of recycled water include: air conditioning, laundry wash, toilet flushing, irrigation of private and public green areas, car cleaning and quenching water reserve as shown in Figure 1 (Asano et al., 2007).

2.1.4 LEGAL FOUNDATIONS

In Germany there are different requirements for the quality of recycled greywater according to the field of reuse.

Irrigation:

In the DIN 19650 there are hygiene parameters for irrigation water defined.

Toilet flushing:

The two common directives in Germany, the leaflet „Betriebswassernutzung in Gebäuden - process water use in buildings“ (Senatsverwaltung für Bau- und Wohnungswesen, 1995) and EU directive for bathing water quality RL 76/160/EWG (1975) and RL 2006/7/EG (2006).

Partial use in washing machines and dishwashers:

There are no exact references specified, therefore recourse to EU directive for bathing water quality RL 76/160/EWG (1975), RL 2006/7/EG (2006) and drinking water ordinance TrinkwV (2011) is taken.

In the international context, some countries released directives or standards with specific requirements for the inner-urban process water quality to ensure safe water reuse (an overview is given in Table 3. The relevant quality parameters are regularly the BOD concentration (regarding the storage capacity), the turbidity (due to the aesthetic concerns) and the microbiological pollution (because of health risks). The specified limit values can vary widely, depending on the directive or standard. While restrictive standards (as in Japan and in the USA) regulate the absence of faecal coliform bacteria, more pragmatic approaches (as in Germany) refer to the quality of bathing water RL 2006/7/EG, (2006) and give limit values for total coliform bacteria (Paris, 2009b).

Table 3: Directives and standards for inner-urban recycling of water; (Paris, 2009b; RL 2006/7/EG, 2006)

Parameter	Unit	Countries					
		EU	USA	Germany	China	Australia	Japan
		Specifications					
		RL 2006/7/ EG, 2006; bathing water quality	USEPA, 2004	fbr-H201, 2005	GB/T 18920-2002	Queensland, 2005 class A (highest requirements)	Public buildings association, 2005
BOD_5	mg/l	No require-ment	≤ 10	$BOD_7 < 5$	≤ 10	20 (median value)	< 20
Turbidity	NTU	No require-ment	≤ 2		≤ 5	2 (5) 95%-percentile (max.)	< 2
Micro-biological quality		<100 /100 ml E. coli; <100/100 ml intestinal coccus	no detectable faecal coliforms/ 100 ml	< 100/ml total coliforms < 10/ml faecal coliforms < 1/ml *Pseudomonas aeruginosa*	≤ 3/l coliforms	< 10 cfu/100ml *E. coli* (median value)	*E. coli* not detectable
pH value	-	No requireme nt	6-9		6-9	6-8.5	5.8-8.6
Chlorine (Cl_2) residual dis-infectant	mg/l	No require-ment	1 (minimum)		≥ 1 after 30 minutes ≥ 0.2 at the end of pipe		0.1 free chlorine or 0.4 bound chlorine

2.1.5 TREATMENT TECHNOLOGIES

Generally there are different treatment technologies for greywater available. A compendium of common biological wastewater treatment methods is listed in Table 4, based on the characteristic features.

Table 4: Comparison of biological wastewater treatment processes based on distinctive features; (Heinrich & Heinrich, 2008)

Treatment method / Criteria	Trickling filter	Biological contactor	Aerated fixed bed reactor	Fluidised bed	Activated sludge treatment	Sequencing batch reactor (SBR)	Membrane bioreactor (MBR)
Cleaning capacity	good - satisfactory	good	good - satisfactory	good - satisfactory	good	very good	very good
Space requirements	low	low	low	very low	low	very low	very low
Level of technology and automation	enineered	engineered	strongly engineered	strongly engineered	strongly engineered	strongly engineered and automated	strongly engineered and automated
Operating and maintenance expense	high	low	fairly high	low	very high	low	very high

This study is specifically limited to the MBR technology and cannot explain all different treatment technologies (for more detailed information see introduction, hypothesis 1-3). It is not possible to go into particulars and describe all advantages and disadvantages of greywater treatment plants. But a short overview of membrane bioreactors strengths and weaknesses is given.

The MBR technique in Figure 5 with submerged membrane modules MBR represents a combination of activated sludge process and membrane filtration under low pressure conditions. Thereby the membrane filtration (ultrafiltration) replaces the conventional secondary clarification in the settling tank, the sand filtration and the disinfection. In activated sludge the bacteria degrade the organic contaminants from the greywater under aerobic conditions. And the permeate is filtered with a slight negative pressure through the membranes (Paris, 2009b).

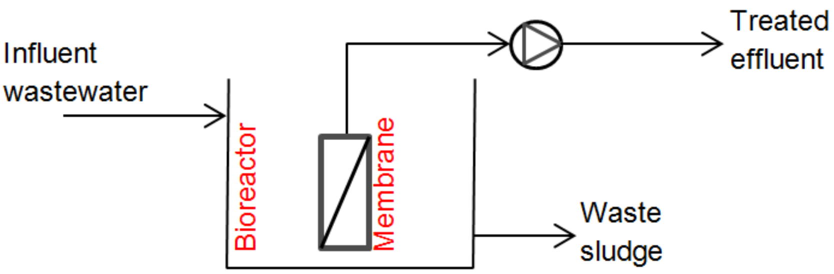


Figure 5: Technical principle of membrane bioreactor; (Bérubé, 2010; modified)

In contrast to the conventional activated sludge process, in a membrane bioreactor the secondary clarification is substituted by a membrane filtration. In general the MBR technology achieves higher removal efficiency than other possible methods such as SBR, biological contractors or the conventional activated sludge treatment. For reuse applications it provides further advantages, since the outlet of a MBR plant is considered as disinfected. By the use of ultrafiltration membranes, an effective retention of bacteria is ensured, because of the pore diameter of less than 0.2 µm and the permeate is free from suspended solids. The disadvantage of the MBR process lies in the two- to threefold higher energy and higher maintenance costs in comparison to SBR. The higher energy consumption results from the intensive ventilation needs for the membrane surface cleaning air, in order to prevent blockage of the membrane. (Cornel & Wagner, 2009)

2.2 DESCRIPTION OF THE GREYWATER TREATMENT PLANT INSTALLED IN THE GIZ'S MAIN BUILDING IN ESCHBORN/GERMANY – MEMBRANE BIOREACTOR (MBR) TECHNOLOGY (REFERENCE PROJECT)

2.2.1 TECHNICAL DESCRIPTION

During the renovation (from 2004 till 2006) of the main building at the headquarters of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH located in Eschborn/Germany a system for the separate collection of urine and brownwater was installed. This system consists of urine-diversion flush toilets, waterless urinals, separate piping systems for urine, brownwater and greywater and tanks for urine storage. The whole research project is called SANIRESCH (SANItär Recycling ESCHborn) (Winker M. , 2011b) and is financed by the Federal Ministry of Education and Research (BMBF) from July 2009 till June 2012. The further project partners are the University of Applied Sciences Mittelhessen (THM), HUBER SE, Roediger Vacuum, RWTH Aachen and the University of Bonn (GIZ, 2011). A general flow chart of the whole project with its treatment of split wastewater streams is presented in Figure 6. One part of this project is greywater treatment via membrane bioreactor to recycle water.

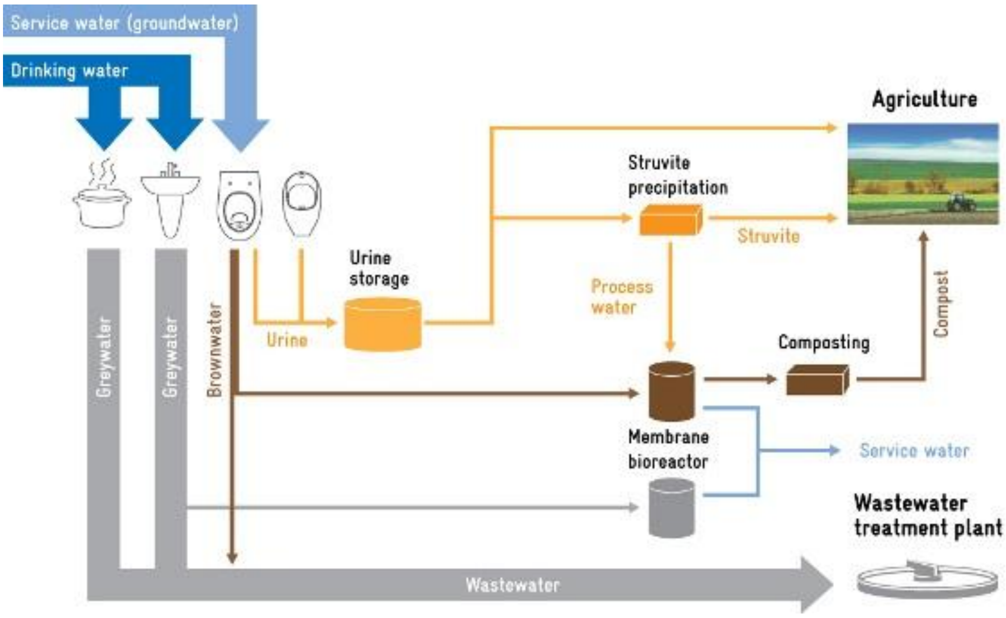


Figure 6: Flow chart of project components of SANIRESCH research project; (Winker M. , SANIRESCH, 2011b)

In the middle part of the main building a separating tube system for partial wastewater flows as greywater was installed. As shown in Figure 7 the side wings of the structure are provided with conventional sanitary facilities. This means in one-third of the building the separate collection system is installed.

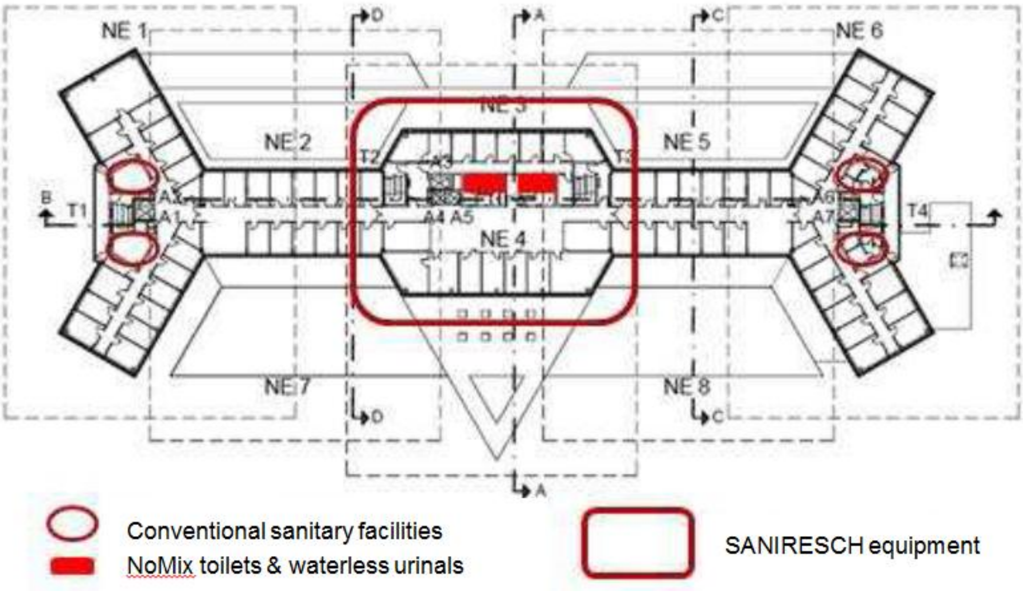


Figure 7: **Ground plot of GIZ main building; (Winker et al., 2011b)**

As part of this thesis the technology used in the GIZ main building in Eschborn to purify greywater was investigated. The membrane bioreactor technology (MBR) in the SANIRESCH research project has a role model characteristic and is a method to recycle greywater sot that it can be reused. In the following section, the technique used, is described and explained and represents the performing conditions in the research project.

The technology of greywater treatment which is implemented in the GIZ's office building is based on the technology of membrane bioreactor (MBR) processing. It combines mechanical and biological treatment in one plant. The treatment plant in Eschborn was developed and built by the company HUBER SE. All technical information refers to technology of HUBER SE.

The treatment plant is located in the second basement of the GIZ-headquarters main building, in a room with a 21 m^2 floor space. The system consists of 3 basins and a control panel and it has the dimensions of 2200 mm of length, 1500 mm of width and a height of 2200 mm. The system went into operation on 13 May 2011 and a visual impression of the hardware is given in Figure 8. The operation of the plant requires, a stable energy supply and the working temperature not to fall below 12 °C so as to keep the biological processes running.

Figure 8: **Greywater treatment plant in the GIZ's main building in Eschborn/Germany; (picture by K. Löw)**

The following operating delineation of the SANIRESCH plant and the technical description is based on instruction manual (HUBER SE, 2011a) and HUBER greywater treatment description (HUBER SE, 2011b):

To outline the function of the plant, the three main components are explained. These include the **intermediate storage tank (1.)**, the **MBR-tank (2.)** and the **storage tank (3.)**, as shown in Figure 9. The plastic tanks are custom-made from polyethylene (PE) and hermetically sealed to avoid odour nuisance. For pressure equalisation the whole system with all containers is connected to an external ventilation system. All connecting pipes between the tanks are provided with sampling taps. All three containers (intermediate storage tank, membrane bio reactor and permeate storage tank) have an overflow for emergency situations, which leads into the collecting pipe that runs into the conventional sewer system. An additional component is the electric measuring and automatic control devices which include a remote data transmission and fault indication function via SMS and telecontrol.

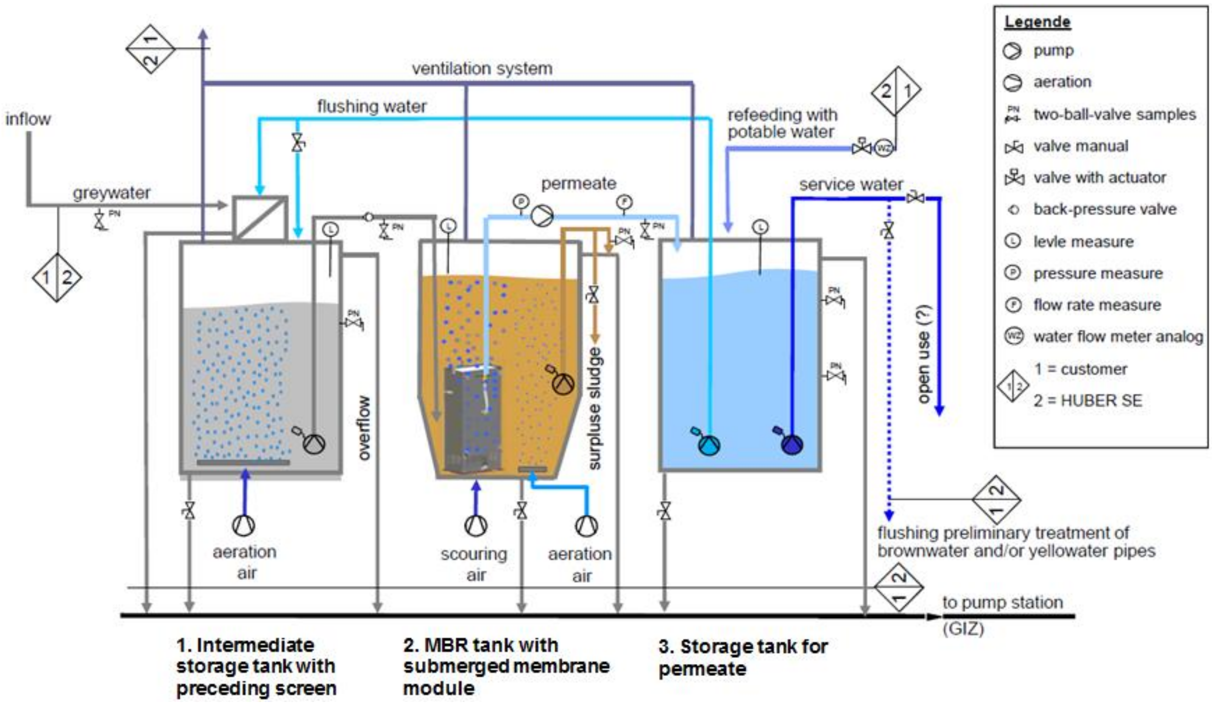


Figure 9: Flow chart of greywater treatment plant; (HUBER SE, 2011b)

1. Intermediate storage tank:

The intermediate storage tank works as a hydraulic buffer for the alternate inflow of greywater before it is pumped into the MBR tank for treatment. On the top of the tank in the area where the inlet is positioned, there is a fine mesh screening (3 mm) fixed to retain debris such as hairs and disturbing material. The cone shaped filtration unit is called HUBER TURNY and is visible in Figure 10. By the force of running-in greywater the sieve turns and a blockage of mesh can be avoided thereby. 99% of the greywater yield can be provided in this way. There is an automatic backwashing process installed where the scouring device cleans the screen by jets of purified greywater once a day for 10 seconds. The contraries are drained through the outflow into the conventional sewer system.

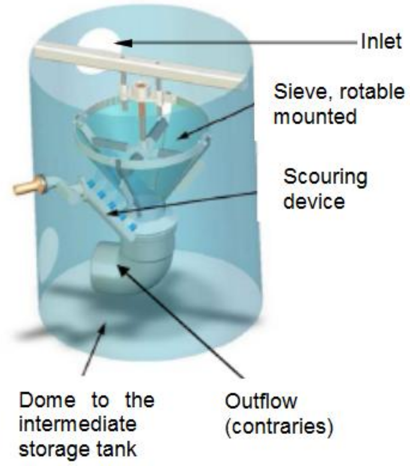


Figure 10: Schematic view of preceding screen on the top of intermediate storage tank; (HUBER SE, 2011b)

The storage volume of the container averages 480 l and possesses an aeration air blower which is fixed on the bottom of the tank. A detailed view of the exact dimensions is shown on Figure 11. To control the level of greywater, there is a probe fixed on the top face of the rectangular tank. Additionally, there is a tap for sampling and a floor drain to empty the container installed. The supply to the MBR container takes place by means of a feeder pump which is joined to the connecting pipe. To preclude the return flow into the intermediate storage tank a non-return valve is installed. Deposits on the floor of the tank from the supply of greywater are avoided by an air blower, thus sediments are stirred up and pumped into the MBR tank.

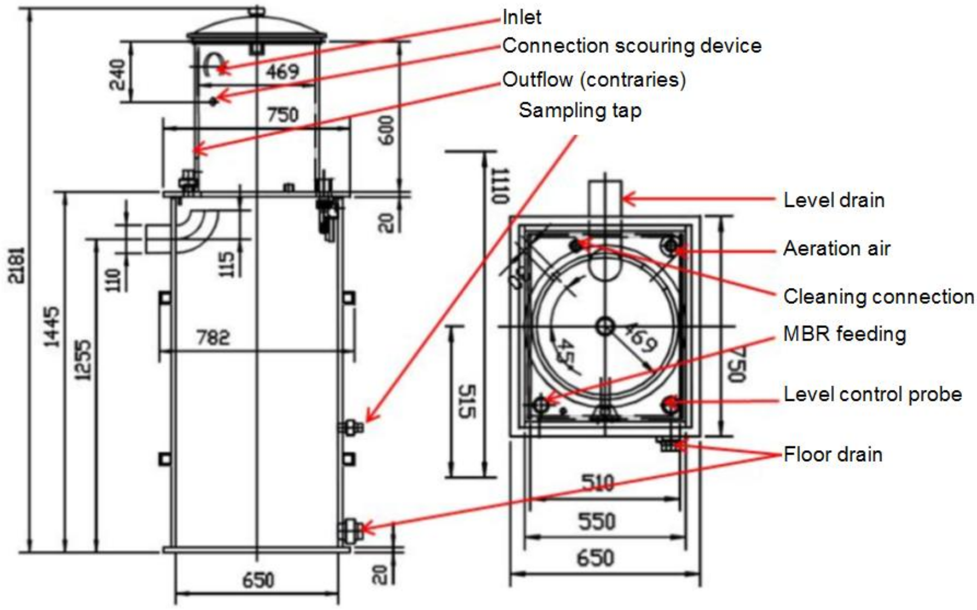


Figure 11: Technical drawing of intermediate storage tank; (HUBER SE, 2011a)

2. Membrane bioreactor tank:

In the membrane bioreactor tank (Figure 12) the cleaning of the greywater actually takes place, it is the core of the plant. In the cone shaped lower part of the 500 l containing tank there are PE frames implemented to avoid distortion. The connections for permeate, MBR feeding and aerating pipes are located on the top of the tank. In addition, there is a level control probe installed.

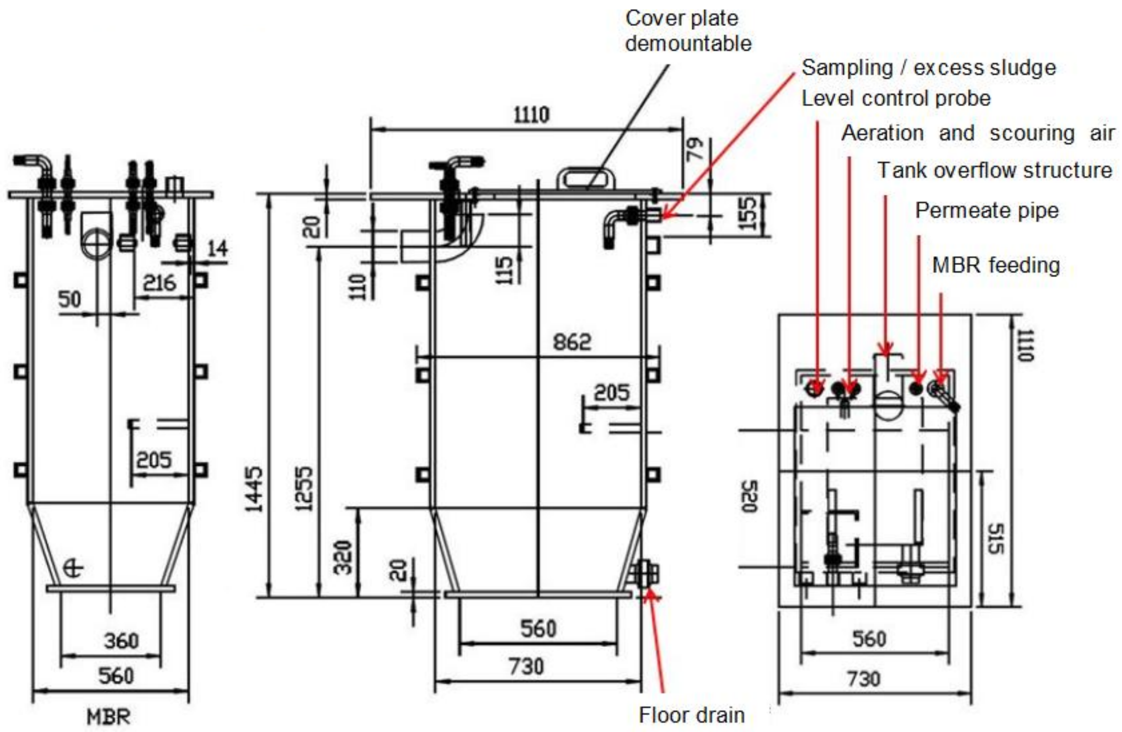


Figure 12: Technical drawing of MBR tank; (HUBER SE, 2011a)

To purify the greywater an ultrafiltration membrane from Polyethersulfone (PES) with a nominal pore diameter of 38 nm and a filter surface of 3.5 m^2 is installed, called MembranClearBox® (see Figure 13). The small pore size of the membrane retains all particles including bacteria and the majority of viruses. The module is submerged in the activated sewage sludge in the MBR tank. An aerator which is mounted on the bottom of the tank provides oxygen to keep the biological processes of microorganisms active and ensures continuous mixing within the container. Another aerator located directly under the membrane module produces scouring air to clean the surface. It is an intermittent process, where the air flows along the surface of the module, which avoids coating, clogging and fouling of the membrane. To purify the water permeate is drawn through the membrane by underpressure of the permeate pump. If the filling level is too low inside the tank, it is automatically detected by a sensor which turns the permeate pump off. Thus, the membrane is prevented from drying out, which would destroy it otherwise. Upon the occurrence of the lower level limit, the system switches to economy mode, which supplies the biology only with oxygen. The data of transmembrane pressure (p_{max} = - 350 mbar) and the flow of permeate is collected and supervised by online remote control. The withdrawal of excess sludge takes place every 4 weeks by a pump hanging at medium-height inside the container.

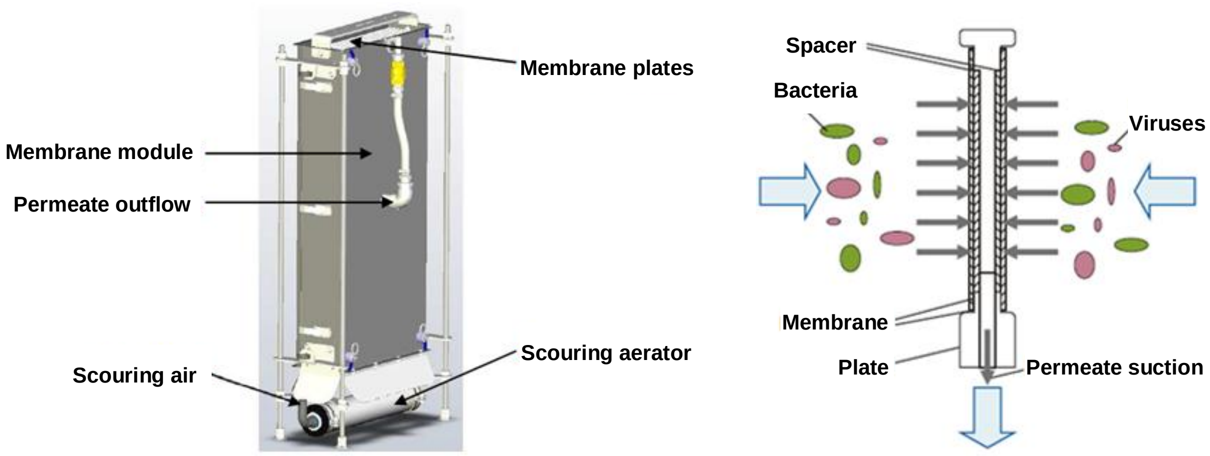


Figure 13: Details of ultrafiltration membrane; (HUBER SE, 2011b; GEP - Freude am Wasser, 2007)

3. Storage tank for permeate:

In the last step the purified water is transported via permeate pump into the storage tank. The container has a volume of 480 l, (see Figure 14). There is a level control probe installed. In case of a lack of process water in the tank, drinking water is automatically fed into it. In the storage tank there is the pump installed to supply the spray bar to clean the TURNY sieve. An additional pump provides the purified water for a further application within the research project, to flush the brownwater pre-treatment plant.

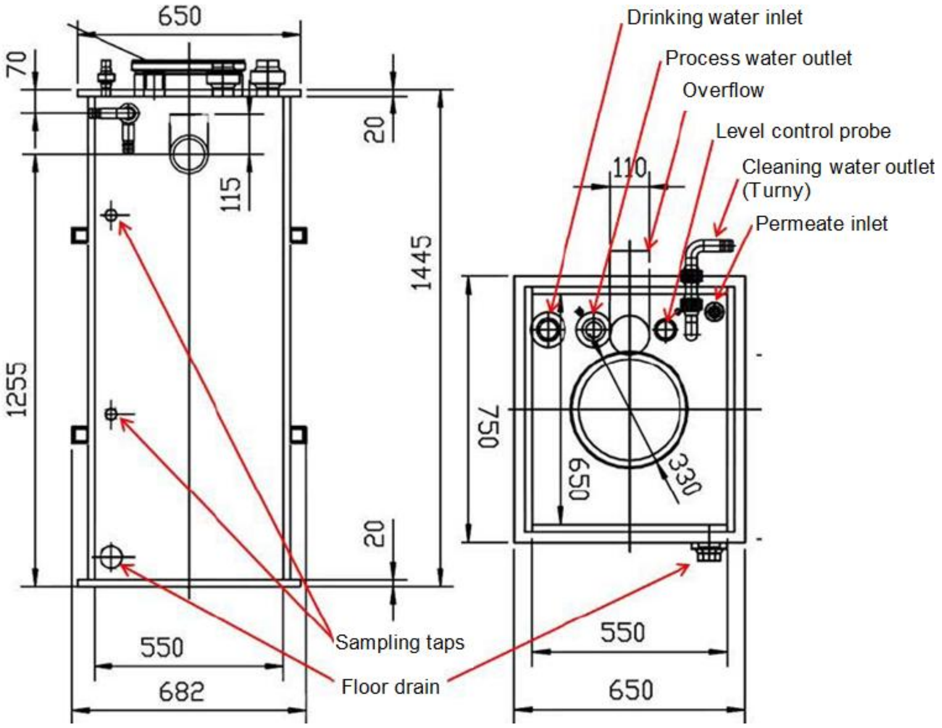


Figure 14: Technical drawing of process water storage tank; (HUBER SE, 2011a)

Detailed overviews of the technical components of the SANIRESCH greywater treatment plant are listed in the appendix chapter 6.1 (in German), including performance parameters and supplier data.

2.3 Water balance for a fictitious calculation of a greywater treatment plant in an office building

To accomplish the investigation of international transferability, an approach was chosen to calculate a fictitious project in an office building in a large-scale, based on the existing research project. Only a realistic showcase calculation of treatment plant is capable to withstand an analysis of international transferability.

The idea is a fictitious calculation of a greywater treatment plant in the entire main building of GIZ's headquarters (Figure 15), with a greywater reuse application for toilet flushing. Greywater from washbasins, kitchen sinks and dish washers are intended to be treated; only the stream flow of the cafeteria has been excluded because of the difficult treatment, due to the high load of solids and grease.

Figure 15: GIZ's headquarters in Eschborn/Germany; (picture by K. Löw)

According to the data collection in August 2009, there were 647 employees occupied in the main building of GIZ. Regarding the toilet usage per person, an assumption of 3 toilet visits per working day was made (2x urination,1x defecation). Each time after using the toilet greywater is produced due to hand-washing. The GIZ headquarters building has been furnished with water saving taps. The armatures feature aerators to minimise the flow rate. In addition, there are sensors assembled to activate the water flow only by movement of hands in front of the sensor tap. According to water&more (2005) (a supplier of water saving armatures), the average amount of water used for hand-washing with such taps is 1.5 l.

Additionally, an assumption of greywater production in the kitchenettes (24 in the building) was made. A daily use of the dishwasher in every kitchenette was estimated and 10 l wastewater from every kitchen sink.

To calculate the water demand for toilet flushing the assumption of 3 toilet visits per person, two times for urination and one time for defecation was used, as mentioned above. There are water saving "NoMix" toilets installed within the GIZ building, unfortunately the facilities are not working properly and several flushes are necessary after every toilet visit to remove the excrements (Winker M. , 2011c). Therefore, an assumption of water volumes for toilets which are working correctly was made, with a 4 l flush for urine and a 6 l flush for faeces (Trincheria, 2010). In addition, there are waterless urinals built in the men's toilets. All data of water balance calculation is assembled in Table 5. In section 3.5.1, the results of the investigation of water balance are summarised.

Table 5: Basic parameters of water balance calculation; (calculation by K. Löw)

Assumptions of wastewater production	
Amount of GIZ employees (dataset: August 2009 week 37)	270 men
	377 women
3 visits of toilet per working day (2x urination, 1x defecation)	Flushing of toilet - men (Trincheria, 2010): 1 x 6 l, 2 x waterless urinal = **6 l/d**
	Flushing of toilet - women (Trincheria, 2010): 2 x 4 l, 1 x 6 l = **14 l/d**
3 times hand-washing	Per employee: 3 x 1.5 l (water&more, 2005) = **4.5 l/d**
Operation of dishwashers	Every dishwasher (BOSCH, 2011) = **16 l/d**
Wastewater from kitchen sinks	Every kitchen sink = **10 l/d**

2.4 Greywater treatment via MBR technology - Analysis and evaluation of international transferability via multi criteria decision analysis

Prior to the assessment of the transferability of membrane bioreactor treatment technology, it is necessary to find a decision making tool which can support the process. It is difficult to come up with a decision that determines in which regions of the world greywater treatment using MBR is reasonable. The technology of membrane bioreactor provides a capable method to recycle greywater with an effective cleaning process. It requires minor space and provides a high quality. However, the investment costs and energy consumption of the plant is relatively high. In this respect, international applications need to be identified, where the requirements and circumstances harmonise ideally with MBR technology, such as water scarcity combined with lack of space and high reuse requirements for permeate. Due to many influencing factors, this challenge has to be mastered by a decision making tool. Certainly it can be answered only by taking into account the immediate context of a specific application. However, it is important that it is based on transparent criteria. Not every factor has the same importance; therefore it is necessary to find a capable instrument for decision making.

2.4.1 Decision making tool

Figure 16 illustrates different methods of multi criteria decision analysis (MCDA) in a tree structure. At first, there is a main distinction between multi objective decision making (MODM) and multi attributive decision making (MADM). Based on the number of alternatives under evaluation, MADM methods are designed to select discrete alternatives, while MODM are more adequate when dealing with multi-objective planning problems with a theoretically infinite number of continuous alternatives (Mendoza & Martins, 2006).

To identify the international transferability of MBR technology, the multi attributive decision making (MADM) is an appropriate method based on a particular number of alternatives. Within the MADM there is the group of multi criteria methods, here the preference structure of decision-maker is incorporated in the model. The analysis performs a complete mapping and evaluation of pre-selected crucial characteristics.

A reasonable model within the group of multi criteria methods is the multi attribute utility theory (MAUT), it is based on strict adherence to use theoretical rationality axioms. In contrast, the utility analysis is a more heuristic method. The cost benefit analysis (CBA) is regarded as a preliminary investigation on these two methods mentioned before and will not be described here. Finally the analytic hierarchy process (AHP) represents a standardized and process-oriented method (Rohr, 2004).

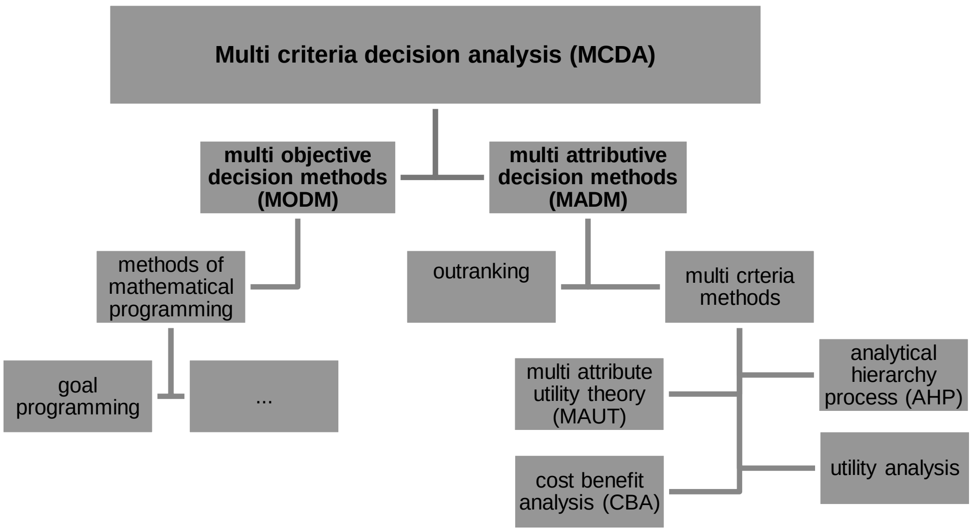


Figure 16: Overview of multi criteria decision making methods; (Oesterdiekhoff, 1993; modified)

For the MAUT and AHP methods there are high demands on the preference articulation of the decision maker necessary, such as result "A" is better than "B". The utility analysis in contrast requires only a medium rating on regulation of priority, equal scoring results without preference are possible. In classical decision theory there are always two alternatives comparable. The decision maker can always make a statement and a clear preference, which of the two alternatives is strictly preferred (strict preference), or if both are equivalent (indifference). Outranking procedures aim to give a decision aid in situations of uncertainty and vagueness (Schuh, 2001).

One of the main tasks of this master's thesis is to find a universally valid instrument for decision-making. Therefore, an assessment system is meant to find the preferential cases of MBR technology application and transfer. It shall identify whether it makes sense to implement an MBR system at a particular place and in a particular application, or not. After an in-depths literature review, the decision was taken to use the utility analysis. The main reason for this decision has been the moderate demand of the tool for preference articulation. In regard of the international transferability of membrane bioreactor treatment technology, there are no first choice decisions available. Worldwide, many hotspots can be identified for meaningful implementation of greywater recycling by MBR treatment. Due to a wide range of influencing factors within the decision-making process, utility analysis seems to be the most appropriate method, as it considers many aspects, not only economic ones such as cost-benefit analysis. Another advantage is the easy and heuristic application of the approach. An overview of further advantages, including completeness, transparency, influence of new alternatives, clearness, required data input, etc., is listed in Table 6.

Table 6: Appraisal of utility analysis; (Schuh, 2001)

Attribute of utility analysis	Performance
Completeness	Yes
Transparency, traceability, objectivity	Transparency and accountability is obtained through the explicit disclosure of respective preferences in the form of criteria weights and aggregation procedures. This prevents that subconsciously factors are incorporated in the criteria rating. Objectivity will not be ensured by the procedure but at least traceability.
Accuracy and validity	Yes
Reliability	Yes
Influence of new alternatives	No influence of new alternatives on existing assessments
Structural openness of method	Yes, new criterion requires merely new weighting of all issues
Convenience and efficiency	Yes
Clearness	Yes
Required data input	According to the analysis method, quasi-cardinal data are necessary, but ordinal data are often regarded as sufficient if a fundamental transformability in benefit points is possible.

The realisation of utility analysis was done as follows: In the first step, the applicable criteria for the decision making must be found. In respect of the international transferability of a MBR treatment plant, e. g. economic considerations and their associated sub items (e. g. acquisition cost, operating costs, etc.) are important. The sub criteria were weighted according to their importance for the objective of the decision making process. Here, percentages are given; the summary of all sub issues is 100% in total. This step results in a matrix that shows all objective criteria in the rows. In the columns, there are respective projects to be evaluated.

To perform the evaluation of a project, each sub point has been assessed regarding accuracy with the statement, e.g. for operating costs the estimation is “10” for high and “1” for low. In every assessment the sub criteria were multiplied by the weighting factors and summarised as a total value. The result is a percentage value that can be set in proportion with the optimal variant of 100% consensus (see Table 7).

Table 7: Sample of a utility matrix; (by K. Löw)

Rating input

	Assessment criteria Discretionary	**Weighting** ∑= **100%**		**Project 1**	
			Description of rating	**Rating**	**Result**
A	**Criterion A**	**10**	high = 10, medium = 5, low = 1, n. a. = 0	**10**	**10**
B	**Criterion B**	**20**	high = 10, medium = 5, low = 1, n. a. = 0	**5**	**10**
C	**Criterion C**	**30**	high = 10, medium = 5, low = 1, n. a. = 0	**10**	**30**
D	**Criterion D**	**20**	high = 10, medium = 5, low = 1, n. a. = 0	**1**	**2**
E	**Criterion E**	**20**	high = 10, medium = 5, low = 1, n. a. = 0	**1**	**2**
	Degree of fulfilment			**Result [%]**	**54**

2.4.2 *IDENTIFICATION OF DETERMINING FACTORS FOR THE ANALYSIS OF INTERNATIONAL TRANSFERABILITY OF GREYWATER TREATMENT*

To provide a basis for the identification of factors of international transferability the fundamental terms of ecology and economy serve the main preconditions. The fundamental aspects are based on the results of a study conducted by Kerpen and Zapf (2005), which identified the following economic parameters:

- Charge for drinking water and wastewater
- Accumulation of greywater in a building (number of residents, consumer habits)
- Investment costs of the system (treatment plant, piping system)
- Operating expenses (maintenance, energy, spare parts)
- Government aid, subsidies, incentives, legal foundation

Apart from economic reasons, criteria of sustainability were taken into consideration in order to ensure a meaningful use of greywater recycling. Especially for urban areas and fast-growing economies, it is necessary to contemplate the environment, surrounding area, and living conditions. This examination caused an expansion of scope regarding ecological and social aspects (SuSanA, 2008).

In regard to a sustainable water management, a framework of recommended action was identified by a research project of the Federal Ministry for the Environmental, Nature

Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) in 1998. The following paragraph characterises the overall concept:
"*A sustainable water management is the integrated management of all artificial and natural water circuits (in part) with respect to three major objectives:*

- *The long-term protection of water as habitat or as a central element of habitats.*
- *The protection of water in its various facets as a resource for the present and for future generations.*
- *The development of options for a durable nature-friendly, economic and social development.*

By meeting the objectives, the requirements arising from the need for sustainable development appearing in other sectors, are also considered. …" (Kahlenborn & Kraemer, 1998).

2.4.3 CRITERIA IDENTIFICATION

Sustainability criteria have been used for classification of the headlines. Based on the literature review of sustainable sanitary concepts, the main components and criteria were identified (Hellström et al., 2000):

- Health and hygiene criteria
- Economic criteria
- Functional and technical criteria
- Environmental criteria
- Socio-cultural criteria

In a further step, appropriate components for the subgroups of the identified main groups needed to be defined. According to literature studies and a master's thesis on a "Framework to assess the international adaptability of the urban sanitation system implemented within the project SANIRESCH" by Josep Maria de Trincheria (2010), the following meaningful criteria were identified and used within this analysis:

- Health and hygiene criteria
    - Quality of purified greywater
    - Stability of permeate quality
    - Legislative requirements for wastewater treatment technologies
- Economic criteria
    - Direct governmental funding for treatment plants
    - Indirect incentives on greywater treatment systems
    - Investment costs of the system (treatment plant, piping system)
    - Operating expenses (maintenance, spare parts)
    - Charge for energy (in general or accumulation in the building)
    - Charge for drinking water (in general or accumulation in the building)
    - Charge for wastewater (in general or accumulation in the building)
    - Price of land
- Functional and technical criteria
    - Yearly maintenance
    - Stability of operation
    - Break downs
- Environmental criteria
    - Water scarcity (physical/economical)
    - Freshwater quality
    - Number of persons situated in the building
    - Accumulation of greywater
    - Sewer system available
    - Population/settlement density
    - Urbanisation rate

- Socio-cultural criteria
    - General acceptance of greywater reuse
    - Ecological awareness
    - Pioneer in this area

Regarding economic issues, no economic criteria of an assessed country such as per capita income or gross national product have been consciously included. It is due to the fact that such a high-tech plant like greywater recycling via membrane bioreactor is not a grassroot solution, which should be implemented in every single household. Additionally, MBR treatment systems are frequently installed in big buildings such as hotels, apartment buildings and halls of residence. In these cases, the economic situation of the investor does often not represent the financial situation of the country.

In the next paragraphs the sub criteria are explained. They are included in order to explain the different issues and the weighting within the utility analysis. In total, the weighting of all criteria results in 100 % and every sub criterion is given a certain value. The complete overview of assessment criteria and weighting within the utility analysis is shown in Table 8.

Table 8: **Assessment criteria for utility analysis of international transferability; (by K. Löw)**

H	**Health and hygiene criteria**	**6%**	
H1	Quality of purified greywater	0	not considered
H2	Stability of permeate quality	0	not considered
H3	Legislative requirements for wastewater treatment technologies, quality directives	6	highly enforced = 10, medium enforced = 5, low enforced = 1, no requirements = 0
E	**Economic criteria**	**39%**	
E1	Direct governmental funding for treatment plants	4	high = 10, medium = 5, low = 1, no = 0
E2	Indirect incentives on greywater treatment systems	4	high = 10, medium = 5, low = 1, no = 0
E3	Investment costs of the system (treatment plant, piping system)	4	high = 1, medium = 5, low = 10
E4	Operating expenses (maintenance, spare parts)	5	high = 1, medium = 5, low = 10
E5	Charge for energy (in general)	5	high = 1, medium = 5, low = 10
E6	Charge for drinking water (in general)	7	high = 10, medium = 5, low = 1
E7	Charge for wastewater (in general)	7	high = 10, medium = 5, low = 1
E8	Price of land	3	high = 10, medium = 5, low = 1
T	**Functional and technical criteria**	**0%**	
T1	Yearly maintenance	0	not considered
T2	Stability of operation and quality	0	not considered
T3	Breakdowns	0	not considered
N	**Environmental criteria**	**41%**	
N1	Water scarcity (physical/economical)	12	high = 10, medium = 5, low = 1, no = 0
N2	Freshwater quality	5	high = 1, medium = 5, low = 10
N3	Number of persons situated in the building	8	big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)
N4	Accumulation of greywater	10	high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1
N5	Sewer system available	2	no = 10, yes = 1
N6	Population/settlement density	2	high = 10, medium = 5, low = 1
N7	Urbanisation rate	2	high = 10, medium = 5, low = 1
S	**Socio-cultural criteria**	**14%**	
S1	General acceptance of greywater reuse	5	high (toilet flushing, irrigation, laundry) = 10, medium = 5 (toilet flushing, irrigation), low = 1 (toilet flushing or irrigation)
S2	Ecological awareness	5	high = 10, medium = 5, low = 1
S3	Pioneer in this area	4	yes = 10, no = 1

The **health and hygiene criteria,** which are mentioned as the first main group, are not regarded as a strong criterion to assess the transferability of membrane bioreactor technology. With this MBR technology, the quality of recycled greywater is of consistently good quality due to the ultrafiltration membrane. With a pore diameter of 38 nm, it fulfils EU bathing water specification, independently of treatment circumstances. In addition, there is no variation of permeate quality (caused by instability of treatment system) expected, due to mechanical filtration properties of the membrane (Paris, 2009b). Since no different technologies are assessed within the scope of this paper, both criteria, **quality of permeate (H1)** and **stability of quality (H2),** are considered as irrelevant.

Only the **legislative requirements for wastewater treatment technologies (H3)** were counted within this main group. This criterion refers to regulations and directives for treated greywater and for reuse applications in evaluated countries. In this regard, the ratings “highly enforced” = 10, “medium enforced” = 5, “low enforced” = 1, and “no requirements” = 0 were given. If there are highly enforced requirements on the quality of purified greywater, then it is a strong motivation to use high-tech treatment via MBR. In the weighting of utility analysis, legislative requirements are included with 6 %.

Economic issues (E) are given a high weighting of 39 % within the utility analysis. This is because there are holistic cost approaches that always provide strong reasons for the decision of greywater treatment plant implementation.

Direct governmental funding for treatment plants (E1) by e.g. subsidies, allowances, loans for plant investment, or financial support is the first sub issue. It was weighted with 4 % within this group. The **indirect incentives on greywater treatment systems (E2)** add another 4 % to the weighting. It includes e.g. tax reductions, discounts, minimised fresh and/or wastewater charges, reimbursements of taxes, or charges. For both criteria, the appraisal is: “high support” = 10, “medium support” = 5, “low support” = 1 and “no support” = 0.

Investment costs of the system (E3), which include the treatment plant, a separate piping system, and all installations necessary for the greywater treatment system, were weighted with 4 % in the utility analysis. Membrane bioreactor treatment plants are relatively expensive. It is expected that the investment expenses are to be amortised at least within 7 - 8 years of operation, then it is possible to save enough money within the next 7 - 8 years to substitute the plant; (lifecycle 15 years). Otherwise there is no stimulus to install such a technology in a building. Therefore, this sub criterion was only weighted with 4 %, as an economic feasibility of the system was presumed. The estimation is: “high price” = 1, “medium price” = 5 and “low price” = 10.

Operating expenses (E4), including maintenance, spare parts, and working time, were weighted with an influence of 5 %. For the appraisal, the regular payments were weighted with a bit more influence than investment cost: This is due to the fact that regular payments are an important factor which stands for a big amount of money which must be spent on a regular basis. The classification is as follows: “high expenses” = 1, “medium expenses” = 5 and “low expenses” = 10.

If the **energy price (E5)** is very high, there is no incentive to implement a MBR treatment system, because of relatively high energy consumption of the plant (see energy calculation in section 3.53.5.1). Therefore, the appraisal of criterion is: “high expenses” = 1, “medium expenses” = 5 and “low expenses” = 10. To assess those issues, the energy price can generally be considered in the country or region. Together with operating expenses, it is a regular payment that can be a high cost factor; hence it was assessed with 5 %.

In contrary, there are **charges for drinking and wastewater (E6 & E7)** which can be saved by greywater treatment. Both criteria are classified with “high charges” = 10, “medium charges” = 5 and “low charges” = 1. If high expenses can be avoided, it is an appeal to implement a recycling system. Each criterion (charge for drinking and wastewater) was weighted with 7 %. The idea behind it was to have a balanced situation of costs, which need to be spent, and expenses that can be saved. The assessment counts 14 % in total for investment, maintenance and energy costs. In contrary, 14 % for drinking and wastewater that can be saved.

Often the **charge for drinking water (E6)** is very high because of water scarcity or missing water pipes. Therefore, supply by tank vehicles is necessary. In this case, it is very useful to recycle greywater in order to use water several times within a building. However, in some countries the price of water is low due to governmental subsidies, despite critical water supply (such as in Jordan (Rothenberger et al., 2011)). That aspect should be kept in mind whenever the water price in arid areas is low.

Regarding **wastewater (E7),** often no sewer system is available in a country or region. Thus, the sewage needs to be removed frequently from own collection systems (tanks), and tank vehicles must then pick it up. Ideally the wastewater is transported to central sewage treatment plants, but often it is only dumped into rivers or the sea. The reduction of wastewater by dual use for showering and toilet flushing is interesting from an economic point of view and secondly also due to less effort of sewage removal.

The **price of land (E8)** is an indirect indicator that determines the decision in urban areas wether to implement greywater treatment via biomembrane reactor, or instead using other systems like constructed wetlands. The MBR technology is extremely compact and can be installed ideally in buildings where space is limited. It was weighted by a low percentage of only 3 %, since it is only a supporting factor. The rating is as follows: “high price” = 10, “medium price” = 5 and “low price” = 1.

The **functional and technical criteria (T)** are considered as obsolete in respect of importance for this evaluation. A comparison with other technologies, which might be better or worse, is not destined. The appraisal of international transferability based on MBR treatment is not influenced by functional or technical criteria. There is no variation in **yearly maintenance (T1)**, **stability of operation and quality (T2)** and **break downs (T3)**. According to experiences drawn by company HUBER SE, e.g. yearly maintenance is necessary, independent of region of application (cf. Table 13 data of maintenance). The stability of operation does not vary if there are big or small greywater volumes. It results always in good permeate quality. Furthermore, an accumulation of breakdowns, caused by environmental conditions such as climate, is not expected. Therefore, this main group can be disregarded.

Environmental criteria (N) are considered as the second strong influencing factor in order to make a decision for implementing a greywater treatment plant. That main criterion was weighted in total with 41 %.

The most important factor within the assessment is **water scarcity (N1).** It is of urgency to implement water saving technologies in buildings. Hence, the criterion was weighted with 12 % in the utility analysis. In this sub group, water scarcity stands for both, physical and economical water scarcity. Physical water scarcity applies to the dry parts of the world or arid regions. However, in an increasing number of regions in the world, physical water scarcity is considered asan anthropogenic problem. Often, overuse and over management of river basins can lead to very serious physical water scarcity. The expression “economic water scarcity” refers to a situation, when a state does not have the necessary monetary means to utilise an adequate source of water (The water project, 2011). For both types, the estimation is: “high” = 10, “medium” = 5, “low” = 1 and “no scarcity” = 0.

If **fresh water quality (N2)** in a country or region is very poor due to chemical or hygienic pollution, it is necessary to provide drinking water from water supply trucks. It is often also an indicator for water scarcity or bad infrastructure. The sub criterion is an indirect factor which supports the implementation of greywater treatment plants, because it can diminish the consumption of drinking water. It was weighted with 5%. In this respect, the following classification was chosen: “high quality” = 1, “medium quality” = 5 and “low quality” = 10.

A further important issue is the **number of persons (N3)** living in the building where the greywater treatment plant shall be installed. Together with **the accumulation of greywater (N4)**, it is an indirect factor to estimate the volume of greywater which is accumulated in the project. This type of evaluation was chosen, because it is easier to answer these both questions, instead of responding to the question of exact greywater volume accumulation.

An important factor for the assessment of a useful greywater plant installation is the dimension of the building represented by **number of persons (N3)**. The bigger the volume of treated greywater, the cheaper the price of treated water. That factor was considered as an important criterion and is weighted with 8 %. The easiest way to estimate this is by the number of persons living in the building. For the classification, the following ranges have been fixed: "big number (> 100 persons)" = 10, "medium number (10 - 100 persons)" = 5, "small number (< 10 persons)" = 1.

The **accumulation of greywater (N4)** was included in the calculation with a weighting of 10 %. On the one hand it is an appeal to reduce water uptake rate by dual use, in case the consumption of water as well as the production of greywater is high. On the other hand, the economic cost calculation is more beneficial when based on high volumes. This makes the sub criterion very important for the appraisal. A "high accumulation of greywater" (= 10) can be equalised with an overnight stay e.g. at a hotel and when water from showers and bath tubs contribute to the overall amount. "Medium accumulation" (= 5) means operation in the daytime plus showering, such as in factories where the staff takes a shower after finishing work. "Low accumulation" (= 1) is expected for buildings with operation hours in the daytime, e.g. in office buildings.

In areas where no **sewer system (N5)** is available, the removal of sewage is very complicated. It is determined by high cost- and time efforts due to the collection with tank lorries. This might be an appeal to reduce sewage water production by means of greywater recycling. On top, if no sewer system is installed, the operators of large buildings, such as hotels, have a great interest that no sewage water passes by on the doorstep. Therefore, the classification is: "no sewer system available" = 10 and "sewer system available" = 1. In total, the weighting of the sub group is not very high with 2 %, because it is only a contributing criterion.

The next factor is **population or settlement density (N6)** in the projected area where the MBR plant shall be installed. In densely populated regions, problems caused by high demand of drinking water are more intense than in low populated areas. In addition, the problems which might be caused by high production of sewage water are more critical, if no appropriate sewer system is available. It has been assumed that space for treatment plants is limited in densely populated areas. This aspect makes MBR technology with its little space requirements highly suitable. Thus, population or settlement density is classified with "high" = 10, "medium" = 5 and "low" = 1. In total, the weighting within the utility analysis is 2 %.

In principle, the installation of a membrane bioreactor makes more sense in an **urbanised area (N7)**, as it goes hand in hand with the sub criteria of settlement or population density above. Despite the similarity between sub criterion N6 and N7, both factors were included, because often there is a high settlement density of hotel complexes far away from urban areas, and this needs to be taken into account as well. If both criteria apply, there is a high appeal to use MBR technology. In this respect, the criterion was weighted with 2 % as well. "High urbanisation" = 10, "medium urbanisation" = 5, and "low urbanisation" = 1, there is no suggestion of city size added, due to different definitions in every country. In Germany for example, a city with a population of 100.000 persons is a major city, but a direct comparison with megacities like Tokyo or Delhi is impossible. Hence, there is the advice to make the decision based on national definition of evaluated area (Berlin-Institut, 2011).

The main group, namely **socio-cultural criteria (S)**, was estimated with 14% in total for the appraisal of international transferability. Not only environmental or economic reasons need to be considered, but also personal and private motives of decision-making.

Regarding general **acceptance of greywater reuse (S1)**, there are different possible ratings. In Germany the acceptance of recycled greywater for the purpose of toilet flushing is very high with approximately 93% (Knerr et al., 2009). In Muslim countries, it is often only accepted to use recycled water for irrigation purposes, due to religious reasons (Sieghart, 2005). The classification was defined with "high acceptance" = 10 for toilet flushing, irrigation, laundry, dish washing, etc.; with “medium acceptance” = 5 for toilet flushing and irrigation (the persons do not get in direct contact with purified water); and “low acceptance” = 1, if only one application like toilet flushing or irrigation is accepted. In total, the weighting of this sub issue is 5 % within the utility analysis.

The **ecological awareness (S2)** of a company or of persons can lead to an implementation of a greywater treatment plant, although the amortisation of the project is not demonstrative. The project of company DEHOUST in Ankara/Turkey (cf. 3.2.) is such an example (Sellner, Grauwasserrecycling - DEHOUST GmbH, 2011). Hence, such motives are weighted with 5 % within the assessment. If the “ecological awareness” is high, the rating is 10; for “medium awareness” it is 5; and for “low awareness” it is 1.

Finally, sub **issue S3 (pioneer in this area)** is a stimulus for the implementation of greywater treatment via membrane bioreactor. It goes in the same direction as S2. However, according to marketing aspects, there is an incentive to become a pioneer in this technology; therefore it was accounted with 4 % in the total weighting. The rating of 10 can be chosen if the “project is a pioneer in the area”, but if there are other MBR projects applied in the region as well, a rating of 1 can be given.

Basically, the classification 0, 1, 5, and 10 was selected for the estimation within the rating, in order to make it easier to choose a value. Certainly it is possible to give ratings between 0 and 10, but it is difficult to define differences e.g. between 2 and 3. An additional advantage is that the different ratings get more influence, which makes the result of utility analysis more obvious.

If there is no data available, the criterion is assessed with N/A (“not available”) in a separate column. In the Excel-sheet, there are N/A answers counted in order to be aware of the inaccuracy of the utility analysis, in case there are too many N/A-answers. A good valuation of a certain project can only be achieved by a good data basis. An appraisal, which includes more than 5 N/A answers must be considered as not meaningful. Within the assessment matrix, the N/A-answers are counted with 0. In total, a weighting of 100 %, minus the weighting of sub issues that have been answered with N/A, can be achieved. An adaption of 100 % is not calculated in case there are N/A values, as this might change the influence of sub issues (change of calculation basis).

2.4.4 Utility Analysis

For the utility analysis of international transferability of greywater treatment via MBR, a few issues are mandatory. Only with fulfilment of the following aspects, an assessment of technology transfer makes sense. Table 9 provides a list of general requirements for greywater treatment application via MBR technology.

Table 9: General requirements for greywater treatment application via membrane bioreactor; (by K. Löw)

M	Mandatory criteria to install a greywater treatment plant with MBR technology
M1	General acceptance of greywater reuse
M2	High requirements concerning quality of recycled water
M3	Stable availability of energy
M4	Temp. > 12 °C
M5	Trained staff for operation available

First of all, the **general acceptance of greywater recycling (M1)** is mandatory. In some circumstances, reuse of purified greywater is not accepted due to religious reasons. Especially in muslim-dominated areas, there is often uncertainty, if recycled water meets the requirements of purity (Sieghart, 2005). Furthermore, hygienic concerns, which are however unfounded, and nauseation can lead to the refusal of such a system.

Issue **M2** focuses on the **quality of recycled greywater**. The membrane bioreactor technology serves a top-quality permeate for in-house reuse. If the recycling application does not require these high quality characteristics, such as irrigation, then it should be taken into consideration that the treatment can take place with a different technique, which does not belong to the high-tech technologies. In some reuse applications, a more nature-orientated treatment (e.g. constructed wetlands) might then be the first choice, especially if space is abundant. Based on the high investment costs and additional costs for energy, MBR greywater recycling is a high end system that should only be used if such high standard is required.

Furthermore a mandatory demand to run a MBR treatment plant is the **stable availability of energy (M3)**. The functioning of pumps and aerators depends on electrical power, which is needed non-stop. Not only the transport of greywater from one treatment container to the other requires energy, but also the activated sewage sludge needs aeration to keep biological processes alive. An energy breakdown can thus demolish the functioning of the activated sludge.

Requirement **M4** is concerned with the **operational temperature of the system**. The temperature in the membrane bioreactor must be maintained > 12 ° C, otherwise problems with biological function of activated sewage sludge can occur (HUBER SE, 2011a).

Working with MBR treatment plants requires well **trained staff (M5)**. The operation of the facility can only be managed by reliable persons, which are familiar with the function of the system. The operating- as well as safety instructions must be noted. It is recommended to keep an operating log where maintenance and any disfunction can be recorded.

The complete matrix of utility analysis is presented in Table 10. To be able to verify the function of utility analysis with all appraisals, estimations, and assumption, the matrix has been discussed with the following 4 experts in the field of innovative water recycling technologies: Ms. Martina Winker (GIZ/Eschborn), Mr. Enno Schröder (GIZ/Eschborn), Mr. Martin Feicht (HUBER SE/Berching) and Mr. Erwin Nolde (Nolde & Partner/Berlin). The consultation of professionals in the field of greywater treatment has led to a process where the first drafts were revised and improved several times, before te final utility matrix was created.

Table 10: Matrix of utility analysis; (by K. Löw)

Rating input

	Assessment criteria Discretionary	Weighting ∑= 100%	Description of rating	Rating	Info not available	Result
H	**Health and hygiene criteria**	**6%**				**0**
H1	Quality of purified greywater	0	**not considered**			
H2	Stability of permeate quality	0	**not considered**			
H3	Legislative requirements for wastewater treatment technologies, quality directives	6	**highly enforced = 10, medium enforced = 5, low enforced = 1, no requirements = 0**			0
E	**Economic criteria**	**39%**				**0**
E1	Direct governmental funding for treatment plants	4	**high = 10, medium = 5, low = 1, no = 0**			0
E2	Indirect incentives on greywater treatment systems	4	**high = 10, medium = 5, low = 1, no = 0**			0
E3	Investment costs of the system (treatment plant, piping system)	4	**high = 1, medium = 5, low = 10**			0
E4	Operating expenses (maintenance, spare parts)	5	**high = 1, medium = 5, low = 10**			0
E5	Charge for energy (in general)	5	**high = 1, medium = 5, low = 10**			0
E6	Charge for drinking water (in general)	7	**high = 10, medium = 5, low = 1**			0
E7	Charge for waste water (in general)	7	**high = 10, medium = 5, low = 1**			0
E8	Price of land	3	**high = 10, medium = 5, low = 1**			0
T	**Functional and technical criteria**	**0%**				**0**
T1	Yearly maintenance	0	**not considered**			
T2	Stability of operation and quality	0	**not considered**			
T3	Breakdowns	0	**not considered**			
N	**Environmental criteria**	**41%**				**0**
N1	Water scarcity (physical/economical)	12	**high = 10, medium = 5, low = 1, no = 0**			0
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**			0
N3	Number of persons situated in the building	8	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**			0
N4	Accumulation of greywater	10	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**			0
N5	Sewer system available	2	**no = 10, yes = 1**			0
N6	Population/settlement density	2	**high = 10, medium = 5, low = 1**			0
N7	Urbanisation	2	**high = 10, medium = 5, low = 1**			0
S	**Socio-cultural criteria**	**14%**				**0**
S1	General acceptance of greywater reuse	5	**high (toilet flushing, irrigation, laundry) = 10, medium = 5 (toilet flushing, irrigation), low = 1 (toilet flushing or irrigatin)**			0
S2	Ecological awareness	5	**high = 10, medium = 5, low = 1**			0
S3	Pioneer in this area	4	**yes = 10, no = 1**			0
	Degree of fulfilment			**Result [%]**		**0**
				n. a. citeria		0

2.5 METHOD TO IDENTIFY IDEAL INTERNATIONAL APPLICATIONS OF MBR TECHNOLOGY

According to the utility analysis, it is possible to evaluate a planned project in regard to its feasibility of international transferability. However, it is also possible to identify areas, regions, or countries, where an implementation of greywater treatment via MBR is particularly reasonable. This latter approach can only outline a rough estimation of global hotspots, due to regional differences. The regional distinctions and conditions may vary widely within narrow spaces, hence it is only possible to make suggestions and give directions. For the investigation of a proposed project, accurate local data must necessarily be used to estimate the transferability of MBR technology.

An evaluation of global hot-spots for international transferability can mainly be done based on a limited number of criteria. It was not possible to investigate the **legislative requirements (H3)** for greywater recycling on an international scale. Also, data on **direct (E1)** and **indirect (E2) governmental support** is difficult to acquire and it was particularly not possible within the given time for this work.

The same problem appeared on the identification of the **water prices (E6)**. All these data is difficult to identify and it varies regionally. For example, the water price depends on various circumstances; the supply by tanker trucks is much more expensive than by public utilities (see Figure 17) and the provision of water supply can differ regionally. Additionally, subsidised water prices are widespread. In the past, water for agriculture was often subsidised to make agriculture more competitive or even to make it generally possible in some regions. Therefore, water is often cheap even though it is very scarce (Paeger, 2011).

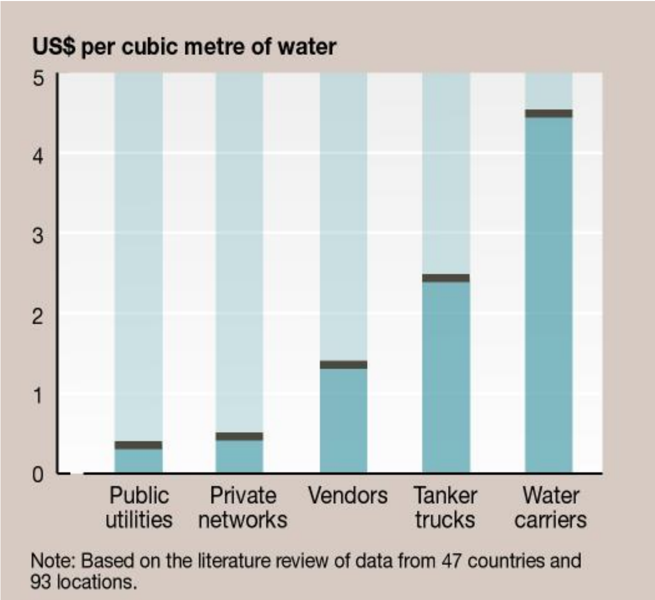


Figure 17: Water price [US$/m^2] for different channels of supply; (UNEP, 2008)

Similarly, **energy (E5)**, **wastewater (E7)**, and **land prices (E8)** differ locally. Hence, these issues were not regarded as appropriate criteria for the evaluation of the ideal international applications for MBR technology.

Economic aspects such as **investment cost (E3)** and **operation expenses (E4)** differ from project to project and cannot be configured or standardised. Therefore, no economic criteria were contemplated in order to identify the international transferability of greywater treatment technology.

The same applies if we look at the **socio-cultural criteria (S)**. A generalisation is not possible, as these aspects must be considered for each project and thus cannot be defined based on a region or a country.

Finally, **environmental criteria (N)** remain for the appraisal of international transferability. The criterion **water scarcity (N1)** is with 12 % the strongest issue within the utility analysis. It was used as an indicator to identify countries around the world that suffer from physical water shortage or are about to suffer from it. The regions with economic water scarcity are incorporated here. In the evaluation, regions with economic water scarcity are not in the main focus, because economic water supply problems indicate immense poverty in the country. A high-tech solution, like greywater treatment by MBR technology, is only valid solution in very limited areas with good infrastructure. For example, safe power supply for the treatment plant is mandatory and this often cannot be provided in extremely poor regions.

After the identification of water scarce countries, the investigation was carried out based on the following environmental criteria, where data availability was good:

- **Freshwater quality (N2)**
- **Population density (N6)**
- **Urbanisation (N7)**

In Table 11 the trimmed-down version of the utility analysis is presented. These criteria can achieve in total a weighting of 21 % within the utility analysis, or 21 scores. For the matrix assessment, the following adjustments were made:

Water scarcity (N1)

Existing water scarcity in most areas of the country = 10

Existing and/or approaching water scarcity in most areas of the country = 5

Freshwater quality (N2)

Environmental Performance Index 2010 (EPI) ranks 163 countries according to 25 performance indicators. Fresh water quality (WQI) is one of them and is included in the calculation within the ranking system. The quality of water is rated by three parameters measuring nutrient levels (Dissolved Oxygen, Total Nitrogen, and Total Phosphorus) and two parameters measuring water chemistry (pH and conductivity). The water quality index (WQI) constitutes a value between 0 and 100; high values representing good quality (Yale University, 2010). In the utility analysis, a conservative scoring system was chosen, to estimate water quality:

WQI 0 - 33 = 10

WQI 34 - 66 = 5

WQI 67 – 100 = 1

Population density (N6)

To estimate of criterion N6, the physiological population density per m^2 was assessed. It considers only those areas of a country which are actually populated, and non-inhabitable regions such as deserts are excluded. On this basis, the population density gives a better indication than viewing the complete area, especially for countries with a high proportion of desert.

Population per km^2 arable land:

0 – 250 = 1

250 – 800 = 5

> 800 = 10

Urbanisation (N7)

Criterion N7 represents the ratio of population of a country living in urban areas. The scoring system with equal proportions was selected.

Rate of urbanisation in the country:

0 – 33 % = 1

34 - 66 % = 5

67 – 100 % = 10

Table 11: Trimmed-down version of utility analysis; (by K. Löw)

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating
N	Environmental criteria	21%	
N1	Water scarcity (physical)	12	high = 10, medium = 5, low = 1, no = 0
N2	Freshwater quality	5	high = 1, medium = 5, low = 10
N3	Number of persons situated in the building	0	big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)
N4	Accumulation of greywater	0	high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1
N5	Sewer system available	0	no = 10, yes = 1
N6	Population/settlement density (based on habitable area of the country)	2	high = 10, medium = 5, low = 1
N7	Urbanisation rate	2	high = 10, medium = 5, low = 1

The utility analysis has a maximum rating of 21 scores or a weighting of 21 %, based on the trimmed-down version of utility matrix. Water scarcity (N1) is the strongest criterion within the analysis and was identified as indicator criterion to identify countries which are rewarding for the examination of the international transferability. This strategy aims to exclude incorrect influences from the analysis. Within the given time of this work it was not possible to assess all countries according the four criteria, but by starting with the most influencing criterion (N1), mistakes should be avoided. Even if the other 3 rated criteria have high values, a weighting higher than 12% (as N1 contributes), cannot be achieved by the maximum rating of N2, N6, and N7. Thus, a completely different result by rating all countries should be avoided with this strategy, but slight differences are possible.

3 RESULTS AND DISCUSSION

3.1 FUNDAMENTAL IDEA OF GREYWATER REUSE BASED ON THE TECHNOLOGY OF MEMBRANE BIORACTOR TREATMENT TECHNOLOGY

The comparison of different treatment technologies in chapter 0 shows the advantages of the MBR technology. With a very good cleaning capacity the treatment is capable to provide process water with a very high quality standard, according EU directive for bathing water quality RL 76/160/EWG (1975) and RL 2006/7/EG (2006). The effective removal of contaminants and bacteria by membrane bioreactor offers the basis for the use in applications with high demands, such as toilet flushing. A further beneficial point is the very low space requirement of the plant; hence the system can be used ideally in densely populated spaces (Paris, 2009b).

The disadvantages are high energy demands due to intensive aeration for membrane surface cleaning to avoid blockage of membrane. A fundamental problem of MBR systems are fouling and scaling, thereby the permeability of the membrane is reduced within a short time. This is reflected in the reduction of the filtrate volume, caused by increase of the transmembrane pressure and hence energy cost (Cornel & Wagner, 2009).

A comparison of sequencing batch reactor (SBR) and membrane bioreactor (MBR) treatment plants in Table 12 shows higher investment costs for MBR technology. The per capita price to recycle greywater shows better results for 8 person-plants than for 4 person-plants. Therefore, economic issues can be improved if the treatment plants are installed in large buildings.

Table 12: Investment costs for treatment plants and house installations (net) for SBR and MBR plants in comparison; (Herbst, 2008)

Treatment technology	Plant for 4 persons	Total costs treatment plant and installation	Plant for 8 persons	Total costs treatment plant and installation
SBR plant	€ 3,400 ca. 850 €/person	€ 5,400 ca. 1,350 €/person	€ 3,600 450 €/person	€ 6,100 ca. 760 /person
installations	€ 2,000 ca. 500 €/person		€ 2,500 ca. 310 €/person	
MBR plant	€ 4,800 ca. 1,200 €/person	€ 6,800 ca. 1,700 €/person	€ 6,300 ca. 790 €/person	€ 8,800 ca. 1,100 €/person
installations	€ 2,000 ca. 500 €/person		€ 2,500 ca. 310 €/person	

Comparative studies have shown membrane bioreactor treatment is the best technology for the greywater recycling, because of its excellent cleaning performance. With minimal space requirement the MBR process demonstrates a high and consistent effluent quality with constantly low biological oxygen demand (BOD) concentration, low turbidity and good coliform bacteria-retentive performance. This also performs well, if there are variations of inflow characteristics (Pidou et al., 2007).

On this account it makes sense to implement such a system only where high water quality is required, especially for toilet flushing, dish washers, washing machines and other cleaning applications. Water for irrigation has in most areas of the world lower quality requirements and therefore no high-tech recycling plant is necessary. With this background the application of compact membrane bioreactor plants makes sense in areas, where little space is available such as in densely populated areas. The small construction of MBR treatment systems is ideally applicable, where deficiency of space prevails or the price of land is prohibitive. Additionally, the cost calculation is beneficial in big buildings, therefore e. g. hotels, apartment buildings or hospitals in urban areas where recycled water is used in the same building for toilet flushing etc., are predestined.

3.2 EXISTING MEMBRANE BIOREACTOR PROJECTS WORLDWIDE

The first experiments in the field of greywater reuse via membrane bioreactor technology were carried out in the late nineties in Great Britain, among others at the School of Water Sciences at Cranfield University (Jefferson, 2000). In the meanwhile many serial MBR products for greywater recycling have been developed and were implemented worldwide.

The German society of experts in service- and rainwater use (Fachvereinigung Betriebs- und Regenwassernutzung e. V. (fbr)) published a list of German companies which work on in the field of greywater treatment (fbr, 2009a). Based on this information an investigation of worldwide existing projects working with MBR technology was conducted. The data collection was accomplished by internet research, e-mail enquiry and personal discussion with experts of different companies (Dehoust GmbH, 2011; GeoTerra Geologische Beratungsgesellschaft mbH, 2011; HUBER SE, 2011c; Jacob, 2011; mall Umweltsysteme , 2011; Sellner, 2011). The outcome of a survey of several different companies is listed in the following table (Table 13).

The overview of international applications comprises information about **country**, **city** and **venture name** or **name of the project** and provides a summary of the worldwide spread of greywater treatment projects using MBR technology. The **type** and **size of building** is additional information to get an insight into the application spectrum. The **start of project** or **running time period** shall give an impression of actuality and the time frame of experience. **Source of greywater** and **use of recycled water** give an overview of the most common reuse purposes. The provided technical information is **treatment capacity** of the plant, interval of inspection and maintenance and **time expense for maintenance**.

Table 13: International greywater treatment projects based membrane bioreactor technology (MBR), sorted in alphabetic country order; (enquiry by K. Löw)

Country	Town	Name of the project	Type of building	Size	Treatment capacity	Time period or project start	Operation time	Greywater production	Reuse	Inspection and main-tanance interval	Time expense for main-tenane	Company
Afghanistan	Mazar e Sharif	-	Police academy	400 persons	20.000 l/d	1 August 2011	4 month	washbasins, shower tray outflows	toilet flusing and irrigation of outdoor facilities	n. a.	n. a.	GreenLife
Austria	Fussach	-	Multi-storey dwelling	45 persons	2.000 l/d	1 January 2009	2 years	washbasins, bath and shower tray outflows	toilet flushing, washing mashines and irrigation	1x per year	n. a.	GreenLife
Chile	n. a.	-	Assembly set (filter and control system)		500 l/d	1 April 2010	1,5 years		n. a.	1x per year	n. a.	GreenLife
Cyprus	Nicosia	-	Gallery	150 persons	6.000 l/d	1 October 2010	1 year	washbasins, a few shower tray outflows	toilet flushing	1x per year	n. a.	GreenLife
Germany	Bad Windsheim	4* hotel "Spät am Kurpark", BMBF project „Hotel“	Hotel	20 rooms	1300 l/d	competely 2009	2 year	washbasins, shower tray outflows	toilet flushing and additional washing mashines and dishwashers	1x per year (change of membrane modules)	ca. 8 h/a	HUBER SE
Germany	Berching	Company HUBER SE	Office building	190 employees	800 l/d	2003-2009	6 years	washbasins, kitchen sinks, dishwasher	till 2007 irrigation of outdoor facilities, afterwards together with rainwater for toilet flushing	1x per year	ca. 6 h/a	HUBER SE
Germany	Berlin	Krause Selbsthilfe Rixdorf e.V.	Multi-storey dwelling	30 persons	1000 l/d	June 2008	report after 12 month	washbasins, bath and shower trays of dwelling and sauna	toilet flushing and additional washing mashines	1x per year	n. a.	geoterra
Germany	Bremen	-	Multi-storey dwelling	12 persons	750 l/d	Dec. 2008	report after 9 month	washbasins, shower tray outflows in combination with rainwater	toilet flushing	1x per year	n. a.	geoterra
Germany	Coswig/ Sachsen	Marco Kunze	One-family dwelling	one family	n. a.	Dec. 2009	n. a.	washbasins, bath and shower trays	n. a.	n. a.	n. a.	mall GmbH

Table 13: International greywater treatment projects based membrane bioreactor technology (MBR), sorted in alphabetic country order; (enquiry by K. Löw)

Country	Town	Name of the project	Type of building	Size	Treatment capacity	Time period or project start	Operation time	Greywater production	Reuse	Inspection and main-tanance interval	Time expense for main-tenane	Company
Germany	Eschborn	SANIRESCH (reference project) GIZ	Office building	200 employees	600 l/d	May 11	0,5 years	washbasins, kitchen sinks, dishwasher	process water for automatic cleaning of greywater and brownwater preceding screen	n. a.	n. a.	HUBER SE
Germany	Espenhain	-	Recycling company		2000 l/d	1 April 2008	report after 16 month	washbasins, shower trays	toilet flushing	1x per year	n. a.	geoterra
Germany	Heidelberg	„Comenius-haus“	Hall of residence	180 appartments	4100 l/d	1 July 1905	n. a.	washbasins, shower trays	toilet flushing	n. a.	n. a.	Dehoust GmbH
Germany	Mainz	Lebenshilfe	Multi-storey dwelling	20-30 persons	2800 l/d	May 2006	5 years	greywater	toilet flushing, washing mashines and irrigation	n. a.	n. a.	Dehoust GmbH
Germany	Mannheim	"Eastside"	Hall of residence	70 appartments	5000 l/d	Oct 2007	report after 2 years	bath and shower trays	toilet flushing	n. a.	n. a.	Dehoust GmbH
Germany	Mechernich	residential accommo-dation for persons with disabilities	Multi-storey dwelling	60-70 persons	2800 l/d	May 2006	5 years	greywater	toilet flushing, washing mashines and irrigation	n. a.	n. a.	Dehoust GmbH
Germany	Nephten	„Im Münchfeld"	Hall of residence	96 persons	5000 l/d	Oct 2010	1 year	greywater	toilet flushing	n. a.	n. a.	Dehoust GmbH
Germany	Nettetal	-	Hospital	187 beds	2200 l/d	January 2009	2 years	greywater	toilet flushing	n. a.	n. a.	Dehoust GmbH
Germany	Östringen	"Wackerhof"	Camping site		6300 l/d	1 June 2007	4,5 years	washbasins, shower tray outflows of the camping site and kitchen sink outflow of the dwelling	toilet flushing	1x per year (change of membrane modules)	ca. 6 h/a	HUBER SE
Germany	Wenden	Lebenshilfe	Multi-storey dwelling	20 persons	1000 l/d	May 2006	5 years	greywater	toilet flushing, washing mashines and irrigation	n. a.	n. a.	Dehoust GmbH

Table 13: International greywater treatment projects based membrane bioreactor technology (MBR), sorted in alphabetic country order; (enquiry by K. Löw)

Country	Town	Name of the project:	Type of building	Size	Treatment capacity	Time period or project start	Operation time	Greywater production	Reuse	Inspection and main-tanance interval	Time expense for main-tenane	Company
Italy	n. a.	-	Solution for yachts (17 plants)	max. 3	250 l/d	1 May 2007	4,5 years	washbasins, shower tray outflows	toilet flushing	1x per year	n. a.	GreenLife
Jordan	n. a.	-	Holiday resort	n. a.	80.000 l/d	n. a.		washbasins, shower tray outflows	toilet flushing and irrigation of golf course	n. a.	n. a.	GreenLife
Kuwait	n. a.	-	Shopping mall	n. a.	28.000 l/d	n. a.		washbasins	toilet flushing	n. a.	n. a.	GreenLife
Luxembourg	Luxembourg	-	Multi-storey dwelling	65 persons	3.000 l/d	1 May 2010	1,5 years	washbasins, bath and shower trays	toilet flushing, washing mashines and irrigation	1x per year	n. a.	GreenLife
Mauritius		-	Assembly set (filter and control system)	n. a.	250/500 l/d	1 June 2010	1,5 years			1x per year	n. a.	GreenLife
Poland	Olsztyn	-	Indoor swimming pool	n. a.	3.000 l/d	1 June 2011	0,5 years	shower tray outflows	toilet flushing	1x per year	n. a.	GreenLife
Saudi Arabia	Jeddah	-	Mobile container solution for demonstration	n. a.	1.000 l/d	1 September 2011	3 month	washbasins, shower tray outflows	toilet flushing	1x per year	n. a.	GreenLife
Turkey	n. a.	Airport I	Airport	n. a.	60.000 l/d	n. a.	n. a.	washbasins, a few shower tray outflows	toilet flushing	n. a.	n. a.	GreenLife
Turkey	n. a.	-	Housing development (7 phases)	3500 one-family dwellngs	250.000 l/d	n. a.	n. a.	bath and shower trays	toilet flusing and irrigation of outdoor facilities	n. a.	n. a.	GreenLife
Turkey	Ankara	ESER company	Office building	60 employees	max. 2.000 l/d	1 August 2010	n. a.	washbasins	together with rain water for toilet flusing and irrigation of outdoor facilities	n. a.	n. a.	Dehoust
UK	n. a.	-	Training centre	n. a.	500 l/d	1 March 2011	0,5 years	shower tray outflows	toilet flushing	1x per year	n. a.	GreenLife
Vietnam	Mekong Delta	SANSED II CanTho university	Hall of residence	180 persons	4500 l/d	2005-2008	0,5 years	washbasins, shower tray outflows, kitchen sinks, additional rainwater	n. a.	1x per year (change of membrane modules)	ca. 6 h/a	HUBER SE

Due to the complexities, involved in data acquisition, caused primarily by the companies obligation to maintain the confidentiality of certain data, not all fields in the tables were received and therefore information is not totally complete. Nevertheless, it provides an overview of the wide range of applications of greywater MBR technology worldwide, there are multi-storey dwellings, hotels, halls of residence, indoor swimming pools, shopping malls, office buildings, assembly sets and so forth. As a result of consultation with German companies in this study, many projects listed have been realised in Germany, but there are still numerous international applications listed as well in the table.

Regarding the type of building where greywater treatment plants are installed, there is prevalence of residential buildings. 18 of the 31 greywater treatment projects are installed in buildings where persons stay overnight. These are buildings where in proportion to edifice size high volumes of greywater are produced, because water from bath tubs and showers accumulates additional to water from hand washing basins. In this case the balance of greywater volume and process water demand can be accomplished very well (see section 2.1.2).

The treatment capacity of collected projects are very different, they vary between 250 l/d for a recycling system for yachts (3 users) and 250.000 l/d for a housing development project in Turkey for 3.500 single-family dwellings. Further big projects are a holiday resort in Jordan with 80.000 l/d, Airport I in Turkey with 60.000 l/d and the police academy with 400 persons in Mazar e Sharif/Afghanistan with 20.000 l/d.

The projects in office buildings are mainly small pilot plants to demonstrate the function of the technology and as a role model for decentralised sewage treatment. The plants in Berching, Eschborn and Ankara were built with this motive, to be a pioneer in this area.

Considering the reuse of purified water within the projects there is an obvious lead of the application for toilet flushing (25 of 31 projects). An additional use of recycled greywater for irrigation is common as well; in 7 applications a supplemental use for washing machines was identified.

Based on a literature study there is another greywater treatment system called "AquaCycle" developed by a German company called Hansgrohe AG / Pontos GmbH. It uses a patented biological/mechanical "SmartClean" process without any membrane, based on fluidised bed technology. The system has been tested with respect to safety and operation by an accredited inspection authority, for treating shower and bath water as a closed system in compliance with the hygienic/microbiological requirements of the EU directive RL 76/160/EWG (1975) and RL 2006/7/EG (2006) relating to bathing water quality (Pontos, 2010). The reason to mention this technology is that the system is constituted in a compact size, similar to MBR treatment plants. Hence, the application areas of these plants are typical scopes for membrane bioreactors as well. In Table 14, there are several international greywater treatment plants using "AquaCycle" technology presented.

Table 14: Greywater recycling projects based on AquaCycle technology by Pontos; (Hansgrohe, 2010)

Country	Town	Name of the project	Type of building	Size	Treatment capacity	Time period or project start	Greywater production	Reuse	Company
Czech Republic	Prague	Mosaic House	Hotel	236 persons	9,000 l/d	n. a.	shower tray outflows	toilet flusing	Pontos
France	Yerres	-	Swimming pool	53 showers	n. a.	n. a.	shower tray outflows	urban irrigation, urban steet cleaning	Pontos
Jordan	Sweimeh	Dead Sea Spa	Hotel	170 rooms	n. a.	April 2009	shower tray outflows	toilet flusing	Pontos
Spain	Barcelona	Casa Camper	Hotel	25 rooms	800 l/d	2005	shower tray outflows	toilet and urinal flusing	Pontos
United Kingdom	Cornwall	Scarlett Hotel	Hotel	37 rooms	n. a.	n. a.	bath tubs, shower tray outflows	toilet flushing	Pontos

In these examples, it comes out clearly that the main proportion is greywater recycling in hotels. All projects are characterised as applications in buildings with very large water consumption. The projects in Spain, Czech Republic and France are situated in an urban area, the others are located in more rural areas but with a good infrastructure.

3.3 Plant technology in Eschborn

As part of this work the technology used for the treatment of greywater in the office building in Eschborn was described, see chapter 2.2.1. The plant in Eschborn is running stable (start-up in May 2011) and results are under evaluation, results are expected in autumn 2011. First test results have shown a high cleaning efficiency and proven the stable operation of the plant. Average COD elimination is presently 95%. The applied ultrafiltration with 38 nm separation size guarantees the retention of all bacteria. Due to its microbiological properties permeate can be used for toilet flushing and irrigation purposes without problems (Huber SE, 2010).

3.3.1 Operating parameters

Within the operation time of approximately 6 month (since start of production on 13 May 2011) the operating parameters were observed and recorded. Since September 2011 the average volume of treated greywater is 500 – 600 l/d. The membrane filtration takes place for 270 s followed by 60 s regeneration time. Between 10 pm and 7 am there is an interruption of operation required for recuperation of membranes (Heynemann, 2011). Generally a filtration time of 20 h/d must not be exceeded (HUBER SE, 2011a). The average flow rate per working hour calculated for 15 h of continuous operation is 40 l/h.

An important attribute of the plant is the flux of the membrane, to characterise the performance. It is defined by the flow of permeate per unit area of membrane in l/m^2*h commensurate with it is permeability described as flux per unit pressure (Bérubé, 2010). The time-variation curve of flux and permeability of the first 130 days of operation are shown in Figure 18. The fluctuation of the numbers are coupled with the fluctuation of the volume of greywater. Based on the flow rate 40 l/h and the membrane surface of 3.5 m^2, the flux is calculated as 11.42 $l/(h*m^2)$. The present transmembrane pressure is 60 mbar (Heynemann, 2011) and this results in a permeability of 190.33 $l/(h*m^{2*}bar)$.

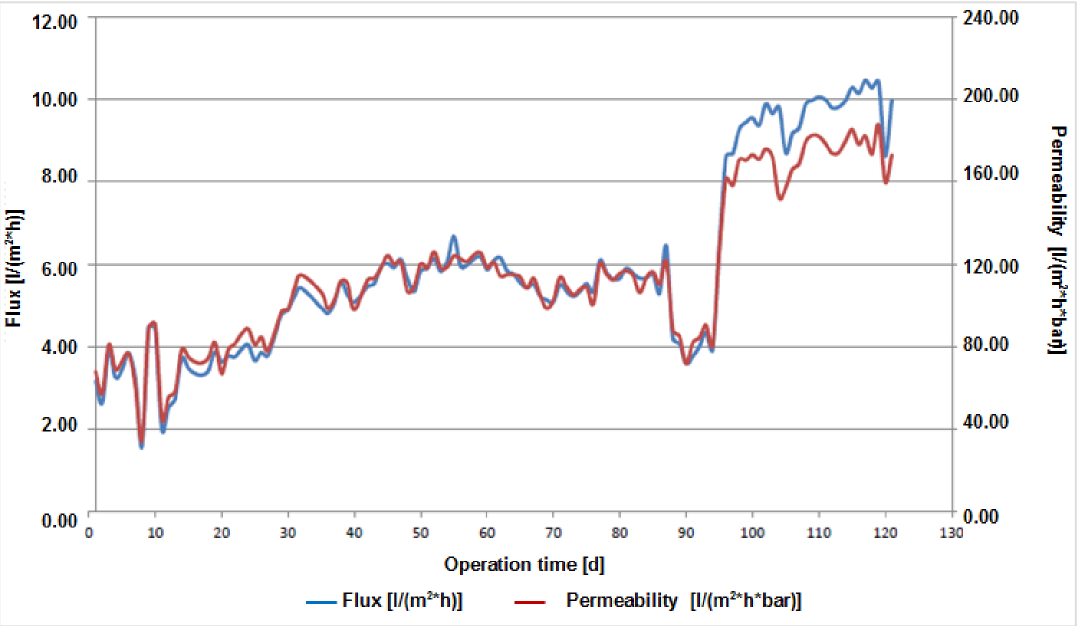


Figure 18: Flux and permeability during the first 130 days of operation; (Heynemann, 2011)

To avoid overloading of biology, the loading of activated sewage sludge (B_{TS}) should not exceed a 0.1 kg COD/kg TS*d (HUBER SE, 2011a). In the biomembrane reactor of the SANIRESCH plant the value of total solids (TS_{MBR}) should be 3-6 g/l in the activated sewage sludge. At the moment the measurements showed results of 5-6 g/l (Heynemann, 2011). The most important process parameters are outlined in Table 15 according to current adjustment made in the treatment plant.

Table 15: Current process parameters of the SANIRESCH plant; (Heynemann, 2011)

Parameters	Values
Average greywater flow rate [l/d]	500 - 600
Biomembrane reactor total solids TS_{MBR} [g/l]	5-6
Filtration time [s]	270
Break [s]	60
Work break	10:00 pm – 7:00 am
Average transmembrane pressure [mbar]	- 60

3.3.2 QUALITY ANALYSIS OF INFLOW, TREATMENT TANK AND PERMEATE IN STORAGE TANK

An analysis of water quality for inflow of greywater, activated sewage sludge and permeate was conducted and represented in Table 16. According to the information sheet H201 (fbr, 2005) a comparison of inflow characteristics was carried out, detailed information about typical greywater values are described in chapter 2.1.2 Table 1. The chemical oxygen demand (COD) of 633 mg/l is a normal dimension when greywater comprises the fraction from kitchen sinks and dish washers. An average value for nitrogen (TN_b) lies between 10 - 17 mg/l, with a value of 13.5 mg/l for the inflow being measured, shows normal characteristics. For phosphorous a normal range is 3 – 8 mg/l, here we have 32.9 mg/l. Such a high value, which represents the fourfold of the average can be explained by the use of dishwasher (detergent) tabs containing phosphate. Due to this fact the nutrient percentage of inflow ratio C:N:P is 100:2.1:5.2, with the values known from the literature provided by fbr being 100:2.4:1.0. Transition from conventional dishwasher (detergent) tabs to phosphate-free products has started and the P-value will be observed in the next month and is available with next results on the SANIRESCH webpage (www.saniresch.de). The pH-value is 7.4 and in the middle of the normal range for greywater. The degree of chemical oxygen demand (COD) degradation amounts to 95.2 %, this presents a good cleaning capacity.

Table 16: Overview of analysis of inflow, membrane bioreactor and permeate; (Heynemann, 2011)

	Inflow of greywater							
	COD	TN_b	P_{total}	pH	T	EC	O_2	TS
	[mg/l]	[mg/l]	[mg/l]	[-]	[°C]	[µS/cm]	[mg/l]	[g/l]
Ø	633	13,5	32,9	7,4	21,6	977	1,2	0,204
min	295	7,0	9,9	7,1	19,8	828	0,20	0,142
max	1025	26,2	58,1	7,8	23,0	1113	2,8	0,398
	Activated sewage sludge in membrane bioreactor							
Ø	-	-	-	8,2	21,7	849	7,7	5,1
min	-	-	-	7,9	20,0	825	4,4	3,5
max	-	-	-	8,4	23,1	1073	9,1	6,0
	Permeate							
Ø	30,2	13,2	17,9	8,2	21,9	983	8,3	-
min	17,2	7,7	9,5	7,5	19,8	825	7,8	-
max	72,6	21,0	30,2	8,5	23,3	1465	8,9	-

An optical impression of the cleaning performance of the system is given in Figure 19. The bottle on the left side retains greywater before treatment with its typical milky, grey colour, solids are not visible. In the bottle on the right side there is purified greywater after treatment in the membrane bioreactor. The slight yellow-brown colour of permeate is caused by humins, which are high molecular organic compounds, usually dark in color with small particle size <2 µm (TUM, 2010). Humins are components of organic matter such as coffee or tea, which is often disposed in kitchen sinks. However, the discolouration does not cause an impairment of the quality.

Figure 19: Raw greywater (left bottle), purified greywater (permeate) after treatment (right bottle); (picture by K. Löw)

In the next step, the quality of permeate was assessed by analytical parameters which are based on the international requirements and directives for recycled greywater. The data in Table 17 compares the results of chemical analysis of purified greywater with threshold values of different regulations. Unfortunately, there are dimensions without reliable results due to often only one sample being measured and hence the calculation of standard deviations has not been possible to date.

Table 17: Results of SANIRESCH permeate analysis vs. international requirements for recycled greywater; (Winker & Heynemann, 2011; Schürmann, 2011)

Parameter	SANIRESCH results	Countries					
		EU	USA	Germany	China	Australia	Japan
		Specifications					
		RL 2006/7/ EG, 2006; bathing water quality	USEPA, 2004	fbr-H201, 2005	GB/T 18920-2002	Queensland, 2005 class A (highest requirements)	Public buildings association, 2005
BOD_5 [mg/l]	BOD_5 = 3.3; BOD_7 = 3.8; O_2 = 8.3 (1 measurement)	No requirement	≤ 10	BOD_7 < 5	≤ 10	20 (median value)	< 20
Turbidity [NTU]	Not measured	No requirement	≤ 2	No requirement	≤ 5	2 (5) 95%-percentile (max.)	< 2

Parameter	**SANIRESCH results**	**Countries**					
		EU	**USA**	**Germany**	**China**	**Australia**	**Japan**
		Specifications					
		RL 2006/7/ EG, 2006; bathing water quality	**USEPA, 2004**	**fbr-H201, 2005**	**GB/T 18920-2002**	**Queensland, 2005 class A (highest requirements)**	**Public buildings association, 2005**
Micro-biological quality	**0 /100 ml E. coli; 1/100 ml total coliforms; <1/100 ml intestinal coccus; (1 measure-ment)**	<100 /100 ml E. coli; <100/100 ml intestinal coccus	no detectable faecal coliforms/ 100 ml	< 100/ml total coliforms; < 10/ml faecal coliforms; < 1/ml *Pseudomonas eruginosa*	≤ 3/l coliforms	< 10 cfu/100ml *E. coli* (median value)	*E. coli* not detectable
pH value	**8-8.5 (22 measure-ments)**	No requirement	6-9	No requirement	6-9	6-8.5	5.8-8.6
Chlorine Cl_2 residual disinfect-tant [mg/l]	**Not measured**	No require-ment	1 (minimum)	No requirement	≥ 1 after 30 minutes ≥ 0.2 at the end of pipe	No requirement	0.1 free chlorine or 0.4 bound chlorine

For biological oxygen demand (BOD), all international standards are met. The criterion turbidity was not analysed within the research project to date. Microbiological quality of permeate was measured by E. coli, total coliforms and intestinal coccus, the specifications are met for Australia, EU, Germany, Japan, UK and USA, only the limit which is set by China cannot be met. This measurement should be repeated with a larger number of samples. The pH value is in the range of 8 – 8.5 and can be proved by 22 measurements. All directives which require pH measures can be fulfilled. A chlorine analysis was not conducted, because in the SANIRESCH plant there is no second step of treatment for disinfection implemented. Thus, the measurement of Cl_2 is irrelevant.

3.4 SANIRESCH RESEARCH PROJECT AND MBR TECHNOLOGY IN GENERAL - COMPARISON AND DIFFERENTIATION

The treatment of greywater within the SANIRESCH research project has role model characteristics and enables the further use of treated greywater. The aim of this project is, to get insights into decentralised wastewater treatment plants. The treatment plant in Eschborn is equipped with a variety of devices to measure the performance of the pilot installation, such as sampling taps. Due to the elaborate extra equipment and devices in the facility, a one-to-one transfer of the installed plant to other projects is not advisable. There are major differences between this pilot plant and a marketable MBR application.

Company HUBER SE carried out a fictitious calculation of a 4-star hotel in Berlin to demonstrate the ecological and economic benefits of a greywater treatment plant (Paris, 2009a). To conduct the comparison and differentiation of prototype and serial plant, the study of company HUBER SE was taken as a reference. The economic feasibility study of the membrane bioreactor technology HUBER GreyUse® is equal to the plant installed in Eschborn. In the fictitious evaluation of the 4-star hotel (capacity of 215 beds) in Berlin, greywater from showers and bathtubs is treated for reuse as toilet flushing water. In Table 18 the main differences of the compared versions are presented.

Table 18: Treatment plant characteristics – Office building in Eschborn (HUBER SE, 2011a) vs. 4-star hotel in Berlin (Paris, 2009a).

Compared settings	SANIRESCH project in Eschborn	4-star hotel in Berlin
People served	Approx. 190 employees	215 beds
Greywater streams treated	Hand washing water, kitchen sinks, dish washer	Showers, bathtubs, hand washing
Amount of greywater generated (m³/d)	0.6	8.5
Required space (minimum)	Length: 2200 mm Width: 1500 mm Height: 2200 mm	Length: 5400 mm Width: 2700 mm Height: 2400 mm
Maximum treatment capacity (m³/d)	1.26	7.5*
Reuse (m³/d)	0.06 (cleaning of preceding screen of treatment plant)	7.5 (toilet flushing)
Energy consumption incl. pressure rise (kWh/m³)	2.38 (detailed information in chapter 2.2.1 and appendix 0)	3.1 incl. pressure rise
Economic issues (net) [€]	5,990 HUBER GreyUse® unit (investment) 8,333 Pipelines 14,323 total	33,089 HUBER GreyUse® unit (investment) 18,000 Pipelines 51,089 total
Maintenance	1x per year Inspection and change of worn out parts (time expense n. a.) 2x per year cleaning of intermediate storage tank (time expense n. a.)	1x per year Inspection and change wear parts (3 h/a)

Compared settings	SANIRESCH project in Eschborn	4-star hotel in Berlin
Sampling	Weekly: • General control of plant operation • Visual inspection of scouring air bubbles (regularity) • control of transmembrane pressure and documentation (by control system) • Visual inspection of contamination of the permeate (sampling tap) • check of operating parameters and comparison with reference values of commissioning • Control of air flow of scouring and aeration blowers • Keep of checklist	-
Removal of excess sludge and further steps	Every 4 weeks manually; discharge into conventional sewer system	Automatically possible; discharge into conventional sewer system or production of biogas
Additional equipment	Sampling taps, aeration of intermediate storage tank, remote data control, remote control of treatment plant	

* It presents the process water demand of the hotel

The energy consumption of the SANIRESCH system was calculated by HUBER SE to be 2.38 kWh/m^3 of treated greywater in normal mode (see appendix 0). In this summary the aeration of the intermediate storage tank is not included, because it is not an essential task and in a serial plant the device would not be assembled. In addition, the power requirement of the remote control and data remote transmission was not taken into account since the amount is marginal (Winker M. , 2011a).

As shown in the brief overview the maximum treatment capacity of the SANIRESCH plant is low, but in comparison the energy consumption is very high. The reason is, the difference of energy demand of aeration blowers, scouring air and a permeate pump differ only slightly if it is a small or a big plant. The main difference in energy consumption is the pressure rise with approximately 25 % supplemental (compare with 6.3).

The reuse of greywater within the research project is with 60 l/d (Feicht M. , 2011a) for the cleaning of preceding screen in the plant very low. In the GIZ building there is no tube and pressure rise system installed to use the purified greywater for example as process water for toilet flushing. The reason why recycled water finds no application in the building is an installed groundwater pumping system which supplies toilet flushing. Because of a high groundwater table in under the structure it is necessary to lower the level continuously in order to make the basement car park accessible. Hence, greywater recycling was not a cost-effective option and the main part of purified water is drained into the sewer system leading to the central wastewater treatment plant located in Frankfurt-Niederrad. Thus, within the research project the ambition of the SANIRESCH pilot plant is focused to prove the function of greywater treatment via MBR technology within an office building (Winker & Saadoun, 2011).

Moreover, in a hotel building the accumulating volume of greywater is much higher than in an office building. The hand washing water contributes the main amount in an office building, but in a hotel the drain from showers and bathtubs plays the leading part. In total a much bigger volume accumulates per capita per day in buildings where persons stay overnight.

The serial MBR plant is constructed exactly for the volume of process water demand in the building, only the greywater which is necessary for reuse is treated. The water balance of greywater production and reuses of recycled water shows a better harmony.

The economic issues of treatment plants and house installations differ significantly. In the 4-star hotel in Berlin the investment cost of the plant is higher, this is caused by bigger containers to store the greywater. The treatment plant in Eschborn purifies small volumes of greywater, hence the tanks are smaller. It can also be seen in the size of required space for the system. For the piping system it is the same case, the SANIRESCH project is only equipped in one-third of the GIZ' s headquarters building, whereas the 4-star hotel's system is fully equipped to service the entire edifice.

The maintenance and inspection of the respective plants is planned in both cases to take place once a year. In the hotel the estimated time expense is 3 h/a, for the plant in Eschborn there is no data available, due to the operation time < 1 a. For the research project an additional cleaning procedure of the intermediate storage tank is scheduled to take place twice a year.

As part of the research project there are weekly sampling procedures, these are necessary to get insights into the functioning of the system. Operational modifications and experiments are scheduled to analyse the treatment plant. For serial products in standardised plants it is not required, their production is stable and thus it is not planned to test different modifications of operation.

According to current performance of the treatment plant in Eschborn a removal of excess sludge is necessary every 4 weeks, this is carried out manually. In a standard plant automatic removal of excess sludge can be implemented, depending on the necessity. These parameters need to be observed in the initial phase of operation, to work out a strategy for stable serial performance of the standard plant.

Sampling taps, aeration of the intermediate storage tank, remote data control and remote control of the treatment plant are special features of the SANIRESCH plant and are due to it being a research project.

3.5 ESTIMATION OF ECONOMIC ISSUES OF A GREYWATER TREATMENT PLANT

3.5.1 GIZ HEADQUARTERS OFFICE BUILDING - ECONOMIC ASPECTS

The MBR research project SANIRESCH was established on the fundamental idea of proving the function of technology in an office building to give a role model for decentralised wastewater treatment. This is a pilot plant which does not include factors of economic benefit in the research aims.

To make the system comparable for standard applications, questions on the economics of the system were roughly estimated based on the whole GIZ headquarters building. By means of a projection of a greywater treatment system for the complete GIZ building, only an approximate calculation was conducted, due to missing data the cost comparison method according to the German working group on water issues (LAWA) was not practicable.

Two scenarios of water balance in the office building are presented including different perspectives of greywater production vs. process water reuse and changes for in-house installations. Scenario I calculates the water balance with normal sanitary facilities (state of the art) and scenario II takes extremely water saving toilets into account. Firstly the evaluation of scenario I was assumed in Table 19.

Scenario I:

With the basic parameters in Table 5 (see section 2.3) total hand-washing water of 2,911 l/d (working day) was calculated for scenario I. In total a greywater amount of 3,535.5 l/d (working day) accumulates. On the other side there is the consumption of water for toilet flushing summarised. In total there is a demand of 7,652 l/d (working day), with a big difference between male and female toilet volumes caused by waterless urinals for men (see Table 5). In addition, there is process water as cleaning water for the preceding screen of the greywater treatment plant necessary, according HUBER SE the amount per day is approximately 60 l (Feicht M. , 2011a). Thus, the calculation shows a result of 7,712 l/d (working day) of process water is necessary.

Table 19: Scenario I: Normal toilets - Greywater amount vs. process water demand; (calculation by K. Löw)

Scenario I: Normal toilets				
	Men	**Women**	**Total**	**Assumptions according to Table 5**
Amount of employees (dataset: August 2009 week 37)	270	377	647	3 visits of toilet per working day.
Greywater amount [l/d]	1,215	1,696.5	2,911.5	4.5 l/(c*d) water for hand washing.
			240	10 l greywater per kitchen sink (24 pcs.).
			384	24 dish washers (BOSCH Electronic aquastop) in the building - 16 l per use in normal mode (BOSCH, 2011).
Total amount TA [l/d]			**3,535.5**	
Amount of water for toilet flushing [l/d]	1,620	6,032	7,652	Flushing of toilet: Men 6 l/d; Women 14 l/d.

	Men	Women	Total	Assumptions according to Table 5
Cleaning water for preceeding screen (Turny) [l/d]			60	
Total consumption TC [l/d]			**7,712**	
Water balance (TA – TC) [l/d]			**-4,177**	**Negative**

Scenario I shows the difference between the amount of greywater which is generated and the volume of required process water for toilet flushing and cleaning of the preceding screen of the greywater plant. The volume of produced greywater is 3,535.4 l/d whereas the consumption is 7,712 l/d, hence the water balance for the reuse application is negative with -4,177 l/d. Only 45 % of daily process water demand in the building can be covered by greywater production. The mismatch between production and demand makes the setting impractical for the implementation, therefore scenario I was abandoned.

Scenario II:

In scenario II modifications to the process water calculation have been implemented (see Table 20). To reduce the usage of process water, super water-saving toilets or vacuum toilets are necessary. Based on the amount of employees, a calculation of toilet flushing shows, it is possible if the toilet consumes only 2 l per flush to achieve an equalised water balance. The water balance in scenario II is positive with 673.5 l/d (working day), this is a good surplus of 23 % to ensure that there is no lack of process water if conditions change slightly. There are toilet models from Gustavsberg (series “WC Nautic”) and Villeroy&Boch available, but 2 l is only the volume for the very saving flush for urine, the faeces flush requires 4 l (Gustavsberg, 2011). Another option is the use of vacuum toilets for example from Roediger vacuum which have a water demand of 1 l per flush for urine and faeces (Roediger Vacuum, 2011).

Table 20: Scenario II: Poor flush toilets - Greywater amount vs. process water demand; (calculation by K. Löw)

Szenario II: Poor flush toilets				
	Men	**Women**	**Total**	**Assumptions according to Table 5**
Amount of employees (dataset: August 2009 week 37)	270	377	647	3 visits of toilet per working day
Greywater amount [l/d]	1,215	1,696.5	2,911.5	4.5 l/(c*d) water for hand washing.
			240	10 l greywater per kitchen sink
			384	24 dish washers (BOSCH Electronic aquastop) in the building - 16 l per normal mode
Total amount TA [l/d]			**3,535.5**	

	Men	Women	Total	Assumptions according to Table 5
Amount of water for toilet flushing [l/d]	540	2,262	2,802	Flushing of toilet: Miniflush or vacuum toilet (Gustavsberg, vileroy&boch, Roediger vacuum): Men 1 x 2 l, 2 x waterless urinal = 2 l; Women 3 x 2 l = 6 l.
Cleaning water for preceeding screen (Turny) [l/d]			60	
Total consumption TC [l/d]			**2,862**	
Water balance (TA – TC)			**673.5**	

Scenario II shows a positive water balance and provides enough water for toilet flushing reuse application. This calculation model can be used as a basis for further investigation. The design of the economic calculation of the GIZ headquarters treatment plant which was carried out, was based on the design of the example of HUBER SE: "Evaluation of a 4-star hotel in Berlin" (Paris, 2009a). The investment and operating costs of the GIZ MBR plant were considered so as to calculate whether the amortisation of the system is possible.

The economic calculation for the greywater treatment system provides insight into both, the expenses and savings incurred by such a system. On one hand the annual expenses for the greywater treatment plant are maintenance costs and energy costs of operation. On the other hand there are fresh and wastewater charges, which can be saved when greywater is treated.

Plant operation costs:

To ensure a treatment plant operates without problems, an annual service is scheduled, in which the functioning of the plant is inspected and all worn parts are replaced with new parts. The price of a yearly service is computed by HUBER SE at 1,069.23 €/a (net) / 1,272.38 €/a (gross) (Feicht M. , 2011c), this price includes replacement of parts and working time. The energy consumption of the plant (see Table 21) is summarised with 314 days in normal mode and 51 days in power saving mode, it results in 2,743.77 kWh/a ((Feicht M. , 2011b) the calculation is attached in appendix 6.3).

Table 21: Calculation total energy consumption; (according to Feicht M. , 2011b):

Days [d]	Energy consumption [kWh/d]	Total energy consumption [kWh/a]	
314	8,45	2653,3	normal mode
51	1,77	90,47	power saving mode
		2743,77	

In appendix 6.5 there is an overview of energy costs in Germany, where the cost increase in percentage is shown as well. The price in 2009 was 0.23 €/kWh (Statistisches Bundesamt, 2011). For 2011 the charge was calculated with an annual increase of 6.5% according the existing trend, to yield a result of 0.26 €/kWh (gross). The assumption that this trend will continue was made and has been taken as a basis for further evaluations and projections.

With the calculated price of 0.26 €/kWh a total energy cost of 707.07 €/a needs to be budgeted for. With maintenance expenses of 1,272.38 €/a the total operation costs sum up to 1,979.45 €/a and are presented in Table 22.

Water costs:

In contrast to energy and maintenance expenses for MBR treatment, the fresh and wastewater charges can be saved. The necessary amount of 2,862 l/d process water can be summarised to 715.5 m^3/a based on 250 working days. This is the volume of substituted drinking water and the total water price is calculated as the sum of costs for drinking and sewage water. In appendix 6.6 the chronological sequence of the water price in Hessen/Germany is shown (Statistisches Bundesamt, 2011). According to the price trend the charge for water in 2011 was calculated with 4.74 €/ m^3 (gross). An increase of 2% was assumed according to inflation. Based on this supposition, further calculations of cost saving by greywater recycling were conducted. As shown in appendix 6.7 a sum of 3,391.47 €/a for 715.5 m^3/a drinking and wastewater can be saved by treatment of greywater by a plant with similar parameters to the one in the SANIRESCH project.

Table 22: Economic cost calculation of GIZ's greywater treatment system (gross); (calculation K. Löw)

Treatment plant HUBER GreyUse®	8,633 €	**(Feicht M. , 2011b)**
Extra costs for separate piping system (additionally to conventional system)	29,750 €	Calculated according Winker & Saadoun, (2011)
Total invest (interest rate 2%/a)	**38,383 €**	Calculated according Paris, (2009a)
Costs of maintenance incl. wear parts (price increase 2%/a)	1272 €/a	(Feicht M. , 2011c)
Energy costs (price increase 6.5%/a)	707 €/a	Calculated according Bundesministerium für Wirtschaft und Technologie, (2010)
Summary of operation costs	**1,979 €/a**	
Water price (fresh and waste water)	**3,391 €/a**	Calculated according Statistisches Bundesamt, (2011)
Total cost saving – difference between saved water costs and operation costs (water price 4.58 €/m^3, price increase 2%/a)	**1412 €/a**	

The annual price increase (2% water price and 6.5% energy price) is added in the course of time, according to annual rising prices for water and energy (see appendix 6.5 and 6.6). There is a visible overview in Figure 20 over a time period of 15 a, which is a normal life time for a greywater treatment plant (Paris, 2009a). The difference between water costs per year and summary of operation costs per year are the annual cost savings. Within 15 years, there is a total cost saving of 23,910.38 € achievable. The table of calculated data for the following 15 years is available in appendix 6.7.

Hitherto only the running costs were considered, the calculation of plant amortisation follows. The described greywater treatment plant with a treatment capacity of 3.75 m^3/d amounts to 7,255.30 € (net) / 8,633.81 € (gross) investment costs, the data collection can be found in appendix 6.4 (Feicht M. , 2011b).

Furthermore, there are costs for installation of an additional separate pipe system and water saving toilets necessary. Within the SANIRESCH programme there is a cost difference of approximately 25,000 € (net) between the conventional pipe system documented (Winker & Saadoun, 2011). It belongs to the partial treatment of urine, brownwater and greywater and is only installed in the middle area of the building, with a separate piping system for each sewage stream. With the background of the conditions an additional piping system only for greywater is estimated to be one third of the costs mentioned above. It results in 8,333 € (net) / 9,916 € (gross) for greywater pipes in the middle path of the building. To equip the whole building with additional separating tubes for greywater, two additional piping systems need to be installed in the side wings of the building. Therefore, 25,000 € (net) / 29,750 € (gross) can be assumed, due to threefold costs for 3 piping paths.

The costs for extremely water saving toilets or vacuum toilets are not included in this calculation. The data situation to estimate the cost for sanitary facilities is very difficult to come to know. Economic assumptions are impossible, due to unavailability of a comparable basis, no reference values are known.

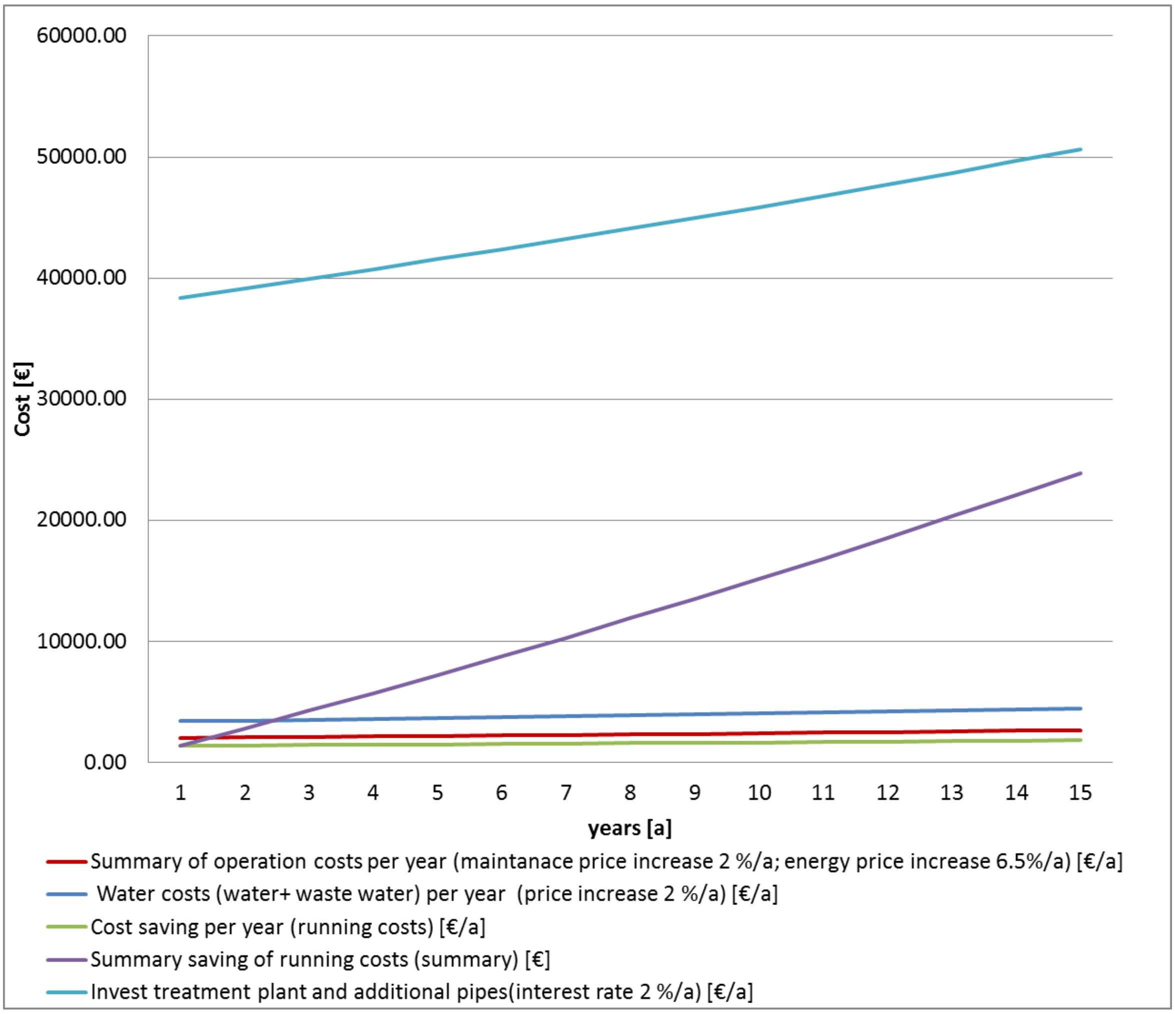


Figure 20: Office building Eschborn - economic calculation of greywater treatment plant operation costs vs. water costs (gross); (calculation and presentation by K. Löw)

With the average cost for energy and maintenance in comparison to water charges, the calculation showed that savings of 1,412 €/a of operating costs are possible. But a benefit is not achievable in an amortisation calculation; the investment costs of € 38,383 cannot be covered. The amount of greywater production and process water demand is not balanced. And only with big efforts (super saving toilets) equilibrium can be obtained. values.

Under economic aspects an amortisation of the complete treatment system with all facilities, including treatment plant, separate piping system and water saving toilets not possible for this example. Especially challenging in an office building is the mismatch with respect to the water balance due to a low production of greywater in the absence of shower and washing greywater outflows and the huge demand of toilet flushing water, hence rendering the application inefficient. The effort to bring the water balance into equilibrium or to a positive output and make the system run smoothly is much too high, and can only be achieved by installing super saving toilets or vacuum toilets.

Under these conditions there is no incentive to use a greywater treatment plant for this specific application. However, economic incentives do exist for the application of greywater treatment plants in different circumstances such as in buildings where people stay overnight, where an advantageous water balance is much easier to achieve by accumulation of showering and bathing water. Examples of such buildings are apartment buildings, halls of residence, hospitals, hotels etc.; here the demand of water is high and therefore the production of greywater as well.

3.5.2 Fictitious 4-star hotel in Berlin - Economic aspects

In comparison the fictitious 4-star hotel calculation of company HUBER SE shows better results regarding economic issues and amortisation (Paris, 2009a). The HUBER GreyUse® unit is installed in the cellar of the building and the additional tubing system can be built in simply, due to modular design of the structure.

The investment and operation costs of the HUBER GreyUse® unit are summarised in Table 23. Included in the annual maintenance is the exchange of faulty membrane module and replacement of worn parts. This ensures a lifecycle of 15 years without any problems. With drinking and wastewater charge of 4.73 €/m³ (net) in Berlin the cost savings resulting from the use of greywater recycling are calculated. The assumptions of price increase for water are 2% and for energy 5% in the preceding years. According to the scenario the payback period is approximately 6 years of operation (see Figure 21). After 10 years of operation 39,369 € expenses can be saved (Paris, 2009a).

Table 23: Economic cost calculation (net) of fictitious 4-star hotel in Berlin; (Paris, 2009a)

Treatment plant HUBER GreyUse®	33,089 €
Tubes and piping system	18,000 €
Total invest (interest rate 2%/a)	**51,089 €**
Costs of maintenance incl. wear parts (price increase 2%/a)	2,012 €/a
Energy costs (0.1379 €/kWh; price increase 5%/a)	1,179 €/a
Summary of operation costs	**3,191 €/a**
Water price (fresh and wastewater)	**12, 537 €/a**
Total cost saving – difference between saved water costs and operation costs (water price 4.58 €/m^3, price increase 2%/a)	**9,347 €/a**

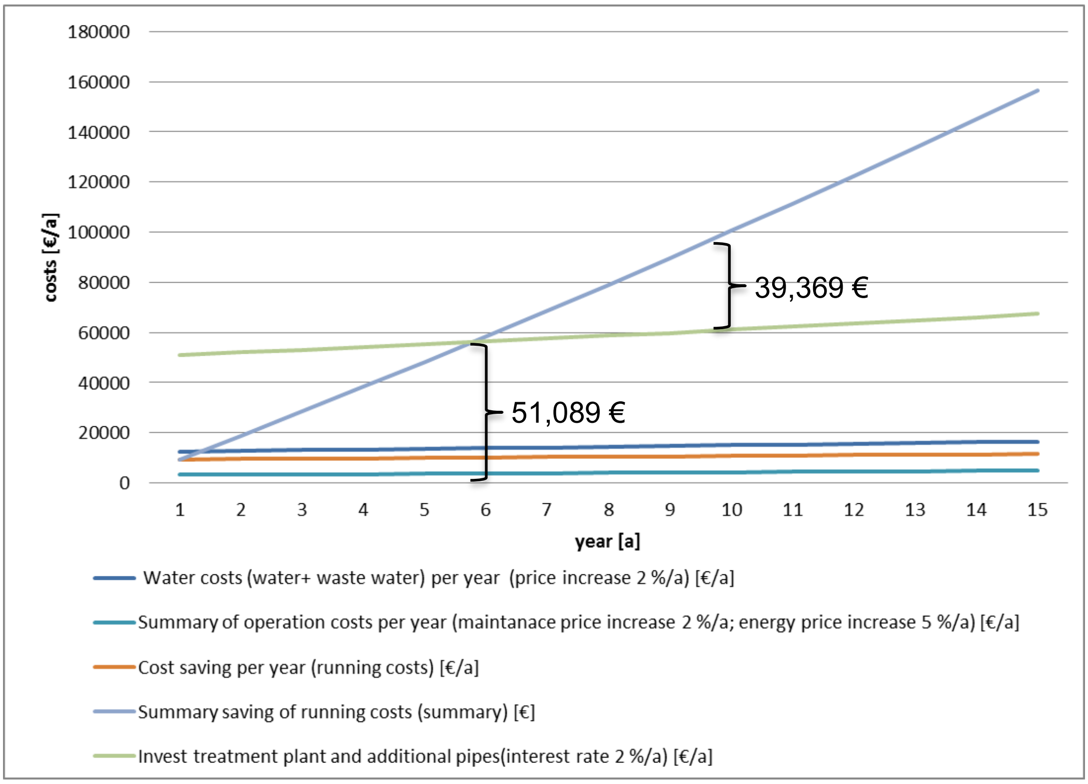


Figure 21: 4-star hotel in Berlin - economic calculation (net) of greywater treatment plant operation costs vs. water costs; (own presentation according Paris, 2009a)

For a hotel application with a huge amount of water consumption the calculation shows much better results and the break even can be achieved after approximately 6 years of operation. Especially in Germany, where no water scarcity exists, economic reasons have to be present so as to stimulate the implementation of greywater recycling systems.

Moreover, an example for a beneficial cost calculation is shown in the hall of residence "Eastside" in Mannheim/Germany, (data of the project is described in Table 13). Here, the amortisation of the treatment plant can be achieved within 6 years of operation (Sellner, 2009). Also, the "Dead Sea Spa" hotel in Jordan offers positive economic aspects with a payback period of about 10-12 years, based on the water saving and the current price for water (the hotel receives water delivered by tankers); (Rothenberger et al., 2011).

3.6 Investigation of international transferability of greywater treatment systems with MBR technology

3.6.1 Basic principles

The prevailing centralised wastewater system in Germany is very well adapted for our local conditions, but the wastewater transport and treatment facilities are not optimally transferable to many other regions of the world. Although it is a powerful technology, the international transfer is often not meaningful because of local climatic, economic and cultural conditions. Reasons for this include a low flexibility with respect to changes in capacity, for example in a rapidly growing city or in inconveniently located settlement structures. There is no possibility to reuse purified water close to the village (e.g. in agriculture or industry) (Herbst, 2008).

Therefore, urban planners are investigating decentralised systems where the wastewater is treated close to the location where it is generated. Even for urban areas prone to natural hazards this may even be an appropriate option (Corcoran et al., 2010)

The unequal dispersal of wastewater ingredients in the sub-streams of domestic wastewater is regarded as a reason for considering a system change (Lange & Otterpohl, 2000), particularly regions with lack of water can benefit from recycling orientated “closing the loop” technologies.

The practice to use treated greywater as process water contributes to the protection of the environment and water resources. Greywater treatment plants reduce the demand for drinking water that is used for purposes other than cooking, drinking or personal hygiene and therefore exert a positive influence on the water balance. Thus, the negative effects of the drinking water extraction and distribution processes are reduced. Additionally, greywater recycling reduces the volume of produced wastewater and consequently, the water pollution risk as well (fbr, 2005).

The separate collection, treatment and reuse of greywater is useful, if the water balance of greywater production and process water demand is almost equal within a building. In new constructed or renovated buildings, it is easy to provide additional piping systems for installation to collect greywater separately from blackwater and distribute the treated greywater in the building again (HUBER SE, 2011c).

3.6.2 Results of utility analysis of international transferability of greywater treatment via membrane bioreactor technology - Matrix of utility analysis

In section 2.4 the method of investigation, evaluation, rating and weighting of international transferability of MBR treatment by utility analysis is explained and described. The complete matrix of utility analysis is presented in Table 24 together with three examples of evaluated projects. Especially the compilation of main groups and its sub issues within the utility analysis was a development process, same as weighting of sub categories. It is based on literature study, discussion with experts and in the end the final adaptation of rating was done by the investigation of existing projects with a good data basis.

Table 24: Excel-sheet for utility analysis; (by K. Löw)

Rating input | Rating input | Rating input

	Assessment criteria Discretionary	Weighting ∑= 100%	Description of rating	Jordan - Dead Sea Spa Hotel Rating	Info not available	Result	Mekong delta - SANSED II CanTho university Rating	Info not available	Result	Germany - Hall of residence "Eastside", Mannheim Rating	Info not available	Result
H	**Health and hygiene criteria**	**6%**				**0.6**			**0.6**			**3**
H1	Quality of purified greywater	0	**not considered**									
H2	Stability of permeate quality	0	**not considered**									
H3	Legislative requirements for wastewater treatment technologies, quality directives	6	**highly enforced = 10, medium enforced = 5, low enforced = 1, no requirements = 0**	**1**		6	**1**		6	**5**		30
E	**Economic criteria**	**39%**				**20.9**			**17.4**			**7.8**
E1	Direct governmental funding for treatment plants	4	**high = 10, medium = 5, low = 1, no = 0**		N/A	0		N/A	0	**0**		0
E2	Indirect incentives on greywater treatment systems	4	**high = 10, medium = 5, low = 1, no = 0**		N/A	0		N/A	0	**0**		0
E3	Investment costs of the system (treatment plant, piping system)	4	**high = 1, medium = 5, low = 10**	**1**		4	**1**		4	**1**		4
E4	Operating expenses (maintenance, spare parts)	5	**high = 1, medium = 5, low = 10**	**5**		25	**5**		25	**5**		25
E5	Charge for energy (in general)	5	**high = 1, medium = 5, low = 10**	**5**		25	**1**		5	**1**		5
E6	Charge for drinking water (in general)	7	**high = 10, medium = 5, low = 1**	**10**		70	**10**		70	**1**		7
E7	Charge for waste water (in general)	7	**high = 10, medium = 5, low = 1**	**10**		70	**10**		70	**1**		7
E8	Price of land	3	**high = 10, medium = 5, low = 1**	**5**		15		N/A	0	**10**		30
T	**Functional and technical criteria**	**0%**				**0**			**0**			**0**
T1	Yearly maintenance	0	**not considered**									
T2	Stability of operation and quality	0	**not considered**									
T3	Breakdowns	0	**not considered**									
N	**Environmental criteria**	**41%**				**38.2**			**22.7**			**20.7**
N1	Water scarcity (physical/economical)	12	**high = 10, medium = 5, low = 1, no = 0**	**10**		120	**0**		0	**0**		0
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**	**10**		50	**1**		5	**1**		5
N3	Number of persons situated in the building	8	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**	**10**		80	**10**		80	**10**		80
N4	Accumulation of greywater	10	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**	**10**		100	**10**		100	**10**		100
N5	Sewer system available	2	**no = 10, yes = 1**	**10**		20	**1**		2	**1**		2
N6	Population/settlement density	2	**high = 10, medium = 5, low = 1**	**5**		10	**10**		20	**5**		10
N7	Urbanisation	2	**high = 10, medium = 5, low = 1**	**1**		2	**10**		20	**5**		10
S	**Socio-cultural criteria**	**14%**				**12.5**			**12.5**			**8**
S1	General acceptance of greywater reuse	5	**high (toilet flushing, irrigation, laundry) = 10, medium = 5 (toilet flushing, irrigation), low = 1 (toilet flushing or irrigatin)**	**5**		25	**5**		25	**5**		25
S2	Ecological awareness	5	**high = 10, medium = 5, low = 1**	**10**		50	**10**		50	**10**		50
S3	Pioneer in this area	4	**yes = 10, no = 1**	**10**		50	**10**		50	**1**		5
	Degree of fulfilment			**Result [%]**		**72.2**	**Result [%]**		**53.2**	**Result [%]**		**39.5**
				n. a. citeria		2	n. a. citeria		3	n. a. citeria		0

“Dead Sea Spa” hotel/Jordan; (according to Table 24):

The Jordan “Dead Sea Spa” hotel was selected as an example, although it is not a project with MBR technology, but it is equipped a with Pontos “AquaCycle” system (see section 3.2). Despite the different treatment method, the greywater treatment application is comparable because of the similar plant system. In addition, there is detailed information available as it is a GIZ project.

In Jordan the legislative requirements are low and only addressed to agricultural and non-domestic purposes (Al-Jayyousi, 2002), hence H3 was assessed with “1”. The information of direct or indirect governmental support by subsidies or similar strategies is not available, that led to N/A answers for issue E1 and E2. Investment costs are regarded as high for the membrane bioreactor plant, hence it is rated with “1”, operation costs are assessed with a medium value, due to annual maintenance, which is not very often. The energy price with 1.37 €/kWh (GTZ, 2007), is in the medium range. Charge for drinking and wastewater (E6 & E7) is very high due to extreme water scarcity and missing infrastructure for water supply and discharge, which led to assessment of N5 with “10” as well (Rothenberger et al., 2011). The price of land E5 is assumed in the medium level, because it is not a densely populated region, but there are many hotels settled in the area, therefore also N6 is rated with “5”. Jordan is one of the most water scarce countries (GTZ, 2010), that led to the estimation of “10” scores for issue N1. According to the water quality index (WQI), fresh water quality in Jordan is poor with 30 of 100 scores (Yale University, 2010), therefore N2 is assessed with “10”. Regarding volume of produced greywater both issues (N3 & N4) are rated with “10”, because the hotel has 160 connected rooms and the people stay overnight (shower water accumulates) (Rothenberger et al., 2011). Urbanisation is low in the area where the “Dead Sea Spa” hotel is located, because it is a region where mainly hotels are situated. In Jordan there is a medium acceptance of greywater recycling assumed, because irrigation with recycled water is a common practice (Al-Jayyousi, 2002) and toilet flushing is applied in this project, therefore S1 is rated with “5”. S2 and S3 are rated with “10”, due to the pilot character of the plant, to show ecological awareness and to be a role model for further projects within the PPP approach (GTZ, 2010).

The result shows 72.2 % fulfilment of the utility analysis, this is quite a high result. According to GTZ report the program is very successful and further projects are planned, because it is an ideal application area for greywater recycling via the treatment plant (GTZ, 2010). The output of the utility study reflects the character of the project and the applicability of greywater treatment and reuse in the region. Thereby, the evaluation of the “Dead Sea Spa” with the utility analysis can be regarded as feasible within the assessment.

Hall of residence of Can Tho University (“SANSED II”)/Vietnam; (according to Table 24):

Another project, which was selected for review is “SANSED II” in the hall of residence of Can Tho University in Vietnam (see section 3.2), it is a research project equipped with HUBER GreyUse® technology.

According to legislative requirements in Vietnam, there are only directives for irrigation purposes available (TCVN 6773, 2000), thus the assessment of issue H3 is “1”. The information about direct or indirect governmental aid, to implement a greywater treatment system was not available and N/A was set for E1 and E2. Again the investment costs are regarded as high for the MBR system; hence it is rated with “1”, operation costs are rated with “5”, due to only annual maintenance. The energy price in Vietnam is relatively high in relation to income (Brömme et al., 2006), hence E5 is assessed with a score of “10”. Charge for dinking and waste water are low with 0.23 US$/$m^3$ (Mierke, 2004) and are rated with “1”. Water scarcity is not prevalent in the area of Can Tho in the Mekong Delta (IWMI, 2006), hence N1 is assessed with “0”. The water quality index (WQI) states fresh water quality in Vietnam with 73 of 100 scores (Yale University, 2010), the high quality led to value “1” for issue N2. The number of people in the building and accumulation of greywater, each is rated with 10, because 180 people live in the hall of residence (see chapter 3.2). A sewer system is available in Can Tho, therefore N5 was set to value “1”. The city Can Tho had 1,121,141 inhabitants in 2004 and the population density is 807/km^2 (Can Tho government's official portal , 2004), hence N6 and N7 were estimated with “10”. The research project has the entitlement of ecological awareness and is a pioneer in this area, thus led to value “10” for issues S2 and S3.

In total the result of appraisal showed 53.2 % performance in the utility analysis. In this case, the environmental aspects such as “water scarcity”, “freshwater quality” and “sewer system available” were not the determining factors to implement a greywater treatment system. Here, the research issues and economic reasons were in the foreground. Not all criteria of sustainability were covered, therefore the result scores approximately 50 %.

Hall of residence ("Eastside“) in Mannheim, Germany; (according to Table 24):

Another hall of residence project was selected as an example; it is the “Eastside” building in Mannheim/Germany with a MBR plant supplied by company Dehoust (see details in chapter 3.2.).

The legislative requirement for greywater treatment according to the fbr-Information Sheet H 201 (fbr, 2005) in dependence on the EU bathing water directive, are medium enforced and rated with “5” in issue H3. In Germany, there are no direct or indirect governmental subsidies for greywater treatment plants available; hence both criteria were assessed with “0”. The investment costs for a membrane bioreactor treatment plant are high, hence rating is “1” for E3 and the operational expenses are medium due to (only) annual maintenance and therefore E4 is rated with “5”. The charge for energy, drinking and wastewater in Germany is low, thus E5, E6 and E7 are assessed with “1”. Regarding price of land, the assumption was made with a rating of “10”, because in the urban area of Mannheim prices are high with approximately 500 €/m^2 based on an area between 300 m^2 and 600 m^2 (Immowelt AG, 2011). In Germany, no water scarcity exists, hence N1 was rated with “0” and the fresh water quality according to WQI is high with 79 of 100 scores, therefore N2 was assessed with “1”. For the issues N3 and N4 values of “10” can be set, due to building size with 70 apartments and greywater production of 5000 l/d. A sewer system is available in Mannheim, which led to rating of “1” for N5. In Mannheim the population density and urbanisation is high and was assessed with “10” for both criteria, the city has 323.794 inhabitants and a population density of 2160 persons/km^2 (Statistisches Landesamt Baden-Württemberg, 2010). The general acceptance of greywater reuse is assumed with a medium value of “5”, regarding ecological awareness a high degree of “10” is presumed. Pioneer in this area is rated with “1”, due to the fact that in Germany often halls of residence are equipped with greywater treatment technologies to save water.

With 39.5 % the utility analysis of the hall of residence in Mannheim showed not such a positive result. In this case there was no primary environmental necessity to implement the system, here economic reasons were the stimulus. Therefore, the utility analysis did not show a high utility. Here the limitations of the system are visible; the matrix is designed to implement all issues of sustainability; to consider the applicability in a holistic approach of environmental, economic, socio-cultural reasons and so forth. The viability of installation of the system in this case is based only on one main reason, hence it is not possible to determine whether it makes sense or not. In this case an economic cost calculation would show the amortisation and savings.

At each assessment, local conditions must be taken into account, which should be integrated into the appraisal. For example charges for water or energy prices can be classified as low according to western standards, but if these rates are judged on the basis of local income ratios, then this estimation looks quite different. Additionally, the circumstances can differ widely within the different regions of a country and in urban or rural areas, this should be taken into consideration as well.

In this comparison of three projects the results differ widely, although the projects can be considered as successful each for itself, although the results are not ideal. The degree of fulfilment for the tree assessed projects is between 72.2 % and 39.5 %. Here the limitation of the assessment is obvious, if the projects are focused only on one criterion such as economic aspects, it is difficult to obtain a high rating. But the utility analysis was selected to cover all criteria of sustainability, to have one tool for all applications; therefore a detailed view on a certain project is always necessary.

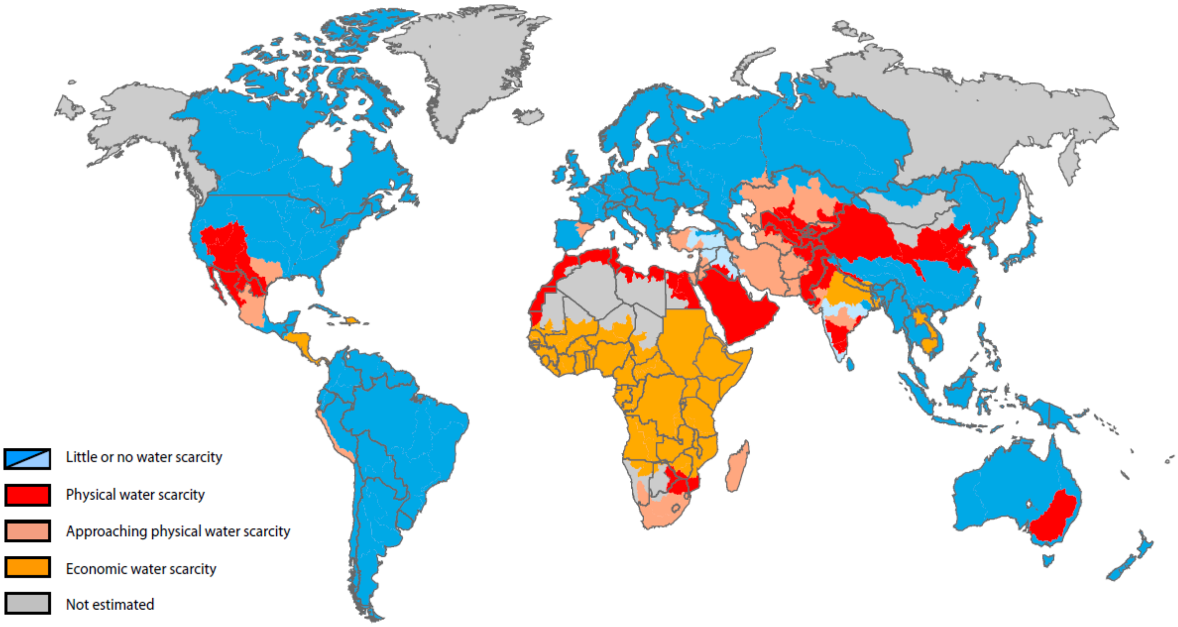
In general, the approach to conduct an assessment in relation to the criteria of sustainable sanitation, estimated by a utility analysis is based on transparent criteria. Certainly, this is no protection against subjectivity and mistakes within the appraisal, because the assessment is made by personal estimations, but it is a tool to make the decision process transparent and traceable. To minimise the subjectiveness, the utility analysis was discussed with some experts and the functionality of the tool was related to existing projects, where the data is available.

3.7 Identification of global hotspots for greywater treatment and reuse by membrane bioreactor technology

The evaluation to identify global hotspots regarding international transferability of membrane bioreactor technology is based on a trimmed-down version of the utility analysis. Only environmental criteria are assessed, to identify ideal countries for implementation of MBR plants. Based on insights provided from the following; water scarcity, freshwater quality, population density and urbanisation rate; an utility analysis was conducted and a rating of international hotspots was compiled. In section 2.5, the method to identify ideal international applications for MBR technology is described and detailed information about the criteria rating is available there.

3.7.1 Global water stress

The availability of water around the world differs extremely. One of the strongest reasons to implement water saving techniques such as greywater recycling is water scarcity. In this paragraph regions of the world were identified which are facing or approaching water scarcity. Figure 22 gives an overview of global water scarcity in physical and economic respect, the definition of physical and economic scarcity in included in the description of the legend.



Red:	Physical Water Scarcity. More than 75% of the river flows are allocated to agriculture, industries or domestic purposes (accounting for recycling of return flows). This definition of scarcity—relating water availability to water demand—implies that dry areas are not necessarily water-scarce. For example, Mauritania is dry but not physically water-scarce because demand is low.
Light Red:	More than 60% of river flows are allocated. These basins will experience physical water scarcity in the near future.
Orange:	Economic Water Scarcity. Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists. These areas could benefit by development of additional blue and green water, but human and financial capacity are limiting.
Blue:	Abundant water resources relative to use: less than 25% of water from rivers is withdrawn for human purposes.

Figure 22: Areas of physical and economic water scarcity; (IWMI, 2006)

In the Near East and North Africa most countries suffer from acute water scarcity, as do countries such as Mexico, Pakistan, South Africa, and large parts of China and India. The bulk of the demand for water in these countries is allocated to irrigated agriculture, and this is also usually the first sector affected by water shortage and increased scarcity. The result is often a decrease of capacity to maintain per capita food production while meeting water needs for domestic, industrial and environmental purposes (UN-Water, 2006).

Physical water scarcity is concentrated in the MENA region (Middle East & North Africa), especially in the countries of Jordan, Oman, Saudi Arabia, United Arab Emirates, Western Sahara Territory and Yemen. In many areas of Algeria, Egypt, Libya, Morocco and Tunisia the problem also occurs.

The main regions with economic water scarcity are concentrated in Sub-Saharan Africa, they are not listed here. In the evaluation, regions with economic water scarcity are not in the main focus, because economic water supply problems usually indicate immense poverty in the country. A high-tech solution of greywater treatment by MBR technology is in such a case only an opportunity in very limited areas, with good infrastructure in such countries. For example, uninterrupted power supply for the treatment plant is mandatory and this can often not be provided in extremely poor regions. In this work, it was not possible to investigate areas with economic water scarcity in relation to their potential for the introduction of greywater recycling via MBR, but with further evaluation useful applications in these regions could certainly be identified.

In total 32 countries which are suffering from lack of water or approaching water scarcity were picked out as hotspots (see Table 25). These countries need to focus on the efficient use of all water sources (groundwater, surface water and rainfall) and on water allocation strategies that maximize the economic and social returns of the limited water resources (UN-Water, 2006). Therefore, water scarcity (N1) was defined as the indicator criterion to identify the most meaningful countries to conduct the evaluation on, based on that pre-selection the identification of hotspots for international transferability of the membrane bioreactor technology was made. All further estimations and appraisals were conducted for these 32 countries.

Table 25: International countries facing water scarcity; (according IWMI, (2006) selected by K. Löw)

	Country	**Water scarcity**
1	Afghanistan	exist./appr.
2	Algeria	existing
3	Australia (south)	existing
4	China (north)	existing
5	Egypt	existing
6	India	exist./appr.
7	Iran	approaching
8	Israel	approaching
9	Jordan	existing
10	Kazakhstan	exist./appr.
11	Kyrgyzstan	exist./appr.
12	Lebanon	approaching
13	Libya	existing
14	Madagascar	approaching
15	Mexico	exist./appr.
16	Morocco	existing
17	Mozambique	exist./appr.
18	Oman	existing
19	Pakistan	exist./appr.

	Country	Water scarcity
20	Peru(coast)	approaching
21	Saudi Arabia	existing
22	South Africa	exist./appr.
23	Spain north east	approaching
24	Syria (south)	approaching
25	Tunisia	existing
26	Turkey (west)	approaching
27	Turkmenistan	approaching
28	United Arab Emirates	existing
29	USA south west	existing
30	Uzbekistan	existing
31	Western Sahara Territory	existing
32	Yemen	existing

3.7.2 *FRESH WATER QUALITY*

An additional criterion to identify the most meaningful target countries for MBR treatment plant applications is fresh water quality (N2). Worldwide the fresh water quality index (WQI) within the environmental performance index (EPI) 2010 (Yale University, 2010) is used to estimate freshwater quality in the utility analysis. It rates every country by a value between 0 and 100, in which 100 is the best score, (for more details see chapter 2.5). An overview of the water quality index scores is presented in Figure 23.

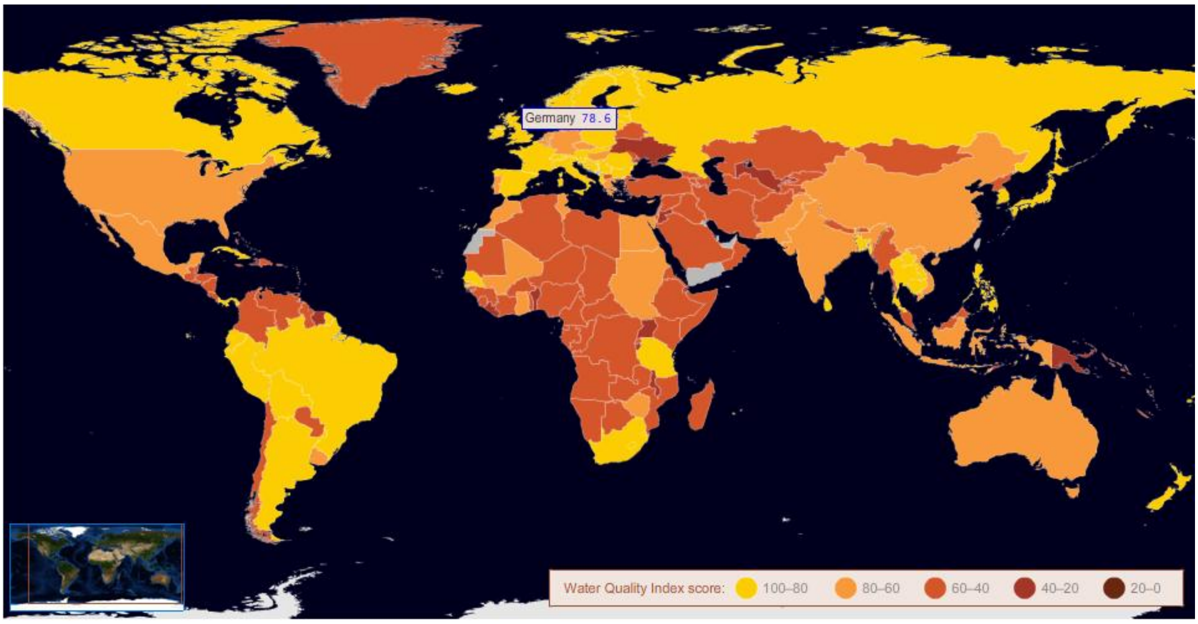


Figure 23: Water quality index according environmental performance index (EPI); (Yale University, 2010)

It is obvious that water quality in Europe is fairly good, just as in Russia, North America and large parts of South America. But in Africa, Middle East, Western Asia, parts of South America and Central America, the quality is poor. The result of investigation within the 32 countries selected for assessment is presented in Table 26 and sorted in descending order.

Table 26: **Water quality index (WQI) based on the 32 countries selected for investigation; (Yale University, 2010)**

	Country	WQI Rating
1	South Africa	84.2
2	Peru	83.4
3	Spain	83.1
4	India	78.9
5	United States of America	77.5
6	China	68.0
7	Tunisia	63.0
8	Morocco	62.9
9	Pakistan	62.6
10	Egypt	62.4
11	Australia	61.7
12	Mexico	61.4
13	Algeria	58.3
14	Turkey	57.9
15	Israel	57.7
16	Iran	49.8
17	Libyan Arab Jamahiriya	49.4
18	Madagascar	47.6
19	Mozambique	46.6
20	Turkmenistan	45.0
21	Syria	45.0
22	Afghanistan	44.8
23	Oman	44.2
24	Kazakhstan	43.4
25	Saudi Arabia	42.4
26	Kyrgyzstan	41.3
27	Lebanon	40.6
28	Uzbekistan	38.0
29	Jordan	30
30	Western Sahara	-
31	United Arab Emirates	-
32	Yemen	-

3.7.3 Population density

The assessment of population density, by "physiological population density" in persons/km^2 arable land, showed high values in MENA region. In particular, Egypt, Israel, Lebanon, Oman, United Arab Emirates, Western Sahara and Yemen, are densely populated. Here often the countries have a high proportion of desert and therefore the population lives in very limited areas of the country. The physiological population density worldwide is shown in Figure 24.

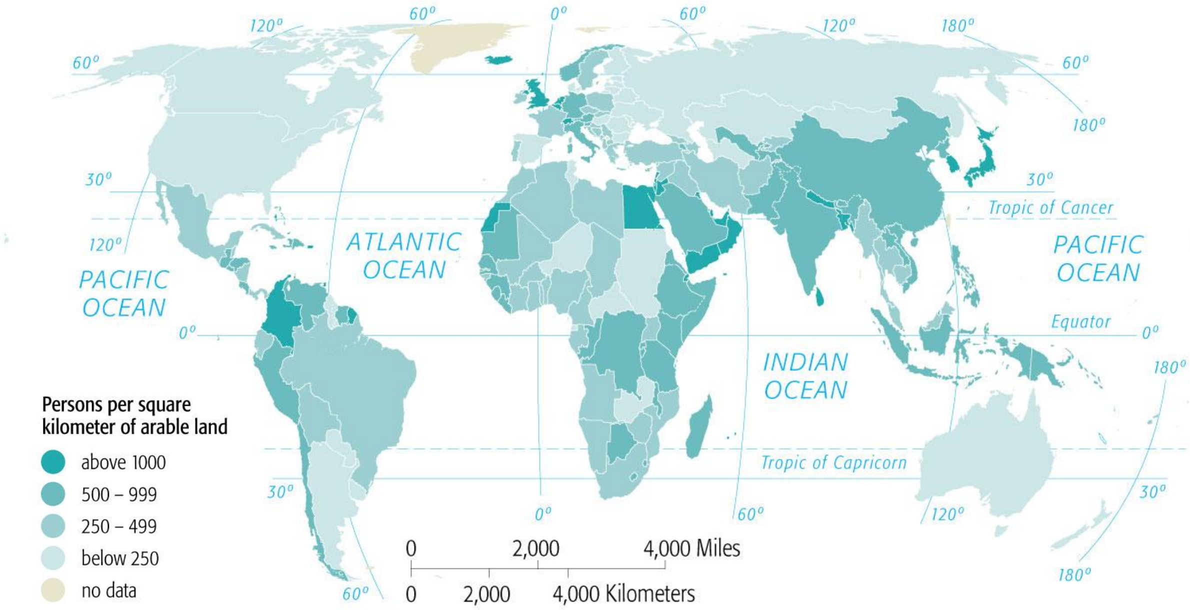


Figure 24: Physiological population density based on population per arable land, [persons/m^2]; (Pearson Education Inc. , 2010)

For the appraisal of most ideal countries to implement greywater treatment via MBR technology, the 32 identified countries suffering from water scarcity, were assessed according to physiological population density; the result is listed in Table 27.

Table 27: Physiological population density of countries which were selected for investigation; (Muller, 2000)

	Country	population/ km^2
1	Oman	11780
2	Western Sahara Territory	6780
3	United Arab Emirates	6404
4	Egypt	2688
5	Lebanon	2290
6	Israel	2147
7	Jordan	1886
8	Yemen	1350
9	China (north)	943
10	Pakistan	834
11	Saudi Arabia	807
12	Peru(coast)	761
13	India	753
14	Madagascar	626
15	Uzbekistan	601
16	Mozambique	473
17	Mexico	436
18	Algeria	431
19	Kyrgyzstan	411
20	Iran	405
21	Syria (south)	404
22	Morocco	387
23	Afghanistan	381
24	Tunisia	381
25	Libya	318

	Country	population/ km²
26	Turkey (west)	303
27	South Africa	300
28	Spain north east	297
29	Turkmenistan	224
30	USA south west	179
31	Kazakhstan	69
32	Australia south	43

3.7.4 URBANISATION

The urbanisation, as one of the issues to estimate the ideal application of membrane bioreactor technology, was assessed on the basis of "United Nations map of urban agglomerations in 2009", (see Figure 25: Urban agglomerations in 2009 (proportion urban of the world: 50.1%); Figure 25). In Australia, North America and Scandinavia the main part of the population lives in urban spaces, but also in France, Libya, Saudi Arabia, Spain and large parts of South America the main proportion lives in cities.

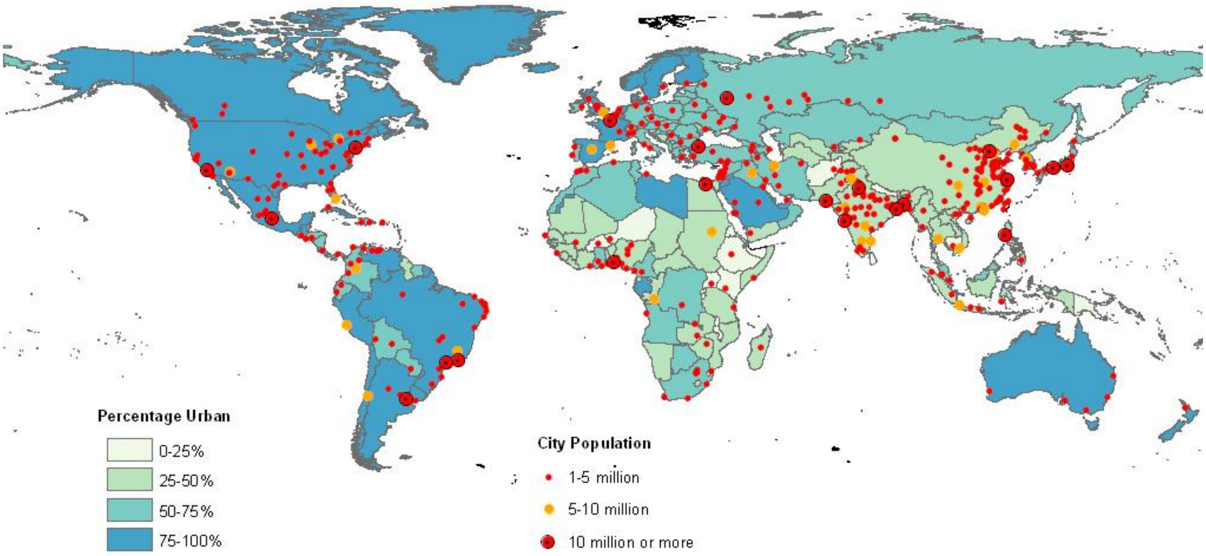


Figure 25: Urban agglomerations in 2009 (proportion urban of the world: 50.1%); (United Nations, 2010)

To explain urbanisation here, especially the rural-urban migrations as a major source of urban growth, a push and pull model can be used. Push factors are not only agrarian overpopulation, but also inappropriate rural ownership structure, inadequate housing, poor infrastructure, lack of jobs and training opportunities. The pull factors include real or perceived better working conditions and higher income, education and training opportunities, especially for the children, the wider range of consumer goods and a less regimented society and family life. In general, the decision to migrate to an urban area is not only determined by one factor, but rather a combination of push and pull forces (Bähr, 2008).

Referring to the identified 32 water scarce countries, the investigation gave the following results of urbanisation rate, as presented in Table 28. The list of countries is sorted in descending order.

Table 28: Percentage of urban population in a country; (United Nations, 2004)

	Country	Urban [%]
1	Western Sahara	93.7
2	Israel	91.6
3	Saudi Arabia	87.7
4	Australia	92.0
5	Lebanon	87.5
6	Libyan Arab Jamahiriya	86.3
7	United Arab Emirates	85.1
8	Oman	77.6
9	Peru	73.9
10	Spain	76.5
11	United States of America	80.1
12	Mexico	75.5
13	Jordan	79.0
14	Iran	66.7
15	Tunisia	63.7
16	Turkey	66.3
17	Algeria	58.8
18	South Africa	56.9
19	Kazakhstan	55.8
20	Morocco	57.5
21	Syria	50.1
22	Turkmenistan	45.3
23	China	38.6
24	Egypt	42.1
25	Kyrgyzstan	33.9
26	Uzbekistan	36.6
27	Mozambique	35.6
28	Pakistan	34.1
29	India	28.3
30	Madagascar	26.5
31	Yemen	25.6
32	Afghanistan	23.3

3.7.5 Result of identification of ideal international applications of MBR technology by utility analysis

The identification of ideal applications of membrane bioreactor technology was accomplished by utility analysis. An assessment of water scarcity, freshwater quality, population density and urbanisation was made by a trimmed-down utility matrix and is presented in Table 29. A detailed description of the rating procedure is assorted in section 2.5 and the utility analysis has a maximum rating of 21 scores. In appendix 6.8 the complete tables of utility matrix are available. Here the results are presented, sorted in descending order.

Table 29: **Ranking of countries ideally fitting for international transfer according to an assessment by utility analysis; (calculation by K. Löw)**

	Country	Rating
1	Jordan	21
2	Uzbekistan	19
3	Oman	18.5
4	Egypt	17.5
5	Libya	17.5
6	Saudi Arabia	17.5
7	Australia (south)	16.7
8	Morocco	16.5
9	Tunisia	16.5
10	United Arab Emirates	16
11	Western Sahara Territory	16
12	Algeria	15.7
13	USA (south west)	14.7
14	China (north)	14.5
15	Yemen	14.2
16	Israel	12.5
17	Lebanon	12.5
18	Mexico	11.5
19	Pakistan	11.5
20	Turkey (west)	11.5
21	Iran	10.5
22	Kyrgyzstan	10.5
23	Pakistan	10.5
24	Syria (south)	10.5
25	Afghanistan	9.7
26	Kazakhstan	9.7
27	Madagascar	9.7
28	Turkmenistan	9.7
29	Peru(coast)	9.5
30	Spain (north east)	9.5
31	South Africa	8.5
32	India	7.7

With a maximum rating of 21 being scored by Jordan it is identified as an ideal country for the implementation of greywater recycling with membrane bioreactor plant technology, due to a correlation of all rated criteria. Water scarcity, poor water quality, high population density and high urbanisation rate is prevailing in this country. An installation of such a system in a building with large water consumption, as well as huge greywater production and a large amount of residents would be an excellent application.

One example for such an application is the “Dead Sea Spa” hotel in Jordan, there are reports of the successful realisation of the project available. The Jordan water authorities are going to use this information as the basis for deciding how to broaden the scope of their greywater guidelines as well as for developing a water performance certificate. The water certificate is intended to serve as a reference tool for future building standards and approval procedures for new buildings, similar to the German energy performance certificate documenting energy efficiency (GTZ, 2010).

Further ideal applications for international membrane bioreactor projects are in the MENA region as well. The countries are all characterised by water shortage and high urbanisation rate in combination with high population density. An overview of the map is given in Figure 26.

This is a rough estimation of ideal application areas for MBR greywater recycling plants by utility analysis. Due to the limited time of this work, a detailed evaluation of worldwide regions divided into small sections was not possible. In a further study, an investigation based on geographic information systems (GIS) could supply more detailed results. It is conceivable, to utilise cartographic modelling, where several thematic layers, such as water scarcity, water quality etc. could be put on top of each other to evaluate the best compliance with the conditions of utility analysis.

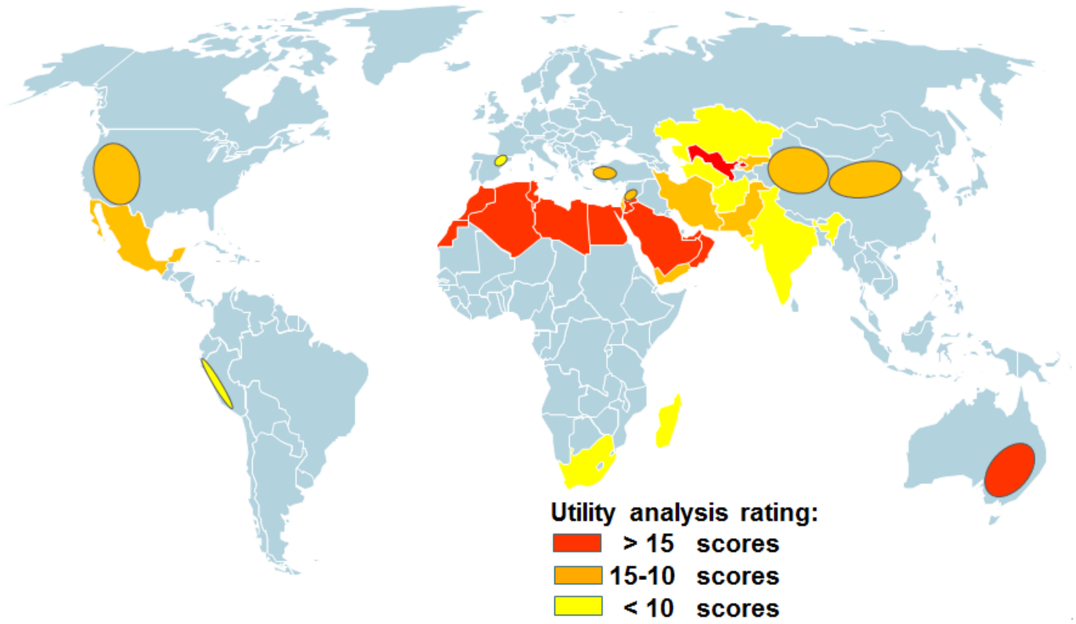


Figure 26: Presentation of countries and regions identified by trimmed-down utility analysis, ideal for greywater treatment via MBR technology; (by K. Löw)

This approach, to assess four environmental aspects, can only outline a rough estimation of global hotspots, due to regional differences. This analysis has a maximum rating of 21 scores or weighting of 21 %, based on the trimmed-down version of utility matrix. By identification of water scarcity as an indicator criterion, a pre selection within the assessment was made. Water scarcity (N1) is the strongest criterion within the whole analysis and thus it provides a good base to identify countries which are rewarding for the examination of the international transferability. This strategy aims to exclude incorrect influences from the analysis. Within the given time of this work it was not possible to assess all countries according the four criteria, but by starting with the most influencing criterion (N1), mistakes should be avoided. Even if the other 3 rated criteria have high values, a weighting higher than 12% as N1 contributes, cannot be achieved by the maximum rating of water quality (N2), population density (N6), and urbanisation rate (N7). The worldwide view on all four assessed environmental criteria without any pre-selection may show a slightly different result, but this was not possible within the limited time of this work.

On top, the estimation is based on the timmed-down analysis with a maximum rating of 21 % of 100 % within the utility analysis, which contributes only one-fifth to the analysis. Hence, it must be taken into consideration that further aspects, apart from environmental criteria, can add a serious weight into assessment as well.

This approach can only outline a rough estimation of global hotspots, due to regional differences. The regional distinctions and conditions of a project may vary widely within narrow spaces, hence it is only possible to make suggestions and give directions. Here, only estimations based on environmental aspects are possible. Further meaningful projcets can be based on legal, economic, socio-cultural, and building specific criteria. A detailed consideration of every criteria is required to identify reasonable applications. For the investigation of a proposed project, accurate local data must necessarily be used to estimate the transferability of MBR technology.

3.7.6 UPCOMING LARGE CITIES IN EMERGING AND DEVELOPING COUNTRIES

By means of the result of the utility analysis, there are countries identified, where a meaningful implementation of greywater recycling via MBR technology is possible. Within these countries there are certainly preferable regions that can be identified. In particular, upcoming large cities in emerging and developing countries are predestined for greywater treatment technologies. In Table 30 there is an overview of existing megacities in 2007 and upcoming megacities in 2025. Within the identified countries where ideal transferability of greywater treatment plants via MBR is given, the megacities can be implied as the favourable hotspots.

Table 30: Worldwide megacities (with populations of more than 10 million) in 2007 and upcoming megacities in 2025; (UN-HABITAT, 2008)

2007

		Population (Thousands)
1	Tokyo	35,676
2	Mexico City	19,028
3	New York-Newark	19,040
4	São Paulo	18,845
5	Mumbai	18,978
6	Delhi	15,926
7	Shanghai	14,987
8	Kolkata	14,787
9	Buenos Aires	12,795
10	Dhaka	13,485
11	Los Angeles-Long Beach-Santa Ana	12,500
12	Karachi	12,130
13	Rio de Janeiro	11,748
14	Osaka-Kobe	11,294
15	Cairo	11,893
16	Beijing	11,106
17	Manila	11,100
18	Moscow	10,452
19	Istanbul	10,061

■: Cities located near a large water body (sea, river or delta)

2025

		Population (Thousands)
1	Tokyo	36,400
2	Mumbai	26,385
3	Delhi	22,498
4	Dhaka	22,015
5	São Paulo	21,428
6	Mexico City	21,009
7	New York-Newark	20,628
8	Kolkata	20,560
9	Shanghai	19,412
10	Karachi	19,095
11	Kinshasa	16,762
12	Lagos	15,796
13	Cairo	15,561
14	Manila	14,808
15	Beijing	14,545
16	Buenos Aires	13,768
17	Los Angeles-Long Beach-Santa Ana	13,672
18	Rio de Janeiro	13,413
19	Jakarta	12,363
20	Istanbul	12,102
21	Guangzhou, Guangdong	11,835
22	Osaka-Kobe	11,368
23	Moscow	10,526
24	Lahore	10,512
25	Shenzhen	10,196
26	Chennai	10,129

■ : New megacities

In accordance with results of the utility analysis, to find out the most ideal applications for greywater treatment via MBR technology, there are megacities in the identified counties like Bangalore, Beijing, Cairo, Chennai, Istanbul, Mexico-City and Shanghai where the implementation of such a measure can be seen to be very meaningful.

Megacities in developing and emerging countries which cannot cope with growth of the urban population, face consequences such as; insufficient living space, overloaded roads and inadequate water and electricity supply. At the same time the growth influences the natural ecosystems and thus the livelihood of the population. Mega-urbanisation is associated with risks and opportunities. On the one hand it provides possibilities to improve the general living conditions. Many mega-cities are engines of growth and centers of productivity. According to OECD (Organisation for Economic Co-operation and Development) calculations, Mexico City and Sao Paulo, generate about 50 percent of the national income. Bangkok contributes more than 40 percent of national gross domestic product, even though only ten percent of the population of the country lives there. In these cities human resources and capital is concentrated and there are also social resources such as charities and local organisations. The concentration of the population in mega cities, offers the possibility of efficient provision of goods and services with relatively low per-capita costs (Hansjürgens & Heinrichs, 2007).

Therefore, greywater recycling via MBR systems can be ideally meet challenges of water scarcity in existing or emerging megacities. Of course, these urban metropolitan areas often have a very high proportion of the population living in slums, but for urban development planning projects, the greywater recycling technology implemented within residential buildings is still an ideal application. This technology has a high potential to improve the living conditions in megacities.

3.8 FUTURE PROSPECTS

3.8.1 LEGAL FOUNDATION

To endorse the dissemination of greywater recycling legal measures are necessary. Governments are developing policies with incentives and/or permits to stimulate water recycling in an industrial context. Possible tools that can be deployed are: increasing taxes on wastewater discharge, requiring the development of wastewater treatment techniques that result in enhanced removal of a wide range of contaminants, and linking permits to progressive use of alternative water sources (Van der Bruggen, 2010).

In Jordan the implementation of a greywater recycling plant in the “Dead Sea Spa” hotel was so successful that greywater recycling shall now become compulsory for all hotels (GTZ, 2010). Even the government in Tokyo requires that water-saving measures be implemented in new multi-storey buildings, such as rainwater collection systems which provide water for the toilets and urinal flushing and greywater recycling systems (Asano, Burton, Leverenz, Tsuchihashi, & Tchobanoglous, 2007). Moreover, for several years the operators of new hotel edifices in Beijing are obliged to use purified greywater for toilet flushing. In big cities shortages, such as interruption of water supply is on the agenda. Laws in China require hotel operators of modern tourism facilities to recycle greywater. The demand for technology in this sector is extremely high. Extreme water shortage is approaching more than 100 of the 660 cities in China (Weitlaner, 2005).

Thus, direct governmental funding for treatment plants via subsidies, allowances, loans for plant investment, financial support or indirect incentives on greywater recycling including for example tax reductions, rebates, minimised fresh and/or wastewater charges, reimbursements of taxes or charges, can be vital instruments to support the dissemination of this very useful technology.

3.8.2 FINANCIAL AND ECONOMIC ISSUES

In regions where no sewer systems exist, wastewater is collected in vaults and removed by suction vehicles. For amortisation calculation, the implementation of a greywater recycling plant shows good performance, because the removal and disposal via suction vehicles is very expensive. The “Dead Sea Spa” hotel in Jordan using greywater recycling showed a payback time of 5-6 years for the investment costs of approx. € 65,000 as water costs are 5 €/m^3 (Rothenberger et al., 2011).

But in many areas where water scarcity prevails, the drinking water and wastewater prices are generally very low, due to governmental subsidies. Therefore, in such areas at first only low cost savings result from the substitution of fresh water by recycled greywater. For these regions the big advantage of a greywater reuse plant is mainly in independence from an unstable water supply. For example 4 - to 5-star hotels can keep their business going, even in times of water shortages or cuts in supply. This can be obtained by using the treated greywater for various purposes such as toilet flushing and irrigation of hotel garden (Paris, 2009a). This is a stimulus to increase the demand for greywater treatment technology in the context of protection of resources which are necessary for production plants, hotels, etc.

Therefore, the consideration to install a greywater recycling plant should not only be decided based on the economic benefit. In different regions of the world the requirements which shall be fulfilled by implementing such a system can be extremely variable. In Germany the installation of MBR systems is mainly based on financial reasons. But in other countries, the maintenance of secure water supply and protection of water resources from exploitation can bring quite a different dimension into the decision-making process for such a system.

3.8.3 TECHNOLOGY AND OPERATION

On the perspective of technology, it is important to ensure a continuous power supply; user-friendly design of the facility which is operated and maintained by trained staff and moreover, the availability of spare parts has to be guaranteed.

Deficiencies in the operation and maintenance can occur, if the system is not operated by a professional, due to a lack of knowledge. Additionally, operational malfunctions caused by blockages and sludge accumulation, through lack of functional monitoring or improper feeding can occur. Furthermore, organisational difficulties may occur due to different intervals of removal of excess sludge of membrane bioreactor (Wilderer & Paris, 2001).

To avoid these problems, the remedy could be an outsourcing of plant operation. A specialised company can operate the system with regulated time intervals for maintenance and for example by means of remote data transmission, which monitors the function of the plant continuously (Becker et al., 2006).

3.8.4 SOCIO-CULTURAL REASONS

Reuse of greywater needs sensitive consideration when taking socio-cultural aspects into account, especially in the case of religiously motivated values and customs and thus, the perception of water. In particular in Muslim-dominated areas, there is often uncertainty, if recycled water meets the requirements of purity. Therefore, public clarification campaigns and involvement of Imams are essential. Here the clarification that the Koran allows the reuse of wastewater, if it is treated via MBR plant can only function after consultation with Islamic scholars and religious dignitaries. To ensure sustainability, it is necessary that the values and moral concepts, which are heavily influenced by Islam in the MENA region are respected (Sieghart, 2005).

Another important factor, relating to socio-cultural factors is the role model character which can be achieved by implementing a greywater treatment plant. The marketing factor to be a pioneer in the field of water saving techniques and therefore, to show best practice in environmental protection, is a stimulus especially for international production companies and worldwide acting hotel chains, to adopt and implement this technology. With respect to the “water footprint” the treatment of greywater is a good opportunity to minimise the drinking water demand for production processes and therefore, to show environmental responsibility.

4 CONCLUSIONS

The membrane bioreactor treatment technology to purify greywater shows excellent cleaning performance with minimal space requirements, but a relatively high energy demand. Therefore, it makes sense to implement such a system only where a high quality of recycled water is required, space is limited and the energy supply is uninterrupted. This is mainly the case in urban areas, where reuse applications are within buildings, where recycled water supplies reuse applications such as toilet flushing.

The functionality of MBR treatment technology has been proven to work in an international context by exemplary projects worldwide. The positive aspects of this technology have been shown based on economic and environmental advantages, demonstrated with many examples collected in this work.

The outcome after a short period of greywater treatment in the existing membrane bioreactor plant in Eschborn showed good results regarding functionality of the system and quality of the permeate. The specifications of EU bathing water directive RL 2006/7/EG (2006) and fbr requirements H 201 (2005) are fulfilled.

Due to the research character of the SANIRESCH plant with all its special features, it is not feasible to transfer it on a one to one basis, when considering economic aspects. Hence, a fictitious cost calculation based on a simplified system design for the whole GIZ headquarters building was conducted to make the system comparable to standard applications. With respect to economic aspects, an amortisation of the complete treatment system, in the context of the GIZ headquarters was not achievable. Only 45 % of daily process water demand in the building can be covered by greywater production. The amount of greywater production and process water demand is not balanced. Only with big efforts, such as super saving toilets, equilibrium can be reached, however accompanied by immense acquisition costs. With the average cost for energy and maintenance in comparison to water charges, the calculation showed that savings of € 1,412 on operating costs in the first year are possible. But in an amortisation calculation, the investment costs account to € 38,383 for treatment plant and additional piping system in the building, therefore a benefit is not obtainable. In an office building, the mismatch with respect to the water balance is too high, thus there is no stimulus to use a greywater treatment plant for this specific application.

However, economic incentives do exist for the application of greywater treatment plants in different circumstances, such as in buildings where people stay overnight, where an advantageous water balance is much easier to achieve. Examples of such buildings are apartment buildings, halls of residence, hospitals, hotels, etc., here an amortisation of the system can be achieved after only a few years. Based on an exemplary cost calculation for a 4-star hotel in Berlin, an application with a high amount of water consumption, the calculation shows much better results and the break even can be achieved after approximately 6 years of operation.

Especially in Germany, where no water scarcity exists, economic aspects are in the foreground when greywater recycling technologies are implemented, whereas in regions of the world, where low availability of water causes significant problems, the reuse technology meets many more targets, such as protection of the environment and water resources, reduction of the volume of produced wastewater and consequently, the water pollution risk as well.

In this respect, the international transferability of greywater treatment via membrane bioreactor technology was assessed, based on the sustainability criteria for sanitary concepts by means of a utility analysis. According to the main groups health and hygiene, economic, functional and technical, environmental, and socio-cultural criteria; 19 appropriate criteria for the subgroups were identified. To every sub criterion, a certain weighting value was given, in order to result 100 % in total in the utility analysis.

The evaluation to locate global hotspots for greywater recycling applications was based on water scarcity, defined as the indicator criterion to identify the most meaningful countries for reuse projects. In total 32 countries, which are suffering from lack of water or approaching water scarcity were assessed by a trimmed-down utility analysis. According to the four rating criteria: water shortage, water quality, population density and urbanisation rate an appraisal based on environmental aspects was conducted. Jordan was identified as a predestined country (with a maximum rating), for the implementation of greywater recycling via MBR plant technology, due to a correlation of all assessed criteria. Further ideal applications for international greywater recycling projects are in the Middle East and North Africa region, especially Oman, Egypt, Libya, and Saudi Arabia can be pointed out. These countries are all characterised by water shortage and high urbanisation rate in combination with high population density, which makes MBR technology reasonable. In addition, a main focus can be on existing or emerging megacities, due to the technology's potential to improve living conditions, when implemented within urban planning projects.

This approach, to assess four environmental aspects, can only outline a rough estimation of global hotspots, due to regional differences. By identification of water scarcity, as an indicator criterion, a pre selection within the assessment was made. The worldwide view on all four assessed environmental criteria without pre-selection may show slight changes, but this was not possible within the limited time of this work. Furthermore, the estimation is based on a maximum rating of 21 % of 100 % within the utility analysis, which contributes only one-fifth to the analysis. Therefore, it must be taken into consideration that further aspects, like economic, socio-cultural and legal criteria, can add a serious weight into assessment as well.

In general, the identified regions represent appropriate conditions based on environmental criteria; further aspects like installation of such a technology in large buildings with high water consumption contribute to making a MBR project even more suitable. The same applies for economic, legal and socio-cultural conditions, if the circumstances meet the sustainable criteria according to the utility analysis, the project becomes more viable. Hence, a consideration of all aspects is always necessary to identify the practicability of membrane bioreactor technology in a certain application. Worldwide, there are a variety of application ranges, where a viable reuse application is possible, but it needs to be well-planned, by taking all background information into account, including economic and sustainable aspects.

To endorse the dissemination of greywater recycling, legal measures are necessary. Governments are developing policies with incentives and/or permits to stimulate water recycling in an industrial context. A further step in the right direction would be an adequate price for drinking and wastewater. Often, the subsidised water price in countries with water scarcity eliminates the stimulus to install water saving technologies such as greywater recycling.

At the moment water reuse technologies are often considered as a gadget without benefit and with the risk of malfunction within a project. To make greywater recycling by membrane bioreactor technology a popular and widespread technology, further development steps are necessary. To achieve marketable plants on a serial scale, the dispersal of ready-made systems which can be offered cheaply, is a step required in the future.

Finally, a general paradigm shift must take place, as today's water and sewage systems are no longer acceptable in respect to sustainability aspects. In particular, it is not an exportable solution to emerging and developing countries, where volumes of wastewater are increasing as well as the scarcity of water. The well-known conventional method with centralised treatment plants is very cost intensive, due to the expensive sewer systems and high operation costs of the sewage treatment plants. These systems are hardly affordable in emerging and low-income economies; hence they should not be promoted as a sanitation solution in such contexts. Additionally, the conventional wastewater treatment methods are only disposal oriented and the potential of recycling and reuse is not taken into consideration. Based on a holistic approach, by "closing the loop" a recirculation of water within the building without any wastewater production is a conceivable future.

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6 APPENDIX

6.1 TECHNICAL DATA OF SANIRESCH GREYWATER TREATMENT PLANT, (IN GERMAN); (HUBER SE, 2011A)

Pumpen:

- Beschickungspumpe MBR (P1)
  Fabrikat : Speck
  Typ: TOP 71WS
  Leistung der Pumpe: 9,4 [m³/h] bei 2 m Förderhöhe
- Permeatpumpe (P2)
  Fabrikat : Timmer
  Typ: DP 60-A
  Leistung der Pumpe (max.): 0,18 [m³/h]
- Überschussschlammpumpe (P3)
  Fabrikat : Speck
  Typ: TOP 71WS
  Leistung der Pumpe: 9,4 [m³/h] bei 2 m Förderhöhe
- Spritzdüsenpumpe (P4)
  Fabrikat : Speck
  Typ: TOP 71WS
  Leistung der Pumpe: 9,4 [m³/h] bei 2 m Förderhöhe
- Betriebswasserpumpe (P5)
  Fabrikat : Speck
  Typ: TOP 71WS
  Leistung der Pumpe: 9,4 [m³/h] bei 2 m Förderhöhe

Vorlage:

- Volumen Vorlage max. 0,48 [m³]
- Typ Belüftungsgebläse Rietschle LP 80
- Membranrohrbelüfter Belüft. Fa. Ott, Schlitzweite 1,2 mm

Biologische Stufe:

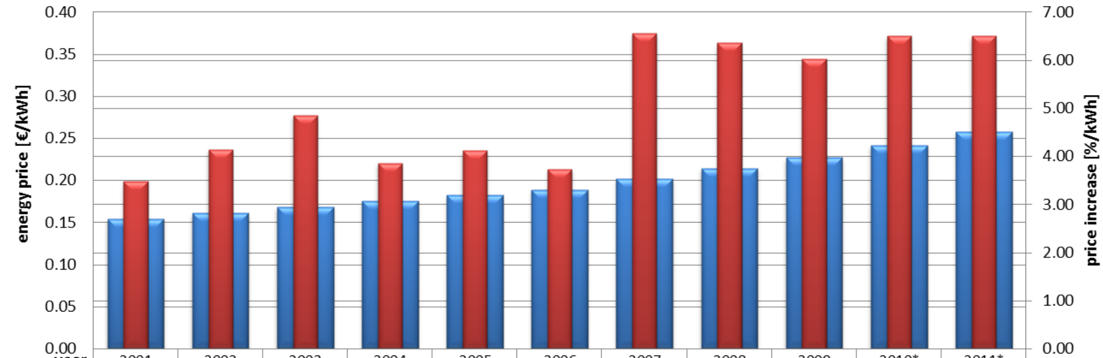
- Volumen Biologie max. 0,5 [m³]
- Typ Belüftungsgebläse Rietschle LP 80
- Membranrohrbelüfter Belüft. Fa. Ott, Schlitzweite 1,2 mm

Filtrationsstufe:

- Membranfläche 3,5 [m²]
- Auslegungsfluss 5 [l/(h*m²)] (einstellbar)
- Auslegungstemperatur 20 [°C]
- Porengröße 0,038 [µm]
- Membranmaterial PES
- TMP* Bereich - 350 [mbar]
- Standzeit der Membran 1[a] (nach Bedarf)
- Typ Spülluftgebläse Rietschle LP 80
- Membranrohrbelüfter Spülung Fa. Ott, Schlitzweite 2,0 mm

*TMP = Transmembrandruck

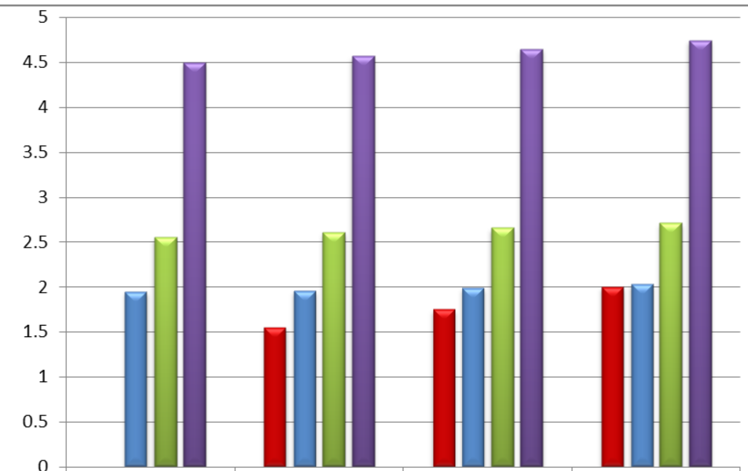
6.5 Energy price (gross) in Germany, (graphic presentation by K. Löw); (Bundesministerium für Wirtschaft und Technologie, 2010)



year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010*	2011*
energy price [€/kWh]	0.15	0.16	0.17	0.18	0.18	0.19	0.20	0.21	0.23	0.24	0.26
price increase [%/kWh]	3.49	4.15	4.85	3.86	4.11	3.73	6.56	6.35	6.02	6.50	6.50

* calculated values

6.6 Water price in Hessen/Germany (gross), (grapic prensentation by K. Löw); (Statistisches Bundesamt, 2011)



year	2008	2009	2010	2011*
average price increase [%/m3]	0	1.56	1.75	2
average price drinking water (Hessen) [€/m3]	1.95	1.96	1.99	2.03
average price waste water (Hessen) [€/m3]	2.55	2.61	2.66	2.71
total water price (Hessen) [€/m3]	4.5	4.57	4.65	4.74

* calculated values

6.7 Data table for economic calculation of greywater treatment plant

Year	Total invest (pipes and treatment plant) [€/a]	Invest treatment plant [€/a]	Mainten-ance [€/a]	Energy costs [€/a]	Total operation costs per year [€/a]	Water costs (water+ wastewater) per year [€/a]	Cost saving per year [€/a]	Total cost saving (summary) [€]
	2% annual interest amount	2% annual interest amount	2% annual interest amount	6.5% annual increase		2% annual increase		
1	38383.81	8633.81	1272.38	707.07	1979.45	3391.47	1412.02	1412.02
2	39151.49	8806.49	1297.83	753.03	2050.86	3459.30	1408.44	2820.46
3	39934.52	8982.62	1323.78	768.09	2091.87	3528.49	1436.61	4257.07
4	40733.21	9162.27	1350.26	783.45	2133.71	3599.06	1465.34	5722.41
5	41547.87	9345.51	1377.27	799.12	2176.39	3671.04	1494.65	7217.06
6	42378.83	9532.42	1404.81	815.10	2219.91	3744.46	1524.54	8741.61
7	43226.40	9723.07	1432.91	831.41	2264.31	3819.35	1555.03	10296.64
8	44090.93	9917.53	1461.56	848.03	2309.60	3895.73	1586.13	11882.77
9	44972.75	10115.88	1490.80	864.99	2355.79	3973.65	1617.86	13500.63
10	45872.21	10318.20	1520.61	882.29	2402.91	4053.12	1650.21	15150.85
11	46789.65	10524.57	1551.02	899.94	2450.96	4134.18	1683.22	16834.06
12	47725.44	10735.06	1582.04	917.94	2499.98	4216.87	1716.88	18550.95
13	48679.95	10949.76	1613.69	936.30	2549.98	4301.20	1751.22	20302.17
14	49653.55	11168.75	1645.96	955.02	2600.98	4387.23	1786.24	22088.41
15	50646.62	11392.13	1678.88	974.12	2653.00	4474.97	1821.97	23910.38

6.8 UTILITY ANALYSIS (TRIMMED-DOWN VERSION) TO IDENTIFY IDEAL INTERNATIONAL APPLICATIONS FOR MBR TECHNOLOGY

Identification of ideal international applications of MBR technology by utility analysis

	Assessment criteria Discretionary	Weighting Σ= 21%	Description of rating	Afghanistan Rating	Afghanistan Info not available	Afghanistan Result	Algeria Rating	Algeria Info not available	Algeria Result	Australia south Rating	Australia south Info not available	Australia south Result	China (north) Rating	China (north) Info not available	China (north) Result
N	**Environmental criteria**	**21%**				**9.7**			**15.7**			**16.7**			**14.5**
N1	Water scarcity (physical)	12	**high = 10, medium = 5, low = 1, no = 0**	**5**		60	**10**		120	**10**		120	**10**		120
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**	**5**		25	**5**		25	**5**		25	**1**		5
N3	Number of persons situated in the building	0	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**			0			0			0			0
N4	Accumulation of greywater	0	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**			0			0			0			0
N5	Sewer system available	0	**no = 10, yes = 1**			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	**high = 10, medium = 5, low = 1**	**5**		10	**1**		2	**1**		2	**5**		10
N7	Urbanisation rate	2	**high = 10, medium = 5, low = 1**	**1**		2	**5**		10	**10**		20	**5**		10
	Degree of fulfilment			**Result [%]**		**9.7**	**Result [%]**		**15.7**	**Result [%]**		**16.7**	**Result [%]**		**14.5**
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		0

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

Rating input | Rating input | Rating input | Rating input

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating	Egypt			India			Iran			Israel		
				Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result
N	**Environmental criteria**	**21%**				**17.5**			**7.7**			**10.5**			**12.5**
N1	Water scarcity (physical)	12	**high = 10, medium = 5, low = 1, no = 0**	**10**		120	**5**		60	**5**		60	**5**		60
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**	**5**		25	**1**		5	**5**		25	**5**		25
N3	Number of persons situated in the building	0	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**			0			0			0			0
N4	Accumulation of greywater	0	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**			0			0			0			0
N5	Sewer system available	0	**no = 10, yes = 1**			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	**high = 10, medium = 5, low = 1**	**10**		20	**5**		10	**5**		10	**10**		20
N7	Urbanisation rate	2	**high = 10, medium = 5, low = 1**	**5**		10	**1**		2	**5**		10	**10**		20
	Degree of fulfilment			**Result [%]**		**17.5**	**Result [%]**		**7.7**	**Result [%]**		**10.5**	**Result [%]**		**12.5**
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		0

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

Rating input (Jordan) · Rating input (Kazakhstan) · Rating input (Kyrgistan) · Rating input (Lebanon)

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating	Jordan			Kazakhstan			Kyrgistan			Lebanon		
				Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result
N	**Environmental criteria**	**21%**				**21**			**9.7**			**10.5**			**12.5**
N1	Water scarcity (physical)	12	**high = 10, medium = 5, low = 1, no = 0**	**10**		120	**5**		60	**5**		60	**5**		60
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**	**10**		50	**5**		25	**5**		25	**5**		25
N3	Number of persons situated in the building	0	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**			0			0			0			0
N4	Accumulation of greywater	0	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**			0			0			0			0
N5	Sewer system available	0	**no = 10, yes = 1**			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	**high = 10, medium = 5, low = 1**	**10**		20	**1**		2	**5**		10	**10**		20
N7	Urbanisation rate	2	**high = 10, medium = 5, low = 1**	**10**		20	**5**		10	**5**		10	**10**		20
	Degree of fulfilment			**Result [%]**		**21**	**Result [%]**		**9.7**	**Result [%]**		**10.5**	**Result [%]**		**12.5**
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		0

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating	Lybia Rating	Lybia Info not available	Lybia Result	Madagaskar Rating	Madagaskar Info not available	Madagaskar Result	Mexico Rating	Mexico Info not available	Mexico Result	Morocco Rating	Morocco Info not available	Morocco Result
N	**Environmental criteria**	**21%**				**17.5**			**9.7**			**11.5**			**16.5**
N1	Water scarcity (physical)	12	**high = 10, medium = 5, low = 1, no = 0**	**10**		120	**5**		60	**5**		60	**10**		120
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**	**5**		25	**5**		25	**5**		25	**5**		25
N3	Number of persons situated in the building	0	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**			0			0			0			0
N4	Accumulation of greywater	0	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**			0			0			0			0
N5	Sewer system available	0	**no = 10, yes = 1**			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	**high = 10, medium = 5, low = 1**	**5**		10	**5**		10	**5**		10	**5**		10
N7	Urbanisation rate	2	**high = 10, medium = 5, low = 1**	**10**		20	**1**		2	**10**		20	**5**		10
	Degree of fulfilment			**Result [%]**		**17.5**	**Result [%]**		**9.7**	**Result [%]**		**11.5**	**Result [%]**		**16.5**
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		0

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating	Mozambique			Oman			Pakistan			Peru(coast)		
				Rating input			Rating input			Rating input			Rating input		
				Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result
N	Environmental criteria	21%				10.5			18.5			11.5			9.5
N1	Water scarcity (physical)	12	high = 10, medium = 5, low = 1, no = 0	5		60	10		120	5		60	5		60
N2	Freshwater quality	5	high = 1, medium = 5, low = 10	5		25	5		25	5		25	1		5
N3	Number of persons situated in the building	0	big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)			0			0			0			0
N4	Accumulation of greywater	0	high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1			0			0			0			0
N5	Sewer system available	0	no = 10, yes = 1			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	high = 10, medium = 5, low = 1	5		10	10		20	10		20	5		10
N7	Urbanisation rate	2	high = 10, medium = 5, low = 1	5		10	10		20	5		10	10		20
	Degree of fulfilment			Result [%]		10.5	Result [%]		18.5	Result [%]		11.5	Result [%]		9.5
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		0

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating	Saudi Arabia Rating	Info not available	Result	South Africa Rating	Info not available	Result	Spain north east Rating	Info not available	Result	Syria (south) Rating	Info not available	Result
				Rating input			Rating input			Rating input			Rating input		
N	Environmental criteria	21%				17.5			8.5			9.5			10.5
N1	Water scarcity (physical)	12	high = 10, medium = 5, low = 1, no = 0	10		120	5		60	5		60	5		60
N2	Freshwater quality	5	high = 1, medium = 5, low = 10	5		25	1		5	1		5	5		25
N3	Number of persons situated in the building	0	big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)			0			0			0			0
N4	Accumulation of greywater	0	high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1			0			0			0			0
N5	Sewer system available	0	no = 10, yes = 1			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	high = 10, medium = 5, low = 1	10		20	5		10	5		10	5		10
N7	Urbanisation rate	2	high = 10, medium = 5, low = 1	5		10	5		10	10		20	5		10
	Degree of fulfilment			Result [%]		17.5	Result [%]		8.5	Result [%]		9.5	Result [%]		10.5
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		0

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

N	Assessment criteria / Discretionary	Weighting ∑= 21%	Description of rating	Tunesia Rating	Tunesia Info not available	Tunesia Result	Turkey (west) Rating	Turkey (west) Info not available	Turkey (west) Result	Turkmenistan Rating	Turkmenistan Info not available	Turkmenistan Result	United Arab Emirates Rating	United Arab Emirates Info not available	United Arab Emirates Result
				Rating input			Rating input			Rating input			Rating input		
N	**Environmental criteria**	**21%**				**16.5**			**11.5**			**9.7**			**16**
N1	Water scarcity (physical)	12	**high = 10, medium = 5, low = 1, no = 0**	**10**		120	**5**		60	**5**		60	**10**		120
N2	Freshwater quality	5	**high = 1, medium = 5, low = 10**	**5**		25	**5**		25	**5**		25		N/A	0
N3	Number of persons situated in the building	0	**big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)**			0			0			0			0
N4	Accumulation of greywater	0	**high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1**			0			0			0			0
N5	Sewer system available	0	**no = 10, yes = 1**			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	**high = 10, medium = 5, low = 1**	**5**		10	**5**		10	**1**		2	**10**		20
N7	Urbanisation rate	2	**high = 10, medium = 5, low = 1**	**5**		10	**10**		20	**5**		10	**10**		20
	Degree of fulfilment			**Result [%]**		**16.5**	**Result [%]**		**11.5**	**Result [%]**		**9.7**	**Result [%]**		**16**
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		0	n. a. citeria		1

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

Identification of ideal international applications of MBR technology by utility analysis

	Assessment criteria Discretionary	Weighting ∑= 21%	Description of rating	USA south west			Uzbekistan			Western Sahara Territory			Yemen		
				Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result	Rating	Info not available	Result
N	Environmental criteria	21%				14.7			19			16			14.2
N1	Water scarcity (physical)	12	high = 10, medium = 5, low = 1, no = 0	10		120	10		120	10		120	10		120
N2	Freshwater quality	5	high = 1, medium = 5, low = 10	1		5	10		50		N/A	0		N/A	0
N3	Number of persons situated in the building	0	big amount (> 100 persons) = 10, medium amount (10 - 100 persons) = 5, small amount = 1 (< 10 persons)			0			0			0			0
N4	Accumulation of greywater	0	high (overnight accommodation) = 10, medium (operation in the daytime + showering) = 5, low (operation in the daytime) = 1			0			0			0			0
N5	Sewer system available	0	no = 10, yes = 1			0			0			0			0
N6	Population/settlement density (based on habitable area of the country)	2	high = 10, medium = 5, low = 1	1		2	5		10	10		20	10		20
N7	Urbanisation rate	2	high = 10, medium = 5, low = 1	10		20	5		10	10		20	1		2
	Degree of fulfilment			Result [%]		14.7	Result [%]		19	Result [%]		16	Result [%]		14.2
				n. a. citeria		0	n. a. citeria		0	n. a. citeria		1	n. a. citeria		1

Rating input (USA south west) · Rating input (Uzbekistan) · Rating input (Western Sahara Territory) · Rating input (Yemen)

Note: Values in grey coloured cells are based on imputed data; (Yale University, 2010)

6.9 Poster

Hochschule Esslingen University of Applied Sciences | Hochschule Reutlingen Reutlingen University | HOCHSCHULE FÜR TECHNIK STUTTGART UNIVERSITY OF APPLIED SCIENCES | Hochschule für Wirtschaft und Umwelt Nürtingen-Geislingen

An innovative greywater treatment system for urban areas – International transferability of a German approach, installed in GIZ's headquarters in Eschborn

Katharina Löw

Supervisors: Prof. Helmut G. Hohnecker (HFT), Dr.-Ing. Martina Winker (GIZ)

Introduction

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH installed a greywater treatment system within the research project SANIRESCH in its headquarters located in Eschborn, Germany (Winker & Saadoun, 2011; see Figure 1). Greywater is domestic wastewater excluding toilet water, therefore easily recyclable. The system is based on the technology of membrane bioreactor (MBR), a method which provides a very good cleaning capacity and effective removal of contaminants (Mallevialle et al., 1996), developed by company HUBER SE. After MBR treatment, the purified water (process water) fulfils the regulations of the EU directive 2006/7/EG for bathing water quality. It can be used optimally for irrigation, toilet flushing or laundry. Within this work the international transferability of this technology was investigated.

Aims of research

- Investigation of membrane bioreactor technology.
- Identification of limitation of the research project.
- Evaluation of economic feasibility of the technology.
- Assessment of the international transferability of MBR technology by utility analysis.

Methods

- Literature study of greywater characteristics and legal foundations.
- Comparison of treatment technologies.
- Investigation of existing MBR projects.
- Assessment of international transferability of MBR technology by utility analysis based on the fundamentals of sustainable sanitation (Hellström et al., 2000).

Plant technology

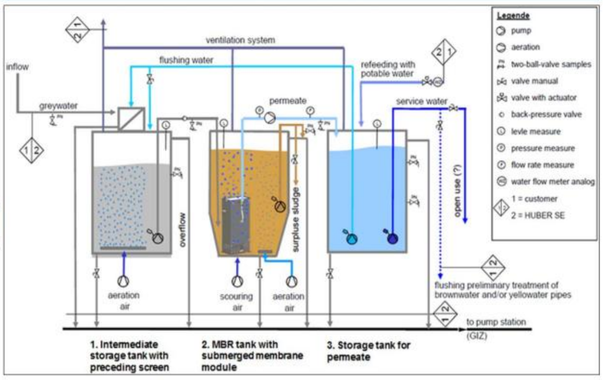


Figure 1: Flow chart of greywater treatment plant ; (HUBER SE, 2011)

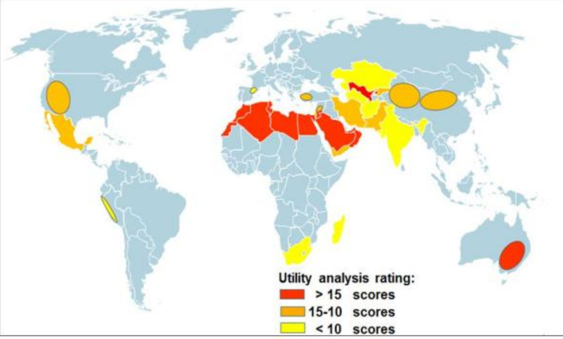


Figure 2: Presentation of countries and regions identified by utility analysis, ideal for greywater treatment via MBR technology

Results & Discussion

- MBR technology for greywater treatment combines an excellent cleaning performance with minimal space requirement, but relatively high energy demand.
- Office buildings mostly have a mismatch of greywater production and process water demand, while residential buildings mainly show beneficial water balances.
- Amortisation of greywater treatment equipment and economic benefits can be obtained, if the production of greywater is high and the water balance is equalised.
- To estimate the international transferability of the technology an appraisal of sustainability criteria via utility analysis was conducted. 32 countries were assessed according environmental aspects based on water scarcity as an indicator criterion. In reference to the four rating criteria: water shortage, water quality, population density and high urbanisation rate; an estimation was conducted.
- Jordan was identified as a predestined country for the implementation of greywater recycling via MBR technology, due to a correlation of all assessed criteria with a maximum rating of 21 scores. Further ideal applications are in the Middle East and North Africa (MENA) region: especially Oman, Egypt, Libya, Saudi Arabia, Morocco, Tunisia, United Arab Emirates, Western Sahara Territory and Algeria (sorted in descending order). These countries are all characterised by water shortage and high urbanisation rate in combination with high population density, which makes MBR technology reasonable; (see Figure 2).

Conclusions

- Worldwide, there are a variety of application ranges where a viable reuse application is possible, but it needs to be well-planned, by taking all background information into account including economic and sustainable aspects, shown in Figure 3.
- To endorse the dissemination of greywater recycling, legal measures are necessary. Governments are developing policies with incentives and/or permits to stimulate water recycling in an industrial context.
- A further required step is the development of marketable plants on a serial scale, to provide ready-made systems which can be offered cheaply.
- Finally, a general paradigm shift must take place based on a holistic approach, by "closing the loop". In order to make a recirculation of water within the building (without any wastewater production) a conceivable future.

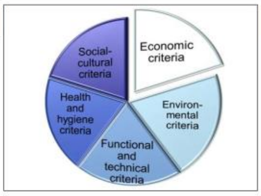


Figure 3: Sustainable criteria for sanitary concepts; (Hellström et al., 2000)

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6.10 ABSTRACT IN GERMAN

Die GIZ hat in ihrem Hauptsitz in Eschborn/Deutschland eine Grauwasserbehandlungsanlage im Rahmen des Forschungsprojekts SANIRESCH installiert. Sie basiert auf der von HUBER SE entwickelten Membranbioreaktor(MBR)-Technologie. Grauwasser ist häusliches Abwasser ohne Toilettenabwasser und daher leicht zu recyceln. Im Rahmen dieser Arbeit wurde die internationale Übertragbarkeit des Systems untersucht.

Durch eine Literaturstudie wurden Grauwassereigenschaften und rechtliche Grundlagen ermittelt. Verschiedene Behandlungsmethoden und vorhandene MBR-Projekte wurden analysiert. Gemäß ihrer wirtschaftlichen Aspekte wurde die SANIRESCH-Anlage im Vergleich zu einer Standardanwendung in einem Hotel bewertet. Mit Hilfe einer Nutzwertanalyse, basierend auf den Grundlagen der nachhaltigen Sanitärversorgung, wurde das Potenzial der weltweiten Anwendung bewertet.

Die MBR-Technologie bietet eine hervorragende Reinigungsleistung mit geringem Platzbedarf, jedoch relativ hohem Energieverbrauch. Durch ungünstige Wasserbilanzen wird ein wirtschaftlicher Nutzen für Bürogebäude nur selten erreicht. Während Wohngebäude positive Wasserbilanzen zeigen und somit wirtschaftliche Einsparungen möglich sind. Für die weltweite Übertragbarkeit, wurden 32 Länder anhand von Umweltaspekten auf Basis des Indikatorkriteriums „Wasserknappheit“ bewertet. Hierbei hat sich die MENA-Region aufgrund hohen Wassermangels, schlechter Wasserqualität, hoher Bevölkerungsdichte und hoher Urbanisierungsrate, als Hotspot gezeigt.

EHRENWÖRTLICHE ERKLÄRUNG

Ich versichere,

dass ich die Master's Thesis (Abschlussarbeit) selbständig und ohne fremde Hilfe angefertigt habe,

dass ich keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe,

dass ich die Übernahme wörtlicher Zitate aus der Literatur oder dem Internet sowie die Verwendung der Gedanken anderer Autoren an den entsprechenden Stellen innerhalb der Arbeit gekennzeichnet habe.

Ich bin mir im Weiteren darüber im Klaren, dass die Unrichtigkeit dieser Erklärung zur Folge haben kann, dass ich von der Ableistung weiterer Prüfungsleistungen nach §16 Abs. 4 SPO ausgeschlossen werde und dadurch die Zulassung zum Studiengang verlieren kann.

Nürtingen, den 09.12.11

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Katharina Löw