# LIFE CYCLE ASSESSMENT OF DECENTRALIZED URBAN WATER MANAGEMENT SYSTEMS

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## ABSTRACT

Modern decentralized water-aware technologies, including for example grey water recycling and rainwater harvesting, enable water reuse at the scale of household or neighborhood. Such options reduce the pressure on the infrastructure and alleviate the need for upgrading, hence reducing the cost of urban growth. However these practices are widely ignored by public planning authorities, architects or engineers. In order to define and evaluate possible approaches and methodologies, a comparative life cycle assessment (LCA) study of conventional and decentralized practices was carried in order to provide practical data and information and to communicate the complex issues of environmental impacts at various levels to the stakeholders and decision-makers.

The study analyses a typical conventional system and a system practicing grey water treatment and recycling, for use in the WC and garden irrigation, at household level. The functional unit is the treatment of wastewater generated by 8 persons, in 1 year, living in 1 two storey house. The wastewater flows are distinguished into "black water" generated by WC, kitchen sinks and dishwasher, and "grey water" generated by wash basin, bath and shower and washing machine.

The quantities and composition of these inputs are based on actual measurements in typical Greek urban households, carried out by the study team, (Andreadakis et al., 2015) and supplemented by bibliographical information (Almeida et al.,1999; Vinnerås et al. 2014) . Wastewater treatment corresponds to minimum pollutants removal efficiency, imposed by the 91/271/EEC Directive. Grey water is treated at the household level by membrane bioreactor technology (MBR). Sludge arising from the treatment of wastewater is stabilized by anaerobic digestion, dewatered to 20% dry solids and applied for land farming. The fertilizing function of sludge and of the related advantages in term of avoided use of chemical fertilizers is not considered in this LCA. Biogas is burned in a dual fuel engine to produce electricity and heat. Electricity is used to supply part of energy requirements in the plant, while part of heat is used in the digester and to satisfy other needs. The infrastructures, i.e., hydraulic piping in the households, sewer network and wastewater treatment facilities are also included in the analysis.

**Keywords**: Wastewater treatment, life cycle assessment, decentralized management, grey water, environmental impacts, energy footprint.

## 1. LCI Inventory

The software GaBi 6.0 (http://www.gabi-software.com) was used for the LCI. The methodology is compliant with the ISO 14040–14044 standards (Guinée, 2002) and follows the current state of the art of attributional (descriptive) LCA. Background data are issued from the GaBi 6.0 Education database and other open source databases (https://nexus.openlca.org/databases).

Foreground data are based on literature values from reliable sources (Doka, 2009, Benetto et al. 2009), which have been checked and reviewed as detailed hereafter and elsewhere (Katsiri, 2015). Inventories for sewerage and wastewater treatment (WWTP) infrastructures were adopted from Doka, 2009. These inventories are per km of sewerage system and $m^3$ of wastewater treated respectively.

Building piping was adapted from Remy, 2006 and the MBR system was inventoried from manufacturer's data. A service life of 100, 30, 40, and 10 years was adopted for the sewerage system, the WWTP, the building and the MBR respectively. This is an important assumption as it influences the contribution the infrastructure has on the overall life cycle of the system. The actual values adopted were based on Swiss data of class 4 systems (5,000 to 15,000 inhabitants), and is based on 5.7 m of sewer per capita, and 3.1 x $10^{-8}$ parts of a WWTP/$m^3$ of wastewater treated.

Transfer coefficients of carbon, nitrogen, phosphorous, sulphur and heavy metals along the various stages of wastewater and sludge treatment were used to characterize the fate of main constituents during operation, and to estimate respective emissions to air, water and agricultural land (Table 1). Transfer coefficients to sludge for heavy metals were assumed to be 50% for cadmium and chromium, 60% for mercury, 70% for nickel and zinc, 75% for copper, and 90% for lead. In addition waste heat is produced from the mineralization of biomass and the incineration of biogas. Auxiliary materials include chemicals for phosphate precipitation and sludge thickening and dewatering. Electricity consumption for WWTP and MBR operation are both waste specific and general (pumps, motors, etc). Electricity and heat production are also waste specific.

## 2. Results and interpretation

LCI results showed that net energy consumption for the conventional system is allocated as 74,3% to WWTP operation, 19,1% for tap water production, 4,4% for sewerage system construction, 2% for WWTP construction, 0,30% for building piping system, whereas energy use for end of life sewerage and WWTP infrastructure is negligible. The grey water system achieves a 23% overall reduction in energy consumption and a 40% reduction in energy consumption for tap water (see figure 1).

**Table 1:** Transfer coefficients in wastewater and sludge treatment

| | **Wastewater treatment** | | | **Sludge and biogas** | |
|---|---|---|---|---|---|
| **Constituent** | **Effluent** | **Air** | **Sludge** | **Air** | **Farmland** |
| Carbon (TOC) | 9.7% | 24.5% | 65.8% | 65% $CO_2$-C | 35% |
| TKN | 5.2% $NH_4$-N<br>15.6% $NO_3$-N<br>5.2% Org N | 49% $N_2$ | 25% | 65%, $NO_2$-N | 35% |
| P | 41.4% | - | 58.6% | - | 100% |
| S | 95.7% | - | 4.3% | 22%, $SO_2$-S | 78% |

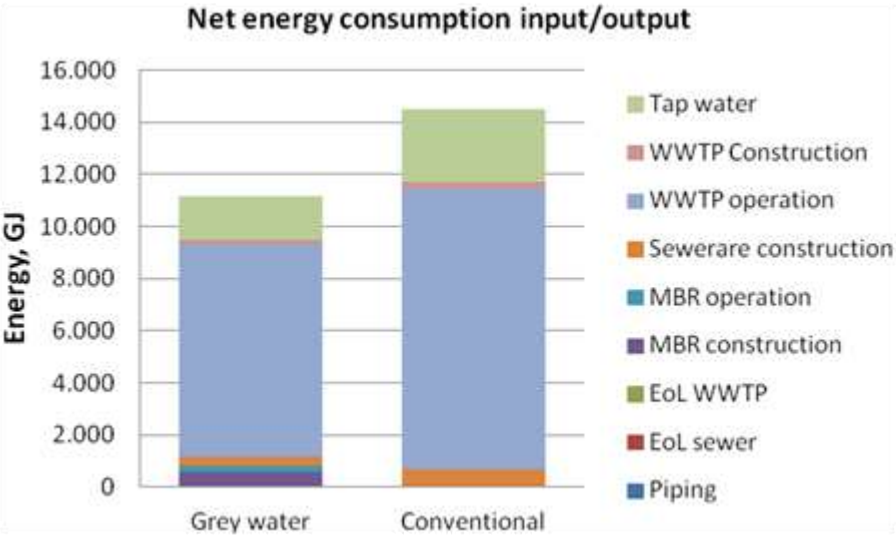

**Figure 1:** Net energy consumption.

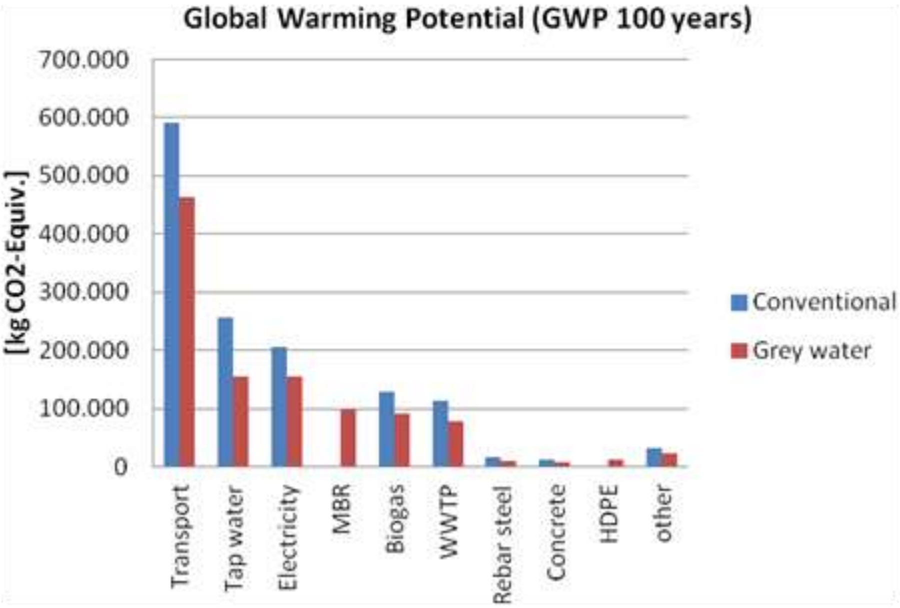

**Figure 2:** Global Warming potential by individual processes in the life cycle

A similar reduction was observed in most of the environmental impacts. The main contributor to Global Warming Potential (GWP), expressed as $CO_2$-equiv., for the grey system is WWTP operation followed by tap water production, MBR operation, sewerage network construction, MBR construction, and building pipes. Looking at the process level, the main contributors to GWP, is transport by lorry, followed by tap water production, electricity at grid, MBR operation, biogas incineration, wastewater treatment and polyethelene production. In the conventional system, steel bar production is higher in the hierarchy as a $CO_2$ contributor, (see figure 2). Wastewater treatment followed by anaerobic digestion are the main contributors to eutrophication potential (EP), and fresh water aquatic Ecotoxicity (FAETP).

## 3. Normalization

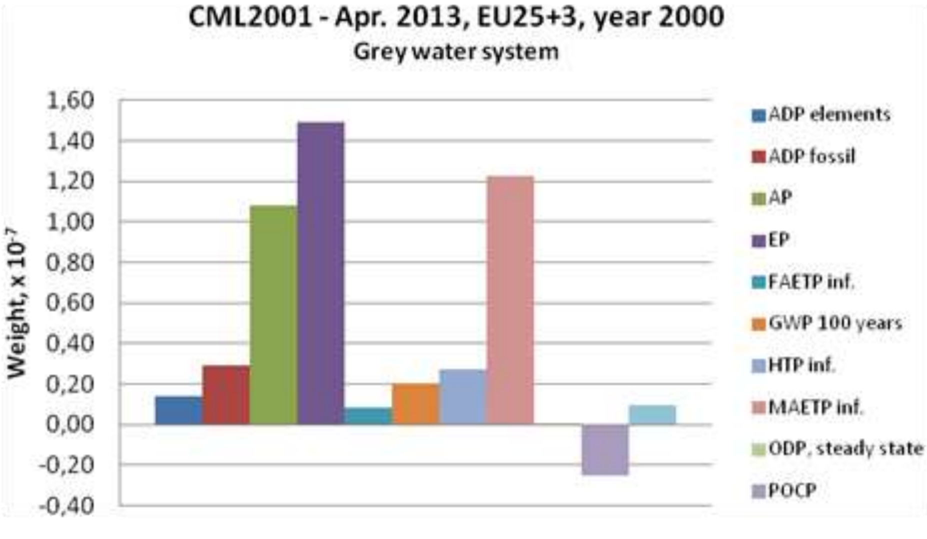

**Figure 3:** Normalization of Environmental impacts for the grey water system.

According to ISO 14042, 1999, normalization is an essential step for LCA. The results for the different impact categories are divided by their respective normalization factors for better understanding of the relative importance and magnitude of these results for each scenario under study. Normalization according to CML2001 - Apr. 2013, EU25+3, year 2000 showed that eutrophication potential (EP) is the most important environmental impact, followed by marine aquatic ecotoxicity potential (MAETP) and acidification potential (AP), (see figure 3). Calculated weights were lower by 30% in the grey water system compared to the conventional system. Only one indicator namely Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) has a higher weight in the grey water system, but its overall significance is very low in both systems.

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## REFERENCES

1. Almeida M.C., Butler D., & Friedler E. (1999), At-source domestic wastewater quality. Urban Water, 1: 49-55.
2. Andreadakis A., Noutsopoulos C., Mantziaras I.D. and Kouris N. (2015), Greywater Characterization and Treatment. IWA Balkan Young Water Professionals 2015, 10-12 May 2015, Thessaloniki Greece.
3. Benetto E., Nguyen D., Lohmann T., Schmitt B., and Schosseler P. (2009), Life cycle assessment of ecological sanitation system for small-scale wastewater treatment. Sci. Total Environ, 407, 1506-1516
4. Doka G. (2009), Life cycle inventories of waste treatment services. Ecoinvent report No. 13. Swiss center for life cycle inventories, Duebendorf 2009.
5. Katsiri A and Anagnostou I. (2014), Hydropolis - Urban development and water infrustucture: Towards innovative decentralized urban water management. Deliverable 4.3 – Environmental Impacts.
6. Remy C., & Ruhland A. (2006), Ecological assessment of alternative sanitation concepts with Life Cycle Assessment. Final report for subtask 5 of the demonstration project “Sanitation Concepts for Separate Treatment of Urine, Faeces and Greywater” (SCST), Technical University Berlin, Germany.
7. Vinnerås B., Palmquist H., Balmér P. & Jönsson H. (2014), The characteristics of household wastewater and biodegradable solid waste—A proposal for new Swedish design values, Urban Water Journal, 3(1): 3-11.