
Reucity
Innovative technologies
for resource efficient cities

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Innovative technologies
for resource efficient cities

lequia UdG

Universitat de Girona

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ABOUT

In the context of growing urban population and demand for gradually depleting resources, coupled with environmental crisis, a shift towards circular and more efficient management of water, food and energy in cities is a necessity. REUCITY delivers knowledge, tools and practical approaches in this direction. It provides options for restructuring and/or decentralizing the urban water infrastructure to facilitate the extraction of water, nutrients and energy from wastewater and enable their reuse in food and energy systems on site. Thus, on one hand the resources can be used for increasing the urban resilience and on the other hand this management assists the existing infrastructure by reducing the waste load.

In short, REUCITY proposes closedloop management of resources in cities, which comprises variety of concepts with the same goal. Grey water separation (all wastewater except the one from toilets) and reuse is one of those management concepts, which aims to close one part of the water cycle. REUCITY presents a greywater (GW) reuse concept based on membrane bioreactor (MBR) technology. The concept: GW separation-treatment-disinfection-storage-reuse is evaluated for hotels in densely urbanised areas. The results show good performance, economic feasibility and positive environmental impacts.

In spite of the clear benefits of closedloop concepts, there are quite a few obstacles that need to be overcome for their wider implementation. A decision support system called LoopAdvisor aims to assist the decision-making process for implementing the REUCITY vision, i.e. closedloop concepts for resources management in cities. It is composed of a database including information about technologies, economics, legislation, products and stakeholders, and combined with tools and engines capable of intelligent search for information in the database guided by selected stakeholders' requirements. The goal is to propose and rank several alternatives for achieving the objectives related to closing water and nutrient cycle at building and neighborhood spatial scale.

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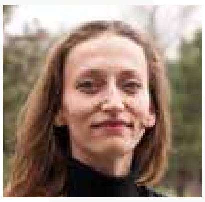

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CONTENT

1\ INTRODUCTION

Wiser management of urban water-food-energy systems will put cities at the frontline of sustainable development

Nowadays, cities are home to half of the world population and this percentage is expected to increase rapidly due to growing urbanization in emerging economies. Thus Food and Agriculture Organisation of the United Nations (FAO) projects that by 2050 the world's population will reach 9.1 billion, that is 34 percent higher than today. 70% of this population will be urban inhabitants. We know that cities are voracious consumers of resources and the growing urban population means that even more demand of water, food and energy will be concentrated in cities.

This tendency places cities at the centre of sustainable development challenge, especially if we consider climate change as an aggravating background. A wiser management of resources, connecting water, food and energy in a sustainable way is one of the key answers to this challenge. In this sense, the recovery of resources from urban wastewater and their reuse is gaining interest. However, its wider application is still very constrained mainly due to the existing linear and predominantly centralized infrastructure and substantial economic, social, and legislative obstacles. As with every major transformation, it is vital to take a systemic approach.

In the following chapters we present in more detail the problems of current urban water management and we provide an alternative vision and concepts that can help make this system more sustainable on the long run.

1\1
Conventional urban water management

Water supply and wastewater

Water is supplied to cities from various sources, surface water or ground water. Once supplied to consumers it becomes wastewater, which is released back to the environment through our collection and treatment systems.

Collection and treatment of wastewater (WW) is done in a typically centralized and linear way, starting with collecting domestic waste flows, sometimes together with industrial and storm water in same collectors ,and transporting them to a central wastewater treatmentplant (WWTP). At the WWTP, constituents like organic matter, nutrients (nitrogen and phosphorous) and partially micropollutants are being removed and the rest discharged to a recipient, i.e., river, see or other water body.

Nutrients are removed from WW by investing energy. The removal of nitrogen from wastewater requires roughly 45 MJ per kg nitrogen. In some cases only the organic matter is removed from WW and the nutrients are released to water bodies, causing eutrophication.

From a different perspective:

A settlement of 150 inhabitants produces 8 200 m^3 of water, 650 kg nitrogen and 270 kg of phosphorous, and 250 kg potassium per year, enough to fertilize 100 m^2 and produce roughly 400 kg of vegetables per growing season. If the water is recycled for nonpotable uses, it will release the pressure to the water supply system. It is important to note that small systems have better control on the sources of pollution, thus the treatment of wastewater can be cheaper.

Transporting waste to the aquatic environment using potable water is highly unsustainable

Storm water

Storm water is collected either in separate collectors and released directly to recipients or in mixed sewer system together with domestic wastewater. In the latter case, the systems need to have combined sewer overflows (CSO) with a function to overflow the excess water during rain events and protect the WWTP from overloading. The reasoning behind CSO is that the sewer system should be designed to retain the first and most polluted flush of the rain event. Later on, as the runoff increases and the water in the sewer becomes more diluted, it is 'safe' to discharge it (overflow it) to recipients. Time has shown that CSOs are a big threat for the receiving water bodies. Many of them do not even retain the first flush and during storm events, the rainwater together with the wastewater from the sewer end up in the environment.

CSO overflowing rain and WW

From a different perspective:

Sustainable urban drainage systems (SuDS) can mitigate these problems and create a multifunctional infrastructure. It is a system for urban drainage that typically uses principles of infiltration, rain water harvesting, water detention on surface and in general retaining the rainwater where it falls by using as much as possible green infrastructure. Examples of SuDS include:

- Rain water harvesting, collecting water from roofs or other impervious surfaces
- Green roofs and green walls to reduce the peak runoff
- Infiltration trenches, soakaways provide controlled infiltration and recharge groundwater

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1 **WTP** // water treatment plant
2 **Water supply system**
3 **Sewer system**
4 **CSO** // Combined sewer overflow
5 **WWTP** // wastewater treatment plant
6 **Discharge of treated WW to aquatic environment**
7 **Unintended reuse**

1\2
The food issue related to the water management

Most of the food for cities is produced in highly unsustainable agricultural systems with high impacts to the environment.

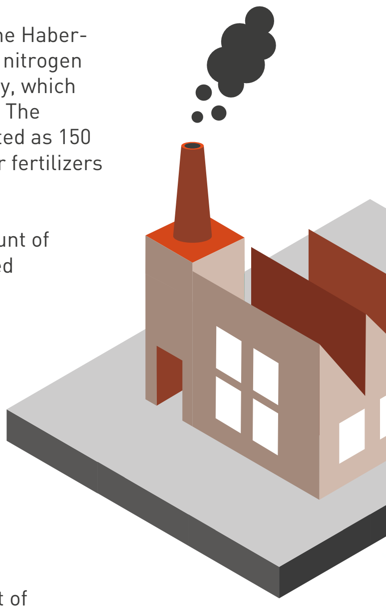
- Water and greenhouse gases (GHG): Agriculture consumes 70% of the total water use and releases a significant amount of GHG, about 30% of the total. This is the result of growing crops and raising livestock, manufacturing fertilizers, storing, transporting and refrigerating food. Much of this is due to the detachment of the food production process from the consumer
- Soil erosion due to unsustainable agropractices induces annual fluxes of 23-42 megatons of N and 14-26 megatons of P off agricultural land. These nutrient losses need to be replaced through fertilization at a significant economic cost driving in turn the unsustainable production of fertilizers.
- Pollution with pesticides and agrochemicals causes serious impacts on human health. The consequences of these practices are yet to be discovered (and experienced) by future generations, due to their persistence in the environment.

Nutrients depletion, fertilizers and eutrophication

Fertilizers used in industrial agriculture are predominantly elaborated from mineral nutrients (nitrogen, phosphorous and potassium), supplied either by mining (phosphorus, potassium) or by energy intensive processing (nitrogen from air).

The generation of ammonia from air in the Haber-Bosch process requires 35-50 MJ per kg nitrogen in the form of fossil fuel for energy supply, which accounts for 2% of the world energy use. The annual production of ammonia is estimated as 150 million tons where 85% of it is utilized for fertilizers production.

Phosphorus mining leads to a huge amount of gypsum byproducts that are contaminated with heavy metals and radioactive elements; more alarming, the forecasted phosphorus production peak is approaching in 2030, with an accelerated depletion of minable phosphorus rock.



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On the other hand, nitrogen and phosphorus in wastewater are considered pollutants, causing eutrophication and their removal requiring significant energy. In fact, most of the energy consumption in activated sludge WWTP is attributed to precisely to nitrogen removal.

2

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1 Production of fertilizers, pesticides, agrochemicals. Fossil fuels based agroindustry
2 Agriculture
3 Food processing
4 Food transport to cities
5 Discharge of treated WW, containing (N, P, K) to aquatic environment
6 Surplus of agrochemicals to water environment

2\ CIRCULAR MANAGEMENT OF URBAN WATER AND RELATED RESOURCES

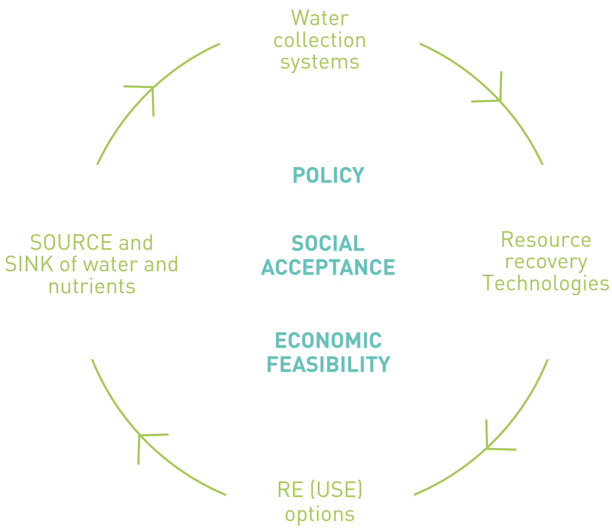
2\1 What is it?

Managing water and nutrients following the circular economy principles can significantly improve the situation in water, food and energy. Our habitats are consumers of water and nutrients (SINK) and producers at the same time (SOURCES). In order to reuse most of the products we need to rethink the whole system, starting from:

- What and how we consume, because this is what we turn into 'waste' through our metabolic processes.
- How we collect our 'waste'. There are plenty of possibilities: putting all our waste in a same 'pipe' and flushing it away, separating waste flows to grey and black water; using lowwater flush toilets, or even not using water for toilet flushing. While there is no perfect solution each one needs to be thought of as a part of a bigger system.
- Based on the collection system in place, appropriate technologies should be selected for maximal recovery of resources, including water, organic matter, nutrients in various forms and energy.
- Finally, solutions and technologies to reuse recovered resources, i.e. return them to their SOURCE, include various schemes for water reuse such as for toilet flushing or irrigation, systems for food production from recovered nutrients, or urban green infrastructure powered by recovered water and nutrients. The products from these systems include: vegetables, blended fertilizers, ornamental plants, plant biomass and others.

This kind of management brings multiple benefits and directly addresses the issues of conventional water management and the food systems. Namely:

- Circular management leads towards 0-waste cities.
- Water reuse decreases the demand for fresh water sources.
- Urban agriculture can significantly reduce the demand for industrial agriculture and all its impacts.
- Green urban spaces relying on local resources increase biodiversity, bring amenity, digest waste and regulate climate.



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Is it feasible?

In spite of the clear benefits of the circular management of resources, there are several key obstacles that need to be overcome before putting such management in practice

Legislation and policy gaps

Currently, there are no common standards or binding regulation for water reuse at the EU level. The EU does support this practice via several community initiatives but the level of reuse and appropriate standards is up to each Member State. Local standards for water reuse are most notably set up in Cyprus, France, Italy, Greece, Portugal and Spain. In many countries, solid products from wastewater that could be used as fertilizers are considered as 'waste' and administrative effort is needed for turning the 'waste' to 'product'. Finally, there is no EU legislation to stimulate urban agriculture and it is not integrated in the Common Agricultural Policy.

Present day valuing system: economic feasibility

It is wellknown that investments in sustainability cannot be valued only through conventional monetary approach, because numerous environmental benefits are non monetary and are not taken into account. Given the planetary environmental situation, the primary goal of circular economy should be resource security, not profit, and therefore our valuing systems should take this priority into account. Therefore, multiple stimulations are needed for the investors in order for such solutions to be implemented. In particular, multifunctionality of systems that apart from their waste conversion function have a recreational, aesthetic and climate regulation function should be stressed. Some recycling schemes (e.g. water saving) are however already economically feasible and there is a growing interest in their application, particularly in water scarce areas. For a wider application of circular management of resources, strong commitment of governments and decision makers is necessary.

Risk of micropollutants and pathogens in food: obstacle or driver?

Micropollutants and pathogens are a legitimate concern if we want to reuse products from wastewater. This, however, should be seen from a broader perspective: wastewater contains micropollutants because they are deeply embedded in our way of living. Thus, most of these pollutants enter the sewer system as a result of human activities, they are transported to a WWTP but they are not successfully removed there. Eventually, they end up in the rivers, from there to biota and consequently to our food. In fact, the entire process of food production is quite concerning: food products can be contaminated at any step, from food growing to food processing, conserving, storage and delivery to consumers. Moreover, when it comes to fish, the contaminants enter food products from the environment that had been previously contaminated by anthropogenic activities or with wastewater. Literature reports dioxins presence in meat and dairy products. According to the European Food Safety Authority (EFSA, 2008) polycyclic aromatic hydrocarbons (PAH) are found in many food products, most notably in cereals and cereal products and vegetable fats and oils. Pesticides are also present in large proportion of agriculture products. Moreover, many other organic micropollutants, besides pesticides, may enter biota and food products.

Considering all these threats, why should wastewater reuse be so concerning? Actually, if managed properly, the products could arguably be safer due to:

- Sources of micropollutants are much easier and better controlled in smaller systems. With a proper quality control, awareness rising and proper reuse technology small systems can provide safe and healthy products.
- By producing fertilizers locally, from onsite resources and in controlled environment, while handling food locally, we can limit the need for transporting, storing and conserving, thus avoid many pollutants otherwise present in our food in the businessasusual food production system.

Existing infrastructure

Closed-loop concepts require changes in the existing infrastructure, associated with additional costs. For example, GW separation needs its own piping which sometimes represents 40% of the total costs of separation, treatment and reuse. Water supply systems are designed to conduct ~200 l/PE day. If we reduce the water use, i.e. less water circulating in the system, there is a concern that the quality of the delivered water may lower due to longer retention times. Similarly, lower volumes of wastewater diverted for treatment may have higher concentration of contaminants and solids, which could affect the treatment process at the existing WWTP. It is necessary to assess the impact of reuse measures to the existing water infrastructure.

Social acceptance

Dealing with wastewater requires a considerable effort to raise awareness and social involvement in the whole process.

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3\
CASE STUDY: ATTEMPT TOWARDS CIRCULAR WATER MANAGEMENT IN LLORET DE MAR

3\1
Water resources management in Lloret de Mar

Lloret de Mar, together with Tossa de Mar and Blanes constitute the main touristic towns of South Costa Brava, one of the most important touristic regions in Europe, with up to 350,000 population equivalents of treated wastewater. In 2013 Lloret had 1.5 million visitors and 5 million overnights. Its hotel capacity was 30,000 beds and more than 120 establishments.

Lloret de Mar municipality (47.87 km^2) consists of the town and a number of neighborhoods and housing developments (39 in total) distributed throughout the municipality, leading to a very dispersed territory. Within its municipality there is a total of seven beaches with a total of 7km of coastline, which explains why Lloret is one of the most important tourist destinations in Catalonia, Spain.

Generally speaking, water resources in the Mediterranean region require a special attention due to rain scarcity in the summer months, which coincides with increased water demand due to tourism as a major economic activity in many towns. This situation not only represents a pressure to the existing water resources, but also to the functioning of the water infrastructure itself, having to serve up to 6 times larger population size in the tourist season. Lloret started experiencing this already in the 1960ies with the growing tourism, which triggered one of the fastest developments in Costa Brava. It was also one of the first municipalities to recognize the insufficiency of the water supply sources for the new conditions and started looking for other solutions: by the 1980 the water supply network was extended outside the municipal borders, i.e. it reached 16 km to the south, to the Tordera aquifer. In 2002 a desalinization plant opened and in 2008 the wastewater treatment plant (WWTP) adopted the traditional tertiary treatment that produces higher quality reclaimed water suitable for multiple nonpotable uses.

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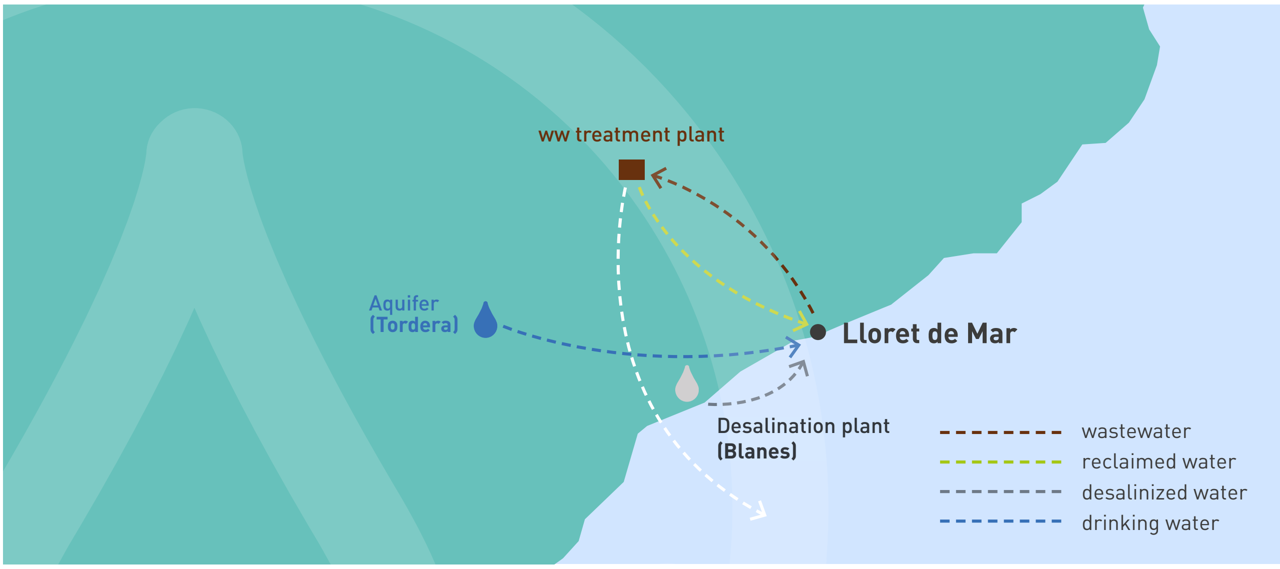
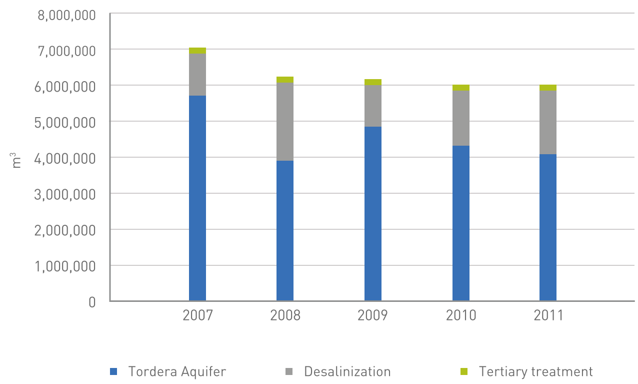


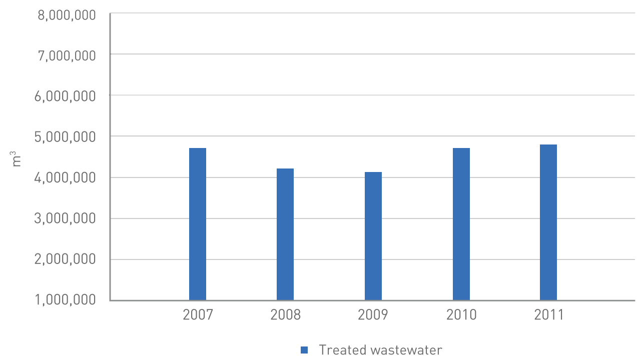
2015	February m³ /day	July;August m³/day
wasterwater flowrate	5800	15,645; 17,400

The portion of WW coming from tourist facilities is more then 10,000 in the dry months. At least half of it is grey water that could be separated and recycled. Thus, roughly 30% of the total consumed water could be managed in a cycle, if the GW from the tourist facilities was separated and reused!

Sources of water supply



Treated wastewater



Today Lloret is fulfilling all water needs from three sources: Tordera aquifer and desalination plant (potable water) accompanied with reclaimed water (for nonpotable uses). All sources have different energy demands, the most expensive being the desalinized water. Reclaimed water can significantly reduce the need for desalinized water and this has obvious advantages but also limitations. Firstly, producing reclaimed water to meet water reuse legislative requirements can be costly. Secondly, the water is reused for nonpotable purposes, meaning that the existing water supply infrastructure cannot be used. Instead, new conveyance system was built to bring the water from the wastewater treatment plant to the city. Nevertheless, it is a solution that substantially helps the existing infrastructure function under all conditions.

The Lloret de Mar WWTP is an activated sludgebased WWTP that has the capacity to serve a population of 185,000 inhabitants from a centralized collection system from the municipality of Lloret de Mar. The average flowrate in 2015 was 10,200 m³/d, with a very important seasonable variability (going from 5,800 in February to 17,400 m³/d in August). The WWTP is a conventional activated sludge system with oxidation ditch biological reactors and anaerobic digestion for suspended solids and organic matter removal. Part of the effluent is tertiary treated and reused for irrigation of private and municipal gardens and golf courses while the rest, so most of the nutrients, is discharged to the Mediterranean sea (94,487 kg N and 12,286 kg P per year in 2015).

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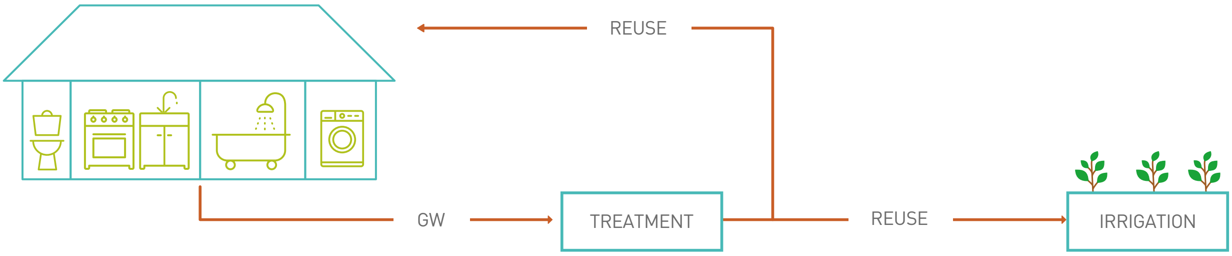

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Greywater separation in Hotel Samba

Why reusing greywater?

- Greywater (GW) is the water coming from showers, hand washing basins, laundries and kitchen. It constitutes the larger (50%-80%) and less polluted part of the WW.
- Separating, treating and reusing grey water not only represents additional (and stable compared to rainfall) water source, but also a way towards sustainable urban water systems. Apart from saving water, it can reduce the load on wastewater (WW) disposal systems, support the cities' green infrastructure and indirectly bring benefits such as amenity, cleaner air, urban agriculture, and if used for heat recovery they contribute to energy demand reduction. Therefore, GW separation and reuse should not only be seen as alternative water source for water deficient areas, but they can trigger more sustainable use of other natural resources as well.
- There is a range of technologies for GW treatment – depending on the final use of the effluent

Hotel Samba

Hotel Samba is a large 3 star resort with 441 air conditioned rooms, green areas and exterior pools, conference rooms, bar and restaurant in the Costa Brava area (Lloret de Mar, NE Spain). In the past the water consumption at the hotel was very high, which triggered measures for water savings. Already in the 1990ies the hotel was advised that the biggest water consumption comes from toilet flushing. To reduce this particular consumption, the hotel separated the GW from rooms' showers and handwash basins. This water is gridded, collected in a GW tank and reused for toilet flushing. At the moment the GW is only being disinfected (with HClO, free Cl at around 2 mg/L) prior to its reuse. Today the water consumption of the hotel is on average 128±35 and 67±20 m^3/day in the high and low touristic season respectively. In average the hotel saves 10 000 m^3 of fresh water yearly due to GW reuse. The treatment of the GW however, appears not always sufficient as there are episodes of odor in summer, which then triggers more chlorine disinfection.

Biological treatment is proven to be better, that is a more efficient option. A membrane bioreactor (MBR) for GW treatment was tested in hotel Samba, to provide high quality water for reuse with multiple benefits and feasible uses.

The pilot MBR at hotel Samba

The pilot plant consists of an entrance tank, a membrane compartment, an aerobic/anoxic reactor (optional), a permeate tank/wash and several pumps. The membrane was a ZW10 submerged ultrafiltration hollow fibre (UFHF) membrane module (Zenon/General Electric) with a nominal pore size of 0.04 µm.

The pilot plant was equipped with a monitoring and control system to be able to constantly check its performance. So, the transmembrane pressure (TMP) values, pH, temperature, dissolved oxygen and several controls on pumps and levels the reactor were stored in a supervisory control and data acquisition (SCADA) system.

The MBR was operated during a period of seven months, from November 2015 until July 2016, with the aim to achieve high quality of the effluent, while minimizing the energy consumption.

Advanced airscour control system was implemented in the pilot plant for GW reuse. The control system modifies the membrane air scour flow rate based on the permeability evolution, which is used as an indicator of the membrane performance and the sludge characteristics.

References · SmarAirMBR®, Patent reference: ES 2333837, 2010

3\3
MBR technology for GW treatment and reuse

MBR operational parameters

The MBR was operated with parameters as shown in the Table below. The MBR performance was monitored by regular sampling (3 times per week) for offline analysis of water quality parameters at the inflow, in the reactor and at the outflow of the MBR, during the whole period of operation. Standard organic, nutrients, pH, alkalinity, conductivity, turbidity and solids were analyzed. Additionally total count, total coliforms, Legionella spp., nematodes and intestinal enterococci were analyzed three times along the experimental period.

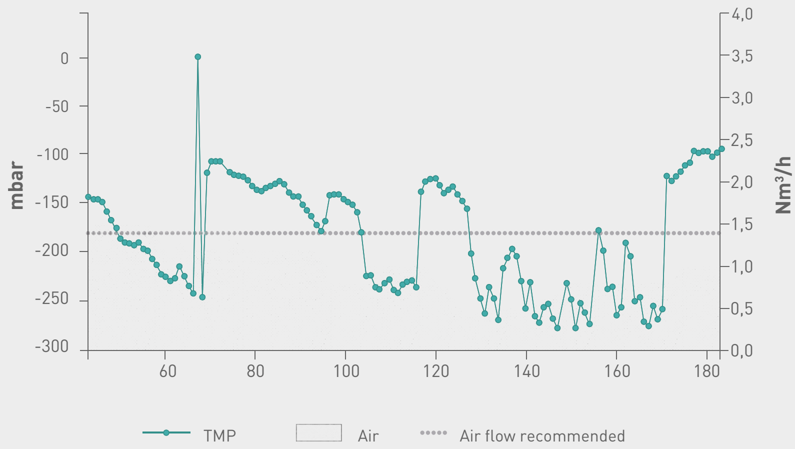
Membrane cutoff	0.04 μm
Membrane surface	0.93 m^2 * 2 modules
Cycles	10 minutes permeate, 1 minute backwashing
Input flow	40 L/h or 1 m^3/day (cca. 15 PE)
Flux	20 LMH per membrane module
HRT	4 h
SRT	22 days
Purge flow	78 L/d
Air flow	from 3.5 optimized to 0.5 m^3/h
SADm	from 1.88 to 0.25 $Nm^3/m^2/h$
SADp	from 94 to 13 Nm^3/m^3

MBR performance: Effluent quality

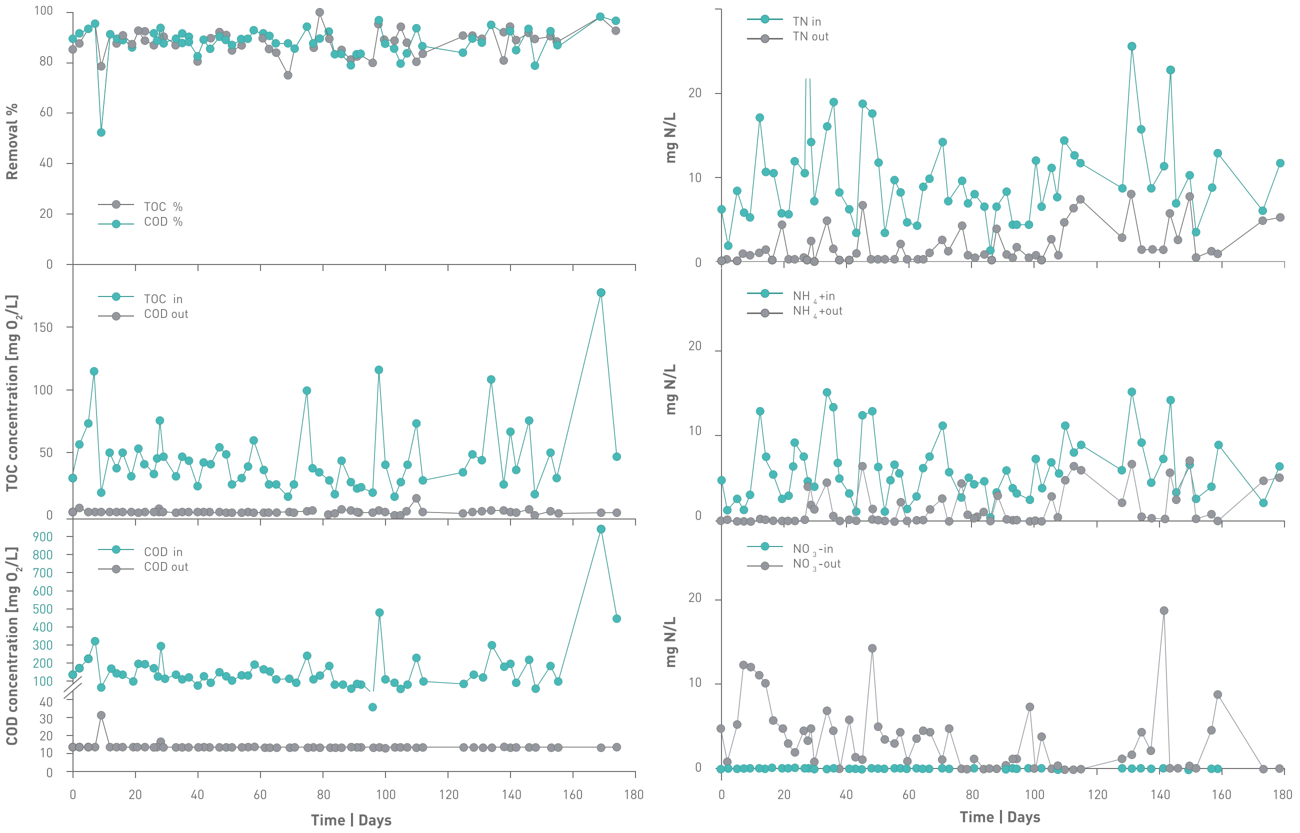
The removal efficiency for COD ranged from 80 to 95 %, where COD concentration in the effluent was below the quantification limit (30 mg/L) with a single exception of 36 mg/l. Ammonia removal was not always stable but on average at high level (80.5±32.2%). Based on the Spanish legislation for water reuse the MBR was always complying also the most restrictive scenario (aquifer recharge) in terms of nitrate (i.e. always lower than 25 mgN/L) and in most of the case (85.1%) in terms of TN (with a limit of 10 mgN/L). It needs to be stressed though, that Nitrogen is not removed but only nitrified. So, the compliance with the aquifer recharge legislation is due to low nitrogen content in the GW, which is normally the case. Pathogen removal was between 3 and 5 logs.

MBR performance: Energy

The major cause of high costs of MBRs is membranes fouling, accompanied with higher requirements for aeration and consequently energy demand. More than 50% of the energy consumption in MBRs goes for air scour to prevent the fouling of the membranes. Specific aeration demand (SAD) for membranes varies significantly from one application to another. Recommended SAD for the MBR pilot was 0.75 $m^3/m^2/h$, which was reduced significantly, using the airscour control system, i.e. up to 66.7 % average being 35.2%, without affecting the standard parameter removal



MBR performance



		Total count	Total coliforms	Escherichia coli	Intestinal Enterocci/Nematodes*	Legionella spp.
		CFU/100 mL	CFU/100 mL	CFU/100 mL	CFU/100 mL	CFU/100 mL
GW	Day 1	$4.1 * 10^{7}$	$3.0 * 10^{6}$	$1.1 * 10^{6}$	<1	<1
	Day 1	$4.1 * 10^{7}$	$3.0 * 10^{6}$	$1.1 * 10^{6}$	<1	<1
	Day 2	$2.6 * 10^{7}$	$4.1 * 10^{6}$	/	<1	<1
	Day 3	$1.6 * 10^{7}$	$1.9 * 10^{6}$	<1	$1.1 * 10^{5}$	<1
	Day 4	$1.5 * 10^{7}$	$1.4 * 10^{6}$	$1.3 * 10^{5}$	<1 *	<1
MBR OUT	Day 1	$1.8 * 10^{4}$	$2.7 * 10^{1}$	$2.7 * 10^{1}$	<1	<1
	Day 2	$1.6 * 10^{4}$	$1.3 * 10^{2}$	$1.1 * 10^{2}$	<1	<1
	Day 3	$5.8 * 10^{3}$	$4.9 * 10^{1}$	<1	<1	<1
	Day 4	$1.6 * 10^{5}$	$2.1 * 10^{2}$	$5 * 10^{0}$	<1 *	<1

3\4 Economic feasibility

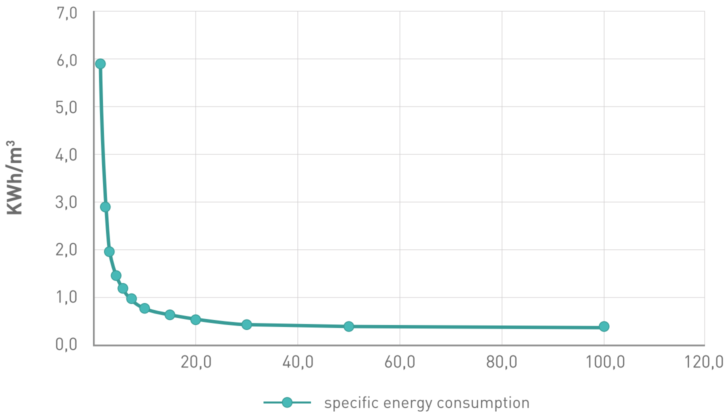
Economic feasibility of MBR based GW reuse system

A feasibility model was developed including: design of the MBR based on required volume of treated water, estimation of the size of the GW separation piping, capital and operational costs (CAPEX and OPEX), yearly depreciation of equipment as well as payback period of investment based on current water and energy prices in Catalonia (Spain) and for a planning period of 20 years.

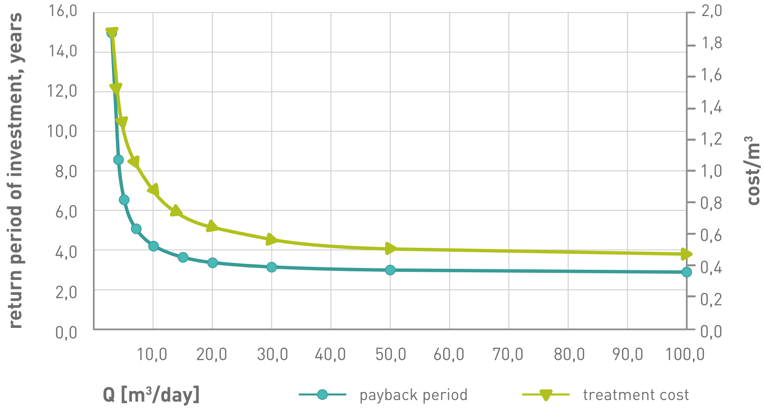
According to the model, GW separation, i.e. installation (piping) has significant part of the total investment. While economy of scale applies in investment and operational costs of the MBR technology, the installation (piping) costs are proportional to the size of application. Because of this, the cost for piping has bigger percentage of the total investment costs for bigger applications: at sizes of 3m^3/day the GW installation costs represent 25% of the initial investment (CAPEX_0) and at sizes of 30 m^3/day the percentage increases to 41%.

Q	CAPEX_0	GW separation	OPEX per year	TOTAL COSTS
(m^3/day)	MBR, piping, disinfection	% of CAPEX_0 years period	Average for 20	for 20 years
1	7,057	13	1,160	36,236
3	11,322	25	1,160	41,278
5	15,592	30	1,167	46,458
7	19,868	33	1,192	52,013
10	26,292	36	1,330	62,362
15	37,024	38	1,443	77,296
20	47,784	39	1,556	92,257
30	69,377	41	1,782	122,253
50	112,807	42	2,298	183,766

GW systems with small capacities have high energy consumption. This is not due to the actual (theoretical) power requirements but due to physical limitations of producing equipment with such small power. Thus, elements requiring power more than necessary need to be installed to systems producing small amounts of treated water, which consequently makes them more expensive.



In terms of **payback period of investment**, economy of scale is obvious between system sizes of 3 and 7 m^3/day, while systems of 1 and 2 m^3/day are not feasible. Namely, the yearly OPEX and the YD is higher than the value of the produced water per year. The return in the investment (building the GW separation and MBR treatment) for systems of 7 m^3/day or more is less than 5 years. Hotels like Samba, that could install systems for reusing 30 m^3/day, achieve a payback period of 3 years.



3\5

The GW reuse potential

Separating, treating and reusing grey water not only represents additional water source (and stable compared to rainfall), but it also opens a path towards sustainable urban water systems. Apart from saving water, it can reduce the load on wastewater (WW) disposal systems, support the cities' green infrastructure and indirectly bring benefits such as amenity, cleaner air, urban agriculture, and, if used for heat recovery, GW reuse systems contribute to energy demand reduction.

For cities like Lloret de Mar, this can be a big step towards more sustainable water management and also more sustainable and responsible tourism: on one hand the city can save a lot of water and thus release the pressure to the scarce water resources in the region and on the other hand it reduces the generation of WW significantly.

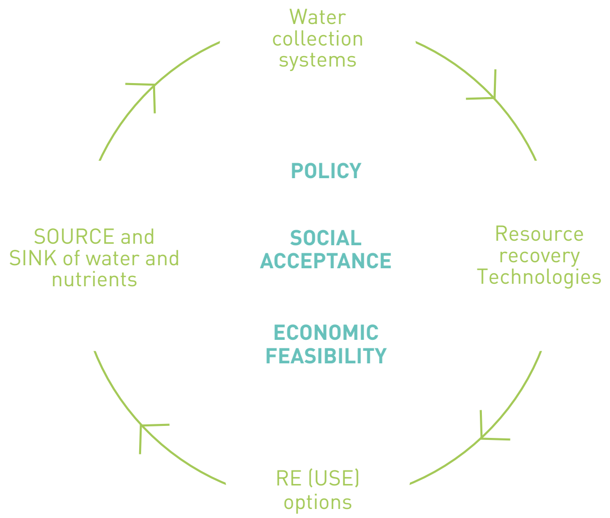
Taking into account that the amount of generated WW coming from tourist facilities in summer (Lloret has a capacity of 30,000 beds) is more than 10,000 m^3/day and at least half of it is GW, around 30% of the total WW could be separated and used in a cycle. Our research argues in favor of MBRbased systems for GW recycling in this setting, for several reasons: (1) MBRs offer high stability, quality and safety level of treated water, which is of extreme importance for the touristic offer; (2) densely populated area with high buildings/hotels makes the solution economically feasible; and (3) the flexibility for the planning of reclaimed water use: this is very important to fit into varying numbers of inhabitants at different parts of the year, i.e. in high and low touristic season. The treated water can be safely stored for longer periods (due to its very low content of organic matter, thus preventing the development of pathogens) and it can be used when appropriate and not only for toilet flushing but for other uses such as irrigation or service water.

4\ LOOPADVISOR: A DSS FOR CIRCULAR MANAGEMENT OF URBAN WATER, NUTRIENTS AND FOOD

4\1 What kind of decisions does it support and who is it for

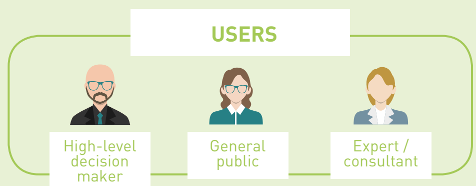
A decision support system (DSS), called LoopAdvisor assists the decision making process for implementing the closedloop concepts for water (resources) management in cities. It follows the circular approach to management at scales ranging from a single house to urban neighborhoods. There are three types of users and uses:

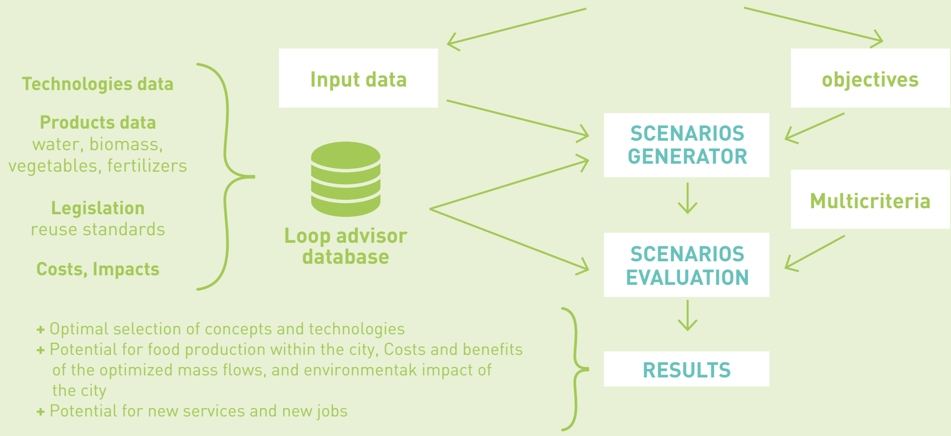
1. Experts/consultants: experts in water engineering, including technology providers. They can use the system as a guide for advising end users/customers. They can also access the database to edit existing data and insert any new technology to be taken into account.
2. High level decision-makers (in water and resources sectors) at city and regional level, urban planners. They can use it as a thorough information guide for decentralization of resources management in cities.
3. General public can use part of the system at a level of information system in closed-loop concepts.



How does it work: overview

The knowledge is integrated in a relational database, including information about technologies' properties (operation, costs), products and legislation. Based on the user's input and objectives and information from the database, treatment scenarios are generated and then evaluated in the next step against multicriteria: costs, robustness, benefits and environmental impacts.





4\2
How does it work: step by step from users' perspective

Input data preparation

The input data are prepared by the user and include the following groups:

+ land use maps (to estimate available space)
+ building type, such as: house, high building, neighborhood, hotel, camping
+ Existing sewer and WWTPs characteristics
+ Number of inhabitants
+ Energy, water, biomass and food prices

Selection of objectives and priorities

The user needs to select three types of objectives, based on which concepts and later technologies are automatically proposed

01: Resource recovery concept	02: Products	03: Ranking priorities
Water reuse	Water	CAPEX and OPEX
Water and nutrients	Fertilizer	Amount of recovered resources
Water nutrients and energy	Food	Environmental benefits
	Plant biomass	
	Energy	

Automatic generation of scenarios

The search engine, which is a part of the DSS, automatically generates treatment scenarios following these steps:

1. Select collection concept, based on Objectives 01, related to treatment/recovery
2. For each concept: Generate treatment configurations based on the compatibility between technologies
3. Filter them according to Objectives 02, related to products
4. Compose scenarios per collection concept

Evaluation of scenarios

Scenarios are automatically evaluated for the following criteria: Economical: CAPEX, OPEX, Technical: reliability, robustness, safety (for reuse), Monetary benefits including values of recovered resources (water, biomass, food and energy) and nonmonetary benefits including environmental benefits of avoided damage. They are finally ranked according to Objectives 03.

4\3
Example: closing the loop at hotel Samba

Input

Urban setting: one building, hotel

Space availability: medium

Existing infrastructure: partially source separation, grey and black water; partially mixed WW

No. inhabitants: 300 rooms, av. 300 PE

Electricity price: 0.18 EUR/kWh

Water price: 2.1 EUR

Average vegetables price: 1.5 EUR/kg

Average biomass price: 0.5 EUR/kg

Waste flows: WW, GW, BW

	WW	GW	BW
Volume, m^3/day	45	31.5	13.5

Concentrations g/m^3

	WW	GW	BW
COD	600	220	900
BOD5	350	150	400
N-tot	70	10	160
NH4	60	4	140
P	10	0.5	40
K	10	0.5	40
TSS	300	15	700

Loads [kg/day]

	WW	GW	BW
COD	27	6.93	12.15
BOD5	15.75	4.725	5.4
N-tot	3.15	0.315	2.16
NH4	2.7	0.126	1.89
Ptot	0.45	0.016	0.54
K	0.45	0.016	0.54

Select objectives

01. Resources recovery:

water and nutrient recovery from 45 m^3/day waste flow, the peaks go to existing sewer

02. Products: Food Plant biomass Water

03. All ranking priorities will be analyzed

Proposed concepts based on the expert knowledge in the Loop advisor

Concept 1. Treatment and reuse of mixed WW

Concept 2. Complete separation and treatment of GW and BW

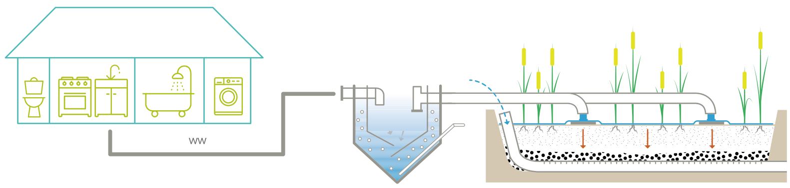
4\4
Automatically generated scenarios 4 examples

Several scenarios were generated for each concept. Four of them are presented here and evaluated.

concept 1: mixed WW

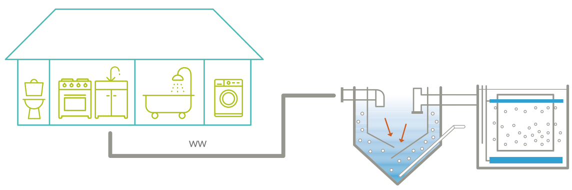
Scenario 1.1

Mixed domestic WW (45 m³/day) is treated mechanically in an Imhoff tank, followed by a constructed wetland. Products from this line are plant biomass and approx. 22 m³/day water, which can be used for various urban uses after disinfection



Scenario 1.2

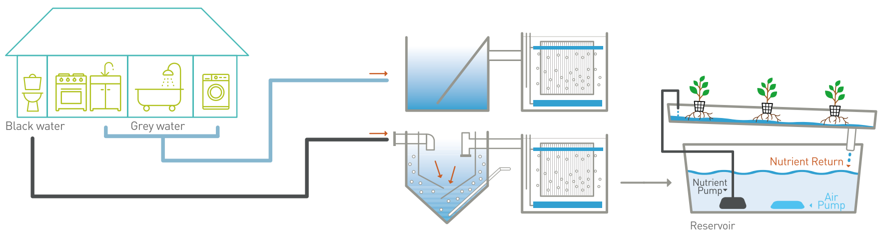
Mixed domestic WW is treated mechanically in an Imhoff tank, followed by a membrane bioreactor. Product from this line is 45 m³/day water and dissolved nutrients, which can be used for various urban uses (irrigation)



concept 2: GW and BW separation

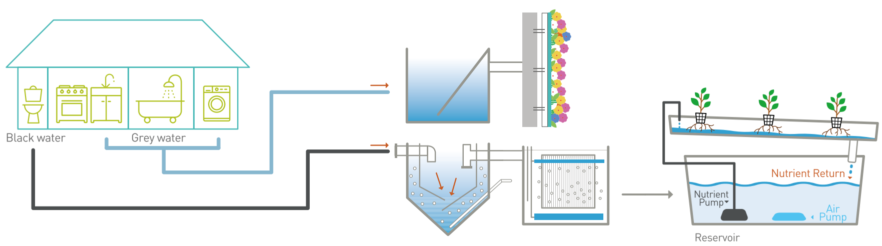
Scenario 2.1

Separated GW (31 m³/day) is treated by mesh screen and then by MBR. The BW (13 m³/day) is taken to imhoff tank followed by MBR. Treated effluent from the MBR is used as liquid fertilizer in a hydroponic system. Products are: 31 m³/day of high quality water for urban uses (toilet flushing, irrigation), approx. 11 tonnes of vegetables/year.



Scenario 2.2

Same as scenario 2.1, except the GW line is treated by a green wall. Products are 23 m³/day water for urban uses (toilet flushing, irrigation), plant biomass, and approx. 11 tonnes of vegetables/year.



4\5
Evaluation of scenarios

Evaluation (economic and environmental)

The evaluation of the four scenarios shows advantages and disadvantages of each, according to different criteria.

1. CAPEX and OPEX

The two scenarios of the concept 2, source separation, have somewhat higher CAPEX and OPEX, particularly the scenario 2.1. However, the monetary benefits are also higher. In terms of CAPEX and OPEX the cheapest scenario is 1.1 and the most expensive 2.1.

2. Resources recovery

Water and nutrients in the scenarios of the concept 1 are used for irrigating of nonproductive landscapes (in terms of food), where part of them end up in the environment. Scenario 1.1 can provide **4 tonnes** of plant biomass and 27 m^3/day of reclaimed water, while scenario 1.2 produces 45 m^3/day of reclaimed water. In turn, both scenarios in the concept 2 produce high nutrient concentrations in the treated blackwater, which is conveniently used in intensive food production system. Thus, most of the nutrients are converted into food. Scenarios 2.1 and 2.2 indicate that approximately **11 tonnes** of vegetables can be produced annually, while treating the WW at the same time and providing 23 m^3/day of reclaimed water for various urban uses (toilet flushing, irrigation). Taking into account the monetary values of the recovered products and the CAPEX and OPEX of the scenarios, the investment of scenario 1.2 is returned in 8 to 10 years, while the investments of the other three scenarios in 4 to 6 years.

3. Environmental benefits

Environmental benefits of scenarios 1.1 and 1.2 include avoided discharge of nutrients, 500 and 700 kg of N and 15 and 90 kg of P per year respectively. In addition to nutrients discharge avoidance, which is higher, scenarios 2.1 and 2.2 include benefits for avoiding unsustainable food production: approximately **3000 m^2** of land use, roughly **900 kg/year of mineral N** production corresponding to **35 000 MJ/year** of energy and **0.4 kg of pesticides** with all their impacts. Thus, in terms of environmental benefits scenarios 2.1 and 2.2. are more favorable.

5\

CONCLUDING REMARKS

Towards circular management of resources in cities

Urban water is a valuable resource and we can and should use it more wisely than we presently do (use-treat-dispose). A shift towards circular management of urban water is viable and economically feasible. In particular, GW separation and reuse in water scarce areas can significantly mitigate the pressure on fresh water resources in economically acceptable way, where sitespecific conditions dictate the selection of the most appropriate technology.

Moreover, circular water management can trigger a change in the management of the closely related food and energy systems. Food production systems can be a core part of the urban water management. This requires a shift towards a cross-sector, resources management. The water-food-energy systems act as sink for nutrients from wastewater, while producing food and plant biomass at the same time. In spite of being a useful part of the treatment and reuse process, urban food production plays a major role in reducing the ecological footprint of cities. It mitigates soil loss, pesticides, agrochemicals and fertilizers application thus, avoiding their leakage to groundwater and significantly reduces water use. Consequently, energy demand can be reduced as demonstrated in this research: less energy demanding fertilizer production, less transport (food miles), less energy for running industrial agriculture systems and of course less GHG emissions.

Shifting towards circular urban resources (waterfoodenergy) management is a way to introduce high quality urban lifestyle and more importantly, to significantly improve the living conditions in many parts of the world, without compromising the ecosystems and their services to humans of today and tomorrow.

6\ ACKNOWLEDGEMENTS

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