



Environmental analysis of a domestic rainwater harvesting system: A case study in France



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ARTICLE INFO

Article history:

Received 26 February 2015

Received in revised form 18 June 2015

Accepted 28 July 2015

Available online 24 August 2015

Keywords:

Rainwater harvesting
Environmental impacts
Life cycle assessment
Water footprint

ABSTRACT

Life cycle assessment methodology along with water footprint analysis was used to assess the environmental impacts of a domestic rainwater harvesting system (RWH) in France. Firstly, the relevance of substituting drinking water (DW) with rainwater in a private individual household was studied. Secondly, the effect of several parameters namely construction of infrastructures, building scale and disinfection were evaluated. The quantification of environmental impacts was performed using Ecoinvent inventory data and Impact 2002+ evaluation method. The water footprint was assessed through the water stress indicator (WSI). From an environmental standpoint, the RWH system has only slightly higher impact than the DW system. The consumption of electricity for pumping generates the strongest impact. The analysis of the WSI showed that the RWH system can relieve a stress on water resources where it exists. Consideration of infrastructures and disinfection turns environmental impacts significantly higher in all impact categories. Setting up the RWH system at bigger scale, i.e., building scale, is a bit less favoured than the RWH system at household scale. This study aims at pointing out areas of improvement which need to be further studied to make RWH systems more sustainable.

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1. Introduction

Similar to the rest of the world, France must conserve natural resources, in particular fresh water. Among the existing solutions for such conservation, the use of roof-collected rainwater has recently sparked major interest (Li and Zhang, 2010). The main idea of this solution is to avoid using valuable drinking water by substituting it with collected roof runoff.

In France, despite reluctance from sanitary authorities (CSHPF, 2006), the increasing demand from private customers leveraged the reconsideration of rainwater harvesting. Since 2008 a new decree authorises rainwater use inside buildings (French Official Journal, 2008). Currently, French law still prohibits the use of harvested

rainwater for drinking, showering or bathing, though it allows its use for toilet flushing, cleaning the ground and under certain conditions, washing clothes.

Nevertheless, this practice remains a controversial issue. On the one hand, benefits are many: harvested rainwater is a free water source for non-potable water use that reduces water stress and environmental pollution, helps to prevent floods caused by soil permeability and is perceived as an adaptive strategy to deal with the reduction of water availability due to climate change (Angrill et al., 2011; Schudel, 1996). On the other hand, researches have already highlighted an increased energy consumption due to the necessity of pumps (Anand and Apul, 2011; Crettaz et al., 1999). In addition, there may be hygienic issues with collected rainwater. As a result, rainwater used for domestic activities requires minimal treatments involving matter and energy consumption (Jolliet et al., 2010).

In this paper, life cycle assessment methodology was used along with water footprint analysis (Boulay et al., 2011a), and data on the RWH system were collected from case studies. First, the substitution of drinking water with rainwater was considered from an environmental standpoint. Second, sensitive parameters, namely infrastructures, scale and disinfection were assessed. Problematic issues that need to be further studied have been identified. This

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study complements the existing literature on rainwater harvesting targeting areas of improvement.

2. Materials and methods

LCA was performed according to the ISO 14040 (AFNOR, 2006a) and the ISO 14044 (AFNOR, 2006b) standards.

2.1. Goal and scope

This study aims at quantifying the environmental impacts of systems that use rainwater in France. It should be noted that this study was restricted to rainwater use for toilet flushing. The RWH system and the DW system have been modelled through a “cradle-to-grave” approach. The study takes place in the Garonne watershed.

2.1.1. Functional unit

The functional unit was defined as “the supply of 30 L of water per day per person for toilet flushing”. It corresponds to the average consumption per day per person for toilet flushing in France (CIEau, 2013).

2.1.2. System description and boundaries

2.1.2.1. Rain water harvesting baseline system (RWH). A commercially available domestic rainwater collection system (Sotralentz Habitat) was studied on a household of four persons. This system which permits to benefit from a tax-credit is common in France. Details of this site are provided in Table 1. Rainwater is channelled through gutters and downpipes to a wire mesh filter before entering an underground high density polyethylene (HDPE) storage tank, which moves through a calm inlet. In the event of an overflow, excess water is fed into a nearby canal. A submerged intake with an inlet filter attached to a float is used to pump water into the house. Prior to use, collected rainwater is treated by passing through a physical filter (25 μm) and an activated carbon filter. When insufficient water is available in the tank, a probe activates a valve to allow for pumping from a backup tank containing drinking water. Rainwater that is collected is available to flush 9-L flush toilets. Water physicochemical and microbiological quality was studied over one year (Vialle, 2011; Vialle et al., 2011a, 2013). The rainwater volumes collected, overflowed or used for flushing toilets were also available from a one-year monitoring campaign (Vialle, 2011; Vialle et al., 2011b). This period corresponds to a rainfall of about 766 mm distributed among 174 days and 40% of these rainy days presented precipitations inferior to 2 mm. A 5 m³ storage tank leads to a water saving efficiency of 87%. This means 87% of the water consumption for toilet flushing can be provided by the roof runoff collected. Elements considered in the system boundaries are presented in Fig. 1.

2.1.2.2. Drinking water production system (DW). The water production plant considered for the life cycle assessment is the plant that supplies potable water to the individual house studied. This plant supplies 1,400,000 m³ of potable water per year and its annual electricity consumption is 1.2 GWh. Surface water pumping is performed with three pumps (3 $\times$ 20 kWh). The process entails clarification (flocculation with 40 g of polyaluminium chloride per m³ of feed water and decantation with 10 kg of sand per day), filtration in sand filters (80 t of sand renewed every ten years), filtration in granular activated carbon filters (25 m³ renewed every five years), pH re-adjustment (1 g of sodium hydroxide per m³; 0.5 g of sulphuric acid per m³), sterilisation/ozonation (three UV reactors renewed every eight years, each containing twelve low-pressure lamps renewed every three years, with ozone produced on site) and finally, disinfection (0.5 g of gaseous chlorine per m³).

The supply is performed with three pumps (75 kWh). The different steps of the water treatment process are summarised in Fig. 2.

In the present case, the rainwater harvesting system and the water production plant are supposed to run for 50 years without renovation; therefore, dismantlement has not been integrated. The reference year is 2010.

2.1.3. Sensitive parameters

The RWH system and the DW system described previously are baseline systems. However, according to the local context, some optional processes might be added to these baseline systems in order to better suit people's needs. The different parameters assessed in this article are (i) construction of infrastructures I, (ii) building scale B and (iii) disinfection step D. Building scale and disinfection have only been studied on the RWH system, as the DW system does not depend of the scale and contains necessarily a disinfection step. More details on these parameters are described in Table 2.

The construction of infrastructures (scenario called RWH/I and DW/I) can be taken into account to assess the whole life cycle of both systems. Transportation of inputs and wastes is also included. Moreover, the RWH baseline system is set up at the household scale. In densely populated areas, buildings are predominant over household. Thus, a higher scale, i.e., building scale with a 30 m³ storage tank which leads to a water saving efficiency of 95% has also been studied and compared to the household scale. Sub processes are the same regardless the scale. This scenario is called RWH/B. A disinfection step can also be added to the RWH baseline system. Disinfection is not required by legislation when rainwater is used to flush toilets. Yet, disinfection is recommended for rainwater used inside households, in order to avoid any sanitary risks (Vialle et al., 2011a). This scenario is called RWH/D.

A first-flush diversion could have been envisaged. Such a system would without doubt result in an improvement of the quality of harvested rainwater but it would not have a major impact on LCA results as it does consume neither electricity nor consumables.

2.2. Life cycle inventory

2.2.1. Data collection

First, flowcharts were constructed for the RWH baseline system and the different options that can be added to this system (RWH/I, RWH/D, Fig. 3) as well as for the DW system (Fig. 4). Sub-processes do not depend on the scale. Flowcharts represent the stages taken into account and describe the indirect inputs and outputs as well. Data were collected for all the unit processes. Regarding the RWH system, data were supplied by the provider of the system, Sotralentz Habitat. With respect to the drinking water production, the operation phase of the plant was subdivided into the treatment steps presented in Fig. 4. First, corresponding data were collected from the plant manager. Second, all orders of magnitude were checked by water production experts. Infrastructures data of the DW system were extracted from the Ecoinvent database.

Then, the quantities of materials, energy and transport required for each sub-process were listed in a Microsoft Excel sheet. Subsequently, the data were normalised to obtain reference flows expressed “per functional unit”. Indirect energy and material flows required to produce direct inputs and outputs were extracted from the Ecoinvent Database. It is important to note that electricity required has been accounted for by considering the French average production mix. Life cycle inventory results were obtained by multiplying reference flows by emission or extraction factors from the Ecoinvent database 3.1 (Swiss Center for Life Cycle Inventories, 2014). SimaPro® software version 8.04 was used for inventorying

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