Asian Journal of Chemistry; *Vol. 24, No. 1 (2012), 339-344*

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Study of the Environmental Impacts of Urban Wastewater Recycling (Case of Boumerdes-Algeria) by the Life Cycle Assessment Method

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(*Received*: 30 December 2010; *Accepted*: 21 September 2011) AJC-10431

The wastewater recycling is proving to be an absolute necessity for dealing with ever growing needs of the precious liquid (water), so several recycling techniques are used and it is very difficult for the decision-makers to choose between those who has the least influential environmental impacts on the environment. The environmental performance of the various water recycling technologies are compared on the basis of the associated potential environmental impacts by using the life cycle analysis, which allows us more the comparison and the selection of appropriate technologies and to identify opportunities for improvement of environmental performance of the water recycling process. For the identification of the environmental impacts we used the Simapro-6 software life cycle assessment (LCA). Software provides you with a professional tool to collect analyze and monitor the environmental performance of products and services. We analyze complex life cycles in a systematic and transparent way, following the ISO 14040 series recommendations. The results of life cycle assessment are discussed in detail in the present paper and the potential domains of improvement are identified. The relevance of the life cycle assessment use in the framework of the treatment of wastewater is discussed and the limits of this method in this field are listed.

Key Words: Wastewater, Simapro-6, Recycling water, Environmental, Impact, Life cycle assessment.

INTRODUCTION

The appropriate use of urban and outer-urban treated waste water, are quickly developed and become a fundamental element of the water integrated management policy into the big towns[1] and coping the water shortage in world, which becomes more and more persistent and can worsening, so in parallel, conservation strategies of this fluid must be developed[2-4]. The wastewater recycling system can represent one of the most important alternatives to limit enormously the problem of water requirements especially in the domain where the consumption is more and more besides the recycling is in clear (net) progress. However the planning and the adoption of a good water recycling technique requires the taking account of a set of factors *i.e.*, social factors, economic and especially of environmental factors[5].

In this study we treat the environmental aspects of wastewater recycling by the application. Of the life cycle assessment, method which has the advantage to be a very effective method in determining significant environmental aspects and that it has been already used in the water and wastewater treatment[6-10]. Although water recycling strategies are designed to address the problem of water scarcity, it is vital that, in attempting to solve this particular environmental problem, we do not unintentionally introduce other problems. The water recycling technology selection which is based on the technical performance must produce effluent[11] of high quality alone may not reflect the most environmentally favourable option. This is particularly true when the recycled water is to be applied on land or released back to the environment or goes back directly to the biotope. The life cycle assessment is used here to show if the technical aspects of water recycling technologies must comply with the requirements of the norm; their environmental performance cannot be assessed when their life cycle is taken into consideration[12].

The major interest of the life cycle assessment application for environmental assessment of water recycling technologies is its holistic approach to the environment. Another interest in favour for life cycle assessment application is that its process is the subject of the standard ISO[13].

EXPERIMENTAL

Recycling technologies chosen for the study: In this case study, three wastewater-recycling technologies are studied.

Microfiltration (MFO) with an ozonation as a stage of disinfection: This process (Fig. 1) has a conventional character of waters treatment with a membrane microfiltration installation. This process find application in several countries and recycled water produced suitable for urban reuse applications and in some cases for spraying and gardening, the efficiency of this technique can be quantified by life cycle assessment, which can compare with the traditional techniques of recycling and allow to see the implications or impact of the process proposed on the environment.

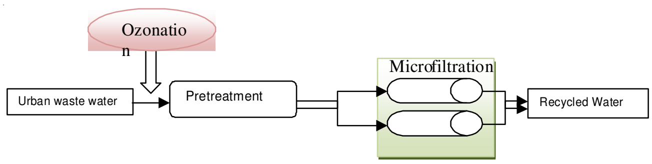

Fig. 1. Microfiltration (MFO) process

Coagulation flocculation followed by a decantation and reverse osmosis (CDRO): The reverse osmosis step is using for removal metals and organic materials, as presented in Fig. 2. The reverse osmosis technology is an genius chemical operation which gives a very high physico-chemical and bacteriological water quality if the reactor is protected by a coagulation decantation process, which remove the maximum of physico-chemical impurities (matter in suspension and colloids) and the reverse osmosis must remove the metals and very fine impurities, then the water obtained has a very high quality level. Although currently principal disadvantage remains the high cost of treatment[14].

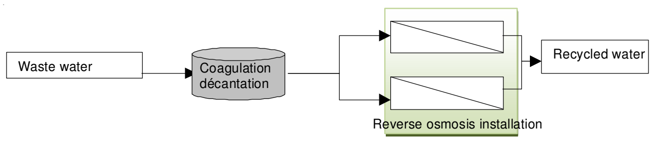

Fig. 2. A coagulation decantation and osmose reverse process (CDRO)

Biological filters station: The slowly filtration is listed in the biological treatment category. The station is composed with two types of sand filter, the particle size distribution of the first filter (Ø: 2,00 cm) is higher than the second the first filter (Ø:1,6 cm) serves for roughing and behaves as a biological reactor, because the biomass is clinging in the porosity of the filter and it will be degraded by the bacteria present in the wastewater and the second filter removal all the small solids matters. They are placed in series and the one is above on the other for the effluent from first filter is conduct directly on the second filter, by gravity (Fig. 3).

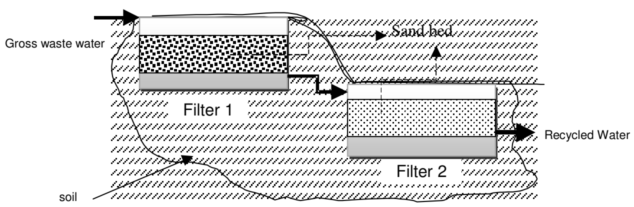

Fig. 3 Biofiltration in slow sand filter (BFS) process

This process technology treatment product a water quality which meets the specific requirements for the limited uses either to the irrigation and groundwater recharge and whose environmental impact is beneficial because this system produced a specific biotope area, the benefits of the use of this system (BFS) are the flexibility and the easily conception. Its construction is simple and economic and its exploitation at low cost and maintenance is very easy[15]. However, it should be noted that the (biological filters station) is possible only for areas not urbanized, without any restriction of the land. In this study we built a pilot filtration system, the dimensions of filters being 2 m × 1 m × 0.60 m, the height of filtration is 0.30 m.

All the three processes use both an advanced technology using the membrane technology and a simple technology based on the use of biological filtering on sand filtration so-called "slowly filtration" and the processes on study have proved their effectiveness sine a very long time in the water treatment and recycling.

The objectives of the study are both to assess the environmental performance of differents processing technologies and to assess the effectiveness of the LCA as a tool to help decision-making in the framework of water recycling.

Environmental assessment of the recycling of wastewater by life cycle assessment method: The life cycle assessment is a compilation and an assessment of incoming and outgoing materials and potential environmental impacts representation of a securing system with one or several function(s), along all its life cycle. Life cycle assessment is a tool, which allows to assess potential environmental impacts of all processes related to one (or several) product(s), service(s), conducted(s) and satisfied one (or several) function(s).

The methodological framework for the LCA has been standardized between 1997 and 2000 by the series of norms ISO 14040 [1] at [4] and includes four phases (Fig. 4).

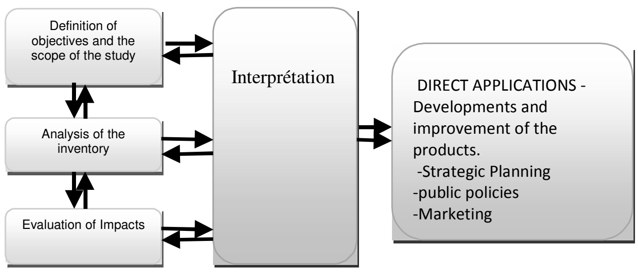

Fig. 4. Methodological framework for the LCA (ISO 14040)

1. Definition of the objectives and scope of the study.
2. Analysis of the inventory of life cycle (ICV).
3. Assessment of environmental impacts of the life cycle (EICV which includes the classification, the characterization and overall assessment of impacts).
4. The interpretation of results.

Life cycle assessment tool allows the support of the process of decision which stamp to choice and/or developed some products, processes and services more respectful of the environment, because it allows to evaluate and compare different alternative scenarios or stages of life cycle. The search for an environmental positioning of a product against its competitors is also the objective of many studies. Finally, the LCA allows to know where to act and not how to act to improve the environmental performance[16].

For the life cycle assessment study we used the version 6 of software Simapro 6, which is useful for collecting, analyzing and monitor the environmental performance of products and services.

It is possible to model and analyze complex life cycles in a systematic and transparent way, following the ISO 14040 series recommendations.

Simapro 6 can be used to screen products for environmental improvements from the first stages of development up to the realization phase. Life cycle assessment can developed for existing products to discover environmental hotspots and compare options for improvements.

It is a prospective study of water recycling technologies which can be possible to used in Algeria. Therefore, the Algerian data taken are preferred and used whenever possible.

The literature in this specific topic in Algeria (Fig. 5) is scanty so we are using previous works[17-19]. And for the microfilteration process and biofilteration in slow sand filter, trustworthy data of the literature have been used[17,20,21].

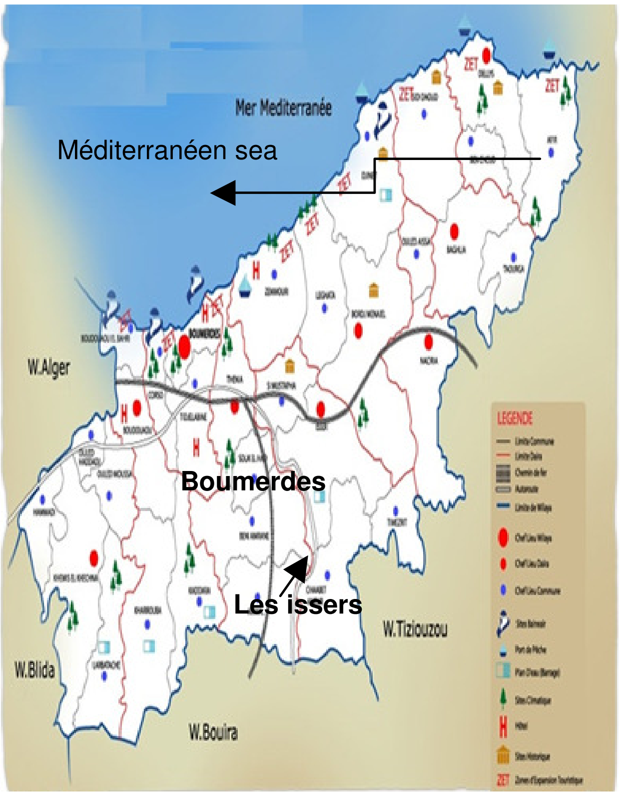

Fig. 5. Wilaya (area of Boumerdes) (Algeria)

Basic functional unit: The functional unit is considered as 5 L of recycled water intended to be used for irrigation sensitive crops such as melon and grapes[2,4,22] and which are grow in abundance in Algeria (especially in the region of ISSERS (Boumerdes, Algeria).

Assumptions: For this study we chose the treated water of the biological treatment station of the urban waste water of Boumerdes city, before being rejected in the sea located at 1 Km from the treatment station and the treated water quality is constant and it presents the characteristics of the raw water (Table-1).

The main parameters of the quality of the treated water effluent (recycled) by the three processes are presented in Table-2.

For the different channels we use for recycling water 5 L of wastewater treated by day and by sector.

TABLE-1
CHARACTERISTICS OF THE RAW WATER INTENDED TO THE IRRIGATION

Parameters of the raw water	Concentration
BOD 5 (mg/L)	198
COD (mg/L)	350
Total nitrogen (mg/L)	54
Phosphorus (mg/L)	11
TDS (total dissolved salts) (mg/L)	500
Water hardness (ºF)	50

TABLE-2
VALUES OF THE PHYSICO CHEMICAL AND BIOLOGICAL WATERS PARAMETERS RECYCLED ACCORDING TO THREE OPTIONS

	MFO	CDRO	FBS
In coming total resources (t/mL)	48	16.6	0.102
Raw materials	45	15	0.1
Energy (MJ/mL	3	1.6	0.002
Substances emitted in the atmosphere (kg/mL)			
CO_2	20	14	235
CH_4	0	0	80
SO_2	24.3	10.2	0.018
NO_X	2	0.45	0.021
CO	3.1	0.65	0.04
MES	1.90	0.8	0.06
Biological Quality of the treated water (g/L)			
BOD_5	8	6	15.4
COD	55	11.3	350
N total	5.55	6	8.1
P total	4	3.5	4.65
Waste (kg/m^3)			
Sludge producted	1.16	2.6	4

The transport of raw sewage in treatment site has not been taken into consideration, because it is common for all the treatment options.

The sludge produced must be treated and recycled as biological solids for the biofilteration in sand filter process, the mud (biomass) formed in the bed of sand can be eliminated periodically and a very spaced in the time. This technique can harm the material balance because the sludge obtained from this process have a better quality than the microfilteration and the coagulation decantation reverse osmosis process because the relatively absence of heavy metals. However, any estimate of the sludge quality from biofilteration in sand filter channel can not be very credible because the typical performance, of biological filters, is highly variable.

The biofilteration in sand filter system is works for optimum performance in an optimum temperature of 23 ºC

For coagulation decantation reverse osmosis system, it is assumed that all the elements traces and heavy metals deleted by the reverse osmosis are tabled in a discharge responding to safety standards.

System boundary: As shown in Fig. 6, departure of the system begins at point of entry of untreated water between the range of water recycling treatment of and ends when the treated water leave the water recycling channel and it's ready to be used for purposes for which this water has been treated. The wastes are treated and eliminated according to the conventional proceedings.

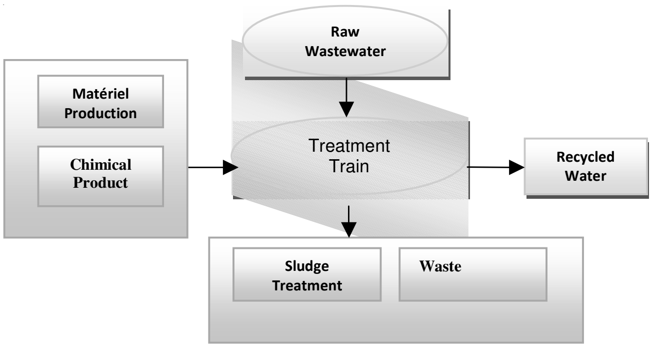

Fig. 6. Case study system boundary

The study covers the basic processes of the three tracks study subjects including the use of energy and chemicals products used in the recycling treatment, then the costs associated with transport vehicles and the equipment off-site are not supported.

Evaluation of the life-cycle impact: The evaluation of the life cycle impact of the conception phase and the water recycling process preparation are included in this study, but excludes the treatment and storage of sludge and handling facilities are assumed to be the same in all options.

The life cycle impact of these latter activities is normally small compared to contributions from other activities[6,7,22] because these operations are supposed to be identical for the three process.

We use the software SimaPro 6, it can handle advanced inventory techniques, but at the same time easy to use. There is even a dedicated LCA wizard that define the data model, by answering a series of questions. SimaPro comes with very large and up to date datasets. SimaPro 6 process records can be used for systems and unit processes, as well as input output data. Each process record, can have multiple outputs; each with an allocation percentage. It is also possible to combine this way of allocation with avoided products (system boundary expansion). Inputs can come from nature or technosphere. These links can both be expressed in physical units and financial terms, allowing to make hybrid data models that combine input output and traditional processes. In this respect it is important to notice that loops may be modelled, as the calculation routines use matrix inversions. In each process record, emissions can be specified into air, water, soil, but it is also possible to specify solid waste and waste streams (gas, liquid and solids) can be linked to a waste treatment. Emissions can be defined using the sub compartments used by eco-invent (*i.e.* emission in high and low population density can be separated). All inputs and outputs can contain uncertainty data, specified as lognormal, normal. These uncertainties can be evaluated in a Monte Carlo analysis. Many documentation fields are available[24].

During the operation, all the activities carried out and the resources consumed at the various fields of water recycling are included. During this phase the life cycle analysis supports the quality and quantity of chemicals products, as well as other incoming and outgoing such as raw materials and energy.

RESULTS AND DISCUSSION

Life cycle impact assessment results: The results obtained are very specific to the set of the assumptions made as such. The results presented here, should not be generalized because they may not show the 'environmental performance of processing technologies objects of this study under all conditions. The potential environmental impacts taken into account by the LCA are the eco-indicators 95V2/Europe[23]. These categories of impact have been chosen because they are the most features in terms of study of wastewater impacts on the environment and each issue is replaced by an equivalent material reference and is then evaluated from of environmental effects. For example, the impact greenhouse effect is calculated in CO_2 equivalent.

Results of the impact assessment: The results of potential environmental impacts of each process (MFO, CDRO, BFS) are presented in (Fig. 7-9).

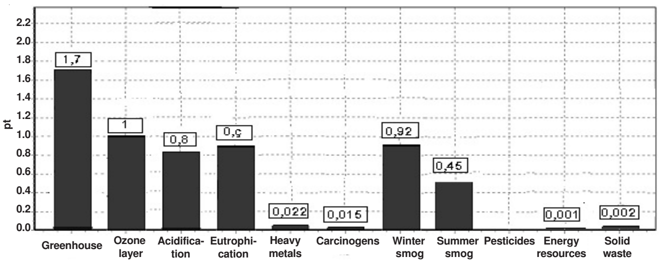

Fig. 7. Potential impact of the chain of recycling MFO

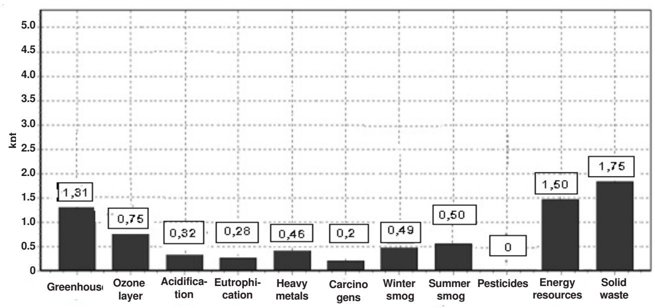

Fig. 8. Potential impact of the chain of recycling (CDRO)

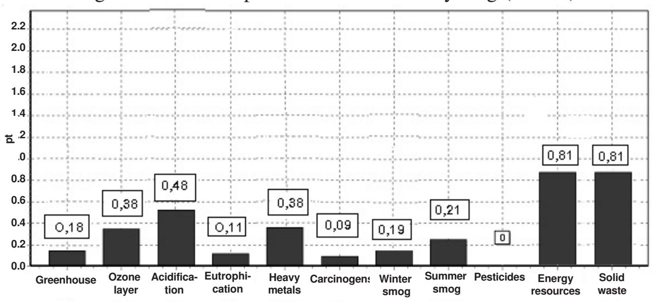

Fig. 9. Potential impact of the chain of recycling BFS

Comparison of the tracks by type of impact : Construction phase (Fig. 10).

Operating phase (Fig. 11).

Analysis and interpretation of results:

Analysis of the life cycle phases contributions: In this part, we focussed on the calculation and comparison of the life cycle impact and in particular the phases of the operation and construction. We found that the construction phase (Fig.

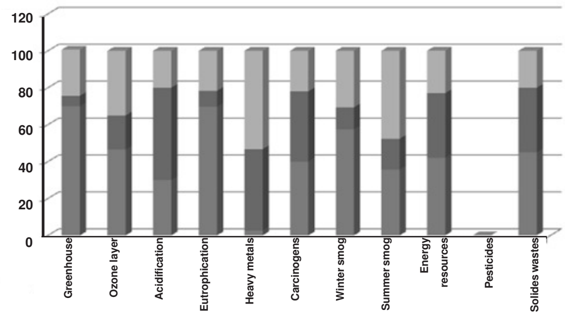

Fig. 10. Incidence of the impact type on the basis of the recycling process (construction phase).

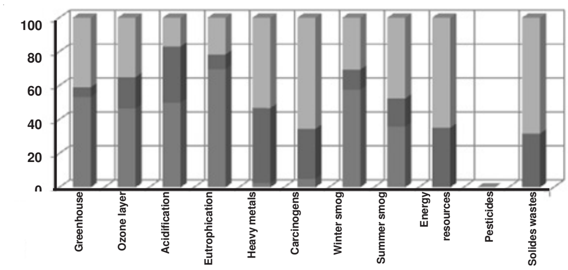

Fig. 11. Incidence of the impact type on the basis of the recycling process (operating phase)

10) have a minor contribution for each impact, except for the BFS or the percentage of environmental impacts of the construction phase for the three streams of the study is approximately 25-38 %. Gives 33 and 50 % for the waters issues of factories waste water treatment[7,23].

The toxicity whose responsibility is caused by heavy metals when it contributes less than 2 % for the three processes. The percentages of, contribution of the eutrophization impact the construction phase in the case of process (CDRO and MFO), are 16 and 20 %, respectively.

For exploitation phase (Fig. 11) and as regards the procedure based on membrane technology, we can note forward without risk and suggested that the two energy-producing channels (between 35 and 45 % of the overall impact) however the importance of the impact is low (between 0, 81 and 1, 50 potential impact unit (PI)) are processes with low energy consumption except for the biologic energy were the energy is used in the operating phase mainly for the treatment of sludge and handling.

Figs. 7-9 show the impact contributions of recycling water, studied by the eco-indicators, so the green house, the ozone layer, acidification are very important for organic process, the values are included entre 70-45 %. Then the energy resources, heavy metals, carcinogenic substances and solid waste are important for the two others channels, at last we note that the MFO processs product relatively less impacts as the two other channels but the quantity of heavy metals (44 %) is its principal disadvantage if some dispositions are not taken, to avoid that all these hazardous products will be found in the sludge and after storage,in the soil.

The life cycle analysis can give some valuable indications on environmental considerations then, in the choice of the technology or the the process that we can use in the water recycling treatment.

Even if the guidelines choice of a recycling technology, must be respected, so to get a very good quality of water recycled, does not necessarily imply an improvement in performance in all categories of impacts, without believing that the best treatment is, but the construction and exploitation costs are the highest.

It is noted that the potential of the environmental impacts determined by the life cycle analysis method can provide useful information for the protection of the environment beyond compliance with the guidelines recycling water method. So the results obtained by the use of Simapro 6 are comparable to the results of other works and study realized[7,23].

Some restrictions may affect the use of the LCA method to help the managers in choising the decision in the water topic, also the planning of the water process recycling must be recognized. These limitations include:

(1) In length period of time the problem of the accumulation of hazardous substances is not considered by the use of the life cycle evaluation, (2) The risks for human health, caused by presence of pathogenic agents are not supported, (3) Average and/or typical data is used. These limitations together with the common data quality problem encountered in LCA studies contribute to the level of uncertainty of the results. The most appropriate ways to overcome some or all of these limitations need to be further investigated to enhance the use of LCA in assessment of water recycling options.

Proposals for improving the life cycle: A number of improvements can be made according to the life cycle assessment results. Opportunities to improve the environmental performance must be subject to regulatory compliance for wastewater and biosolids recycling and applications.

The most critical identified points to be the subject of priority improvement are: (1) sludge quality and quantity and (2) energy consumption. If the maximum of recycling treated effluent and biosolids is undertaken, the increase in potential impacts on terrestrial environments is unavoidable.

This case study shows that sludge quality and quantity have a relatively high influence on the overall environmental performance of the water recycling options. The burden associated with sludge quality and quantity appears to overwhelm the environmental improvements caused by the water recycling technology. This means that efforts towards improving water recycling technology may be in vain if the associated sludge flows deliver large contaminant burdens. As such it may be crucial to consider developing an advanced sludge treatment process to separate metals from sludge, or more practically, a control-at-source strategy. If this is not feasible, consideration may need to be given to safely landfilling the sludge with high heavy metals content.

High energy consumption and greenhouse gas impacts normally come with a benefit of achieving high treated effluent quality although the cost of achieving this is clearly shown in the global warming potential and smog impact categories. On this basis, if reducing energy consumption is not possible then the option of shifting to a cleaner energy source should be study. The cleaner energy source should result in a significantly reduced level of air pollution with a resultant improvement in the environmental performance of the technology.

Conclusion

The study shows how the exploitation of the environmental tool like the life cycle assessment can be applied to assess differents waters treatment process and their possible reuse in different areas such as irrigation. The results obtained by the life cycle assessment method having used the software Simapro 6 in the field of water recycling are rich in information as regards the potential environmental impacts caused by all aspects of treatment operations. It is interesting to note that the best use of life cycle assessment in the system of water recycling system that it is very effective for the evaluation of technology process of wastewater treatment and to provide suggestions on how to improve the environmental performance of each sector. The results of life cycle assessment, indicated in the present document, suggest that the biofilteratio in slow sand filter option is most respectful of the environment friendly out of the three technologies under all impact categories for the most impacts. In general, technologies based on natural treatment processes have relatively lower environmental impact than membrane based technologies.

The use phase has a larger contribution (mainly due to electricity consumption) to most environmental impacts. The development scale has an inverse correlation with per capita impact.

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