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Cost-performance indicator for comparative environmental assessment of water treatment plants

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HIGHLIGHTS

- ► Novel indicator for fair comparison of two potable water production plants
- ► Cost-Performance is the ratio of environmental impact (LCA score) and total quality gain.
- ► Total quality gain is based on 8 parameters and on a certified water valuation system.
- ► The difference of CPs is evaluated through a t-test.
- ► Application of ReCiPe method leads to a clear advantage for one site.

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ABSTRACT

To compare potable water production plants on the basis of the environmental impacts generated by the treatment, including water resource depletion, Life Cycle Assessment (LCA) methodology is often used as referential. A comparison based only on the environmental impacts can however be misleading. Criteria for drinkability are usually defined as thresholds and the actual water quality gain achieved by different treatment chains shall be considered in the assessment for a fair comparison. Otherwise, chains treating low quality water resources could be disadvantaged as compared to alternatives using higher quality water resource, also when the depletion of the raw resource is included in the impact assessment. In this study, a novel Cost-Performance (CP) indicator has been developed and tested for the case of two existing water treatment plants located in the Paris Region. CP is the ratio between the total environmental impact generated by the treatment (i.e. the LCA score, eventually monetarised) and the total quality gain from raw to treated water. For the test case, three life cycle impact assessment methods, ReCiPe, Stepwise and Eco-costs (the latter two including monetarisation) have been considered. The water quality gain is based on 8 relevant parameters measured before and after treatment. The parameters are further aggregated using the French water quality valuation system SEQ-Eau. Paired t-test is then used to calculate the confidence interval for the average quality gain which then determines the confidence interval of the CP. Independent t-test on the CPs of the two alternative plants allows checking if their performances can be distinguished. Although in the specific test case the comparison is not conclusive, due to the similarity between the water quality gains, realistic breakthrough values have been obtained, especially using ReCiPe. The meaningfulness of the monetarisation of the LCA results has been highlighted as well.

1. Introduction

Life Cycle Assessment (LCA) is a recognized methodology to compare alternative products and processes according to the overall environmental impacts generated over their whole lifecycle. The studied products and processes have to be comparable in order to derive consistent (unbiased) results, i.e. they have to fulfil the same function or to respond to the same need on the market. While in the case of manufactured products it is often simple to guarantee the comparability of the alternatives, in the case of industrial processes the resulting outputs from alternative processes may have different composition, nature and quality. This is typically the case of processes treating waste materials. The composition of the resulting treated waste depends on the treatment process: a heavier treatment may result in a less harmful treated waste and vice versa. In an overall LCA balance, such effects are taken into account through the assessment of the impacts generated by the treatment process (via the consumption of electricity, reagents etc.) and the impacts generated by the treated waste in the environment (which will be of course less

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important in the case of a heavier treatment). For example, the Ecoinvent module developed by Doka (2007) calculates, depending on the input composition of wastewater, the lifecycle inventory of the treatment process including the direct emissions to water of pollutants which have not been completely removed. Larsen et al. (2010) compared advanced technologies for pharmaceutical removal in wastewater and calculated the net impact as the difference between the generated and avoided impacts, the latter being related to the removal of nutrients, heavy metals and pharmaceuticals. A similar approach was followed by Igos et al. (2012) to assess solutions for decentralized pharmaceutical effluent treatment at hospital.

The comparison of potable water production processes is however a special case, mainly for two reasons: i) the quality of the final product (i.e. the potable water) depends on several physico-chemical parameters and varies according to the treatment steps, despite all the minimum drinkability thresholds have to be fulfilled; ii) the heaviness of the treatment depends on the quality of the water resources, and these two elements together can lead to different potable water qualities at the end. As water resources are increasingly scarce and polluted, potable water producers need to justify any additional cost related to the treatment processes. In order to fairly compare alternative potable water production chains, it is therefore essential to weight the generated environmental impact by the actual water quality gain, from the water resource to the potable water. Bonton et al. (2012) reviewed previous LCA studies applied to drinking water production and highlights the lack of quality evaluation in the functional unit, either for treated or raw water (e.g. in Friedrich, 2001; Mohapatra et al., 2002; Raluy et al., 2005). To overcome this problem, Bonton et al. compared an existing treatment plant focused on nano-filtration with a virtual conventional plant which would treat the same water resource and deliver the same potable water in terms of organic matter content, alkalinity, pH, hardness and disinfection requirements (viruses). Apart from this attempt, from our literature review no other study expressing the gain of water quality when comparing existing drinking water production sites has been found.

The aim of this study is to propose an operational methodology to fairly compare water production plants according to the overall environmental impact generated by the treatment for an equivalent water quality gain achieved. A cost-performance indicator is developed and further tested on the comparative LCAs of two potable water production plants located along the Seine River in France (named Site 1 and Site 2, for confidentiality reasons), which are comprehensively described and discussed in this paper. Life cycle inventory is based on average operational data for the plants: for the sake of simplicity the phases of construction and decommissioning of the plants are neglected. Life cycle impact assessment considers midpoint and endpoint assessment methods, which are further monetarised and aggregated into single score results. Water quality gain is evaluated against physico-chemical parameters, measured before and after the production chain, through a statistical approach based on two main steps, detailed in Section 2.3: i) the choice of the relevant parameters describing water quality and ii) the evaluation of an average water quality gain considering all the parameters together.

2. Methods

2.1. Life cycle inventory

The inventory of the potable water production plants used as test case for the cost-performance indicator is built on primary data collection carried out by means of questionnaires filled out by the CIRSEE, the research laboratory of the water producer Suez Environnement. The inventory is based on monthly measurements for the year 2007 and 2006 for Site 1 and Site 2 respectively. Data refer to the whole plant since a detailed inventory at unit process level was not available.

2.1.1. Plant Site 1

Water from the Seine River is pumped to the plant located 85 m above the water level. Two treatment lines follow the same steps (Fig. 1). First, pre-ozonation oxidizes organic matter and improves the further step of flocculation. This reaction takes place in contact towers where ozone is injected via hydro-injectors. Two types of coagulants are used for settling (Aqualenc and aluminium sulphate), as well as a polymer (ASP25). Sludge is directly discharged into the wastewater network. The water goes then through sand filters to remove the maximum amount of suspended matter. The second line uses a filter with biolite (expanded clay material). Filters are washed by air and water, the washing water being recycled before the settler. Post-ozonation is similar to the pre-ozonation but targets in particular viruses. Granular Activated Carbon (GAC) filtration contributes to an efficient reduction of undesirable organic matter. Site 1 uses only virgin GAC, which is then reactivated and reused elsewhere. Three possible scenarios using different rationales of allocation of the impacts of production, regeneration and end of life of GAC have been investigated (SI-2.C) and finally the scenario B has been retained for the inventory. Washing water is directed to the wastewater network. After mixing, water is finally disinfected by chlorination using bleach (sodium hypochlorite). The plant also includes four additional generators supplied by fuel, which are used in case of power disconnection. The detailed inventory of primary data is provided in Table SI-1.

2.1.2. Plant Site 2

Raw water flows by gravity from the Seine River to the screener, and is then pumped to reach the operating building. First, a pretreatment by injection of chlorine, sulphuric acid, Powder Activated

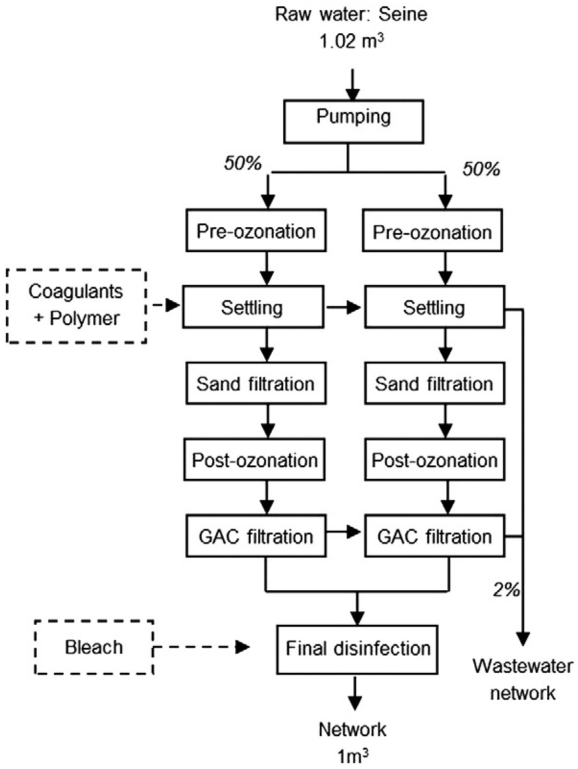

Fig. 1. Flow diagram for Site 1. Description: The figure presents the treatment line of the production of potable water for Site 1. The reagents used for each unit process are in dashed boxes. GAC is granulated activated carbon. The volumes pumped and produced are displayed, as well as the percentages for sludge treatment.