Sustainable Production and Consumption 15 (2018) 173–181

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Research article

Life cycle analysis applied to analytical methods for the detection of waterborne pathogens

Carmen M. Torres [a,*], María J. Figueras [b], Francesc Castells [a]

[a] Departament d'Enginyeria Química, Universitat Rovira i Virgili, Països Catalans 26, 43007, Tarragona, Spain
[b] Departament de Ciencies Mèdiques Bàsiques, Universitat Rovira i Virgili, Spain

ARTICLE INFO

Article history:
Received 13 February 2018
Received in revised form 6 July 2018
Accepted 11 July 2018
Available online 18 July 2018

Keywords:
Carbon footprint
Laboratory analyses
Pathogen detection
Drinking water
Parametric variability
Scenario analysis

ABSTRACT

The Carbon Footprint (CFP) of novel analytical methods for waterborne pathogens detection is calculated to evaluate their environmental impact compared to the conventional methods used so far in drinking water analysis. These new-flanged methods are developed under the EU project Aquavalens that has as objective the development of sustainable technologies to provide water system managers with tools to better control the safety of water supplies and their impact on public health.

The sources of primary data for the CFP calculation were the project partners, who were at same time part of the non-expert audience of the Life Cycle Assessment to whom the results are addressed. The new analytical methods are based on the use of two types of pathogen detection products, hereinafter referred to as analytical products: an on-line monitoring device and two ready-to-use kits for molecular detection techniques. These products were designed and manufactured by the producer partners of the project and they were tested experimentally in six European locations by different end-users partners. Specific questionnaires were designed to obtain flows of materials, energy and wastes associated to the analysis of one water sample, with special attention to packaging in the production of the analytical products and transport and energy consumption during the analytical procedure conducted.

The use phase was identified as the major contributor to the CFP along the whole life cycle of the new analytical products. Up to 66% reduction was calculated for the Aquavalens analytical methods in relation to conventional methods when pathogens from the three groups (bacteria, protozoa and viruses) were analysed. The parametric variability calculated through Monte Carlo simulation showed the effect of different praxis and management during sampling and laboratory work. The collection of the samples, and specifically the transport to and from the sampling points to the laboratory, was found to be the most determinant contributor in the total CFP. Besides, the analysis considered alternative scenarios for the type of vehicle used in the sampling transport and different electricity production mixes.

1. Introduction

The effects on the environment of pollution and overexploitation derived from the human activities is one of the most serious concerns that modern society must counteract. Within all hazard impacts, the escalation of emissions of greenhouses gases stands out due to the increasingly visible consequences resulting from the climate change. Through the EU2020 European Strategy (COM/2010/0639), the European Union (EU) shows its determination to tackle the problem and fight against Climate Change. Evidence of this are the initiatives by the European Climate Change Programme (ECCP) and the so-called "winter package" with which the EU wants to lead the clean energy transition in the member states and to reduce CO_2 emissions by at least 40% by 2030 (COM/2016/0860).

The Research and Development (R&D) projects funded by the EU explicitly require the monitoring of environmental impacts within the development of innovative products. In this sense, it has been suggested that Life Cycle Assessment (LCA) is a suitable tool for the environmental evaluation of emerging technologies developed during R&D projects (Baldasarri et al., 2016), since ISO 14 040 supports an iterative process of upgrading the LCA as new data becomes available (ISO, 2006a,b). In this context, in the EU funded Aquavalens project, new-flangled technologies, hereinafter referred to as analytical products, that integrate sample preparation and detection in the analytical method are developed to better determine the presence of pathogen in the drinking water supplies. As part of its objectives, it includes the environmental impact evaluation through the calculation of the Carbon Footprint

---

[*] Corresponding author.
E-mail address: carmenmaria.torres@urv.cat (C.M. Torres).

https://doi.org/10.1016/j.spc.2018.07.003
2352-5509/

of the new analytical methods developed in the Aquavalens project (Torres et al., 2017).

Many examples of LCA can be found in the literature applied to a variety of products and processes, from the production of nanomaterials (Som et al., 2010) to the entire economy of a region or an industrial sector (Cortés-Borda et al., 2015). The Aquavalens products integrate the necessary materials for the collection of the water sample, concentration and detection of specific pathogens. On the other hand, the system scope has to represent the implementation of the novel analytical methods that could replace the current methods used in water analysis. Although the novel and conventional analytical products have the same function, that is the detection of pathogens in water samples, the use phase implies different laboratory materials and equipment, sampling patterns and generated wastes. Therefore, even if the objective is the environmental assessment of the new developed analytical products, the LCA system describes a service that is the analytical procedure behind the application of the novel products to produce information about the presence of pathogens in drinking water samples. In this sense, the approach differs from the most common LCA studies applied to the comparison of two product alternatives where the scope is focussed mainly on the phases of manufacturing and supply chain.

As mentioned above, LCA can be applied in the comparison of alternative products or to envisage the environmental advantages that novel developments can have with respect to current technologies. LCA also allows the evaluation of scenarios for future trends in different spatial and temporal contexts. In this LCA, the CFP of the new analytical methods was evaluated in the scenario for their future implementation in water safety campaigns based on the data collected from different partners. These partners tested the new analytical products during the monitoring of sampling points in drinking water treatment plants and in the supply networks of different locations. Furthermore, scenarios of carbon footprint reduction were identified considering the type of energy used for transport (electric car) and energy consumption activities (different electricity mixes).

LCA methodology is globally recognized and standardized (ISO, 2006a,b; BSI, 2011; JRC EC, 2010; GHG Protocol, 2011). However, given the specific characteristics of each case study, occasionally there are some difficulties in its application. In virtue of a comprehensive literature review, Reap et al. (2008a, b) highlighted the challenges concerning the limitations on data availability, uncertainty of the input data, resolution of the model, necessary assumptions, and sensitivity to unsettled parameters. In the present study, the variability on the results is analysed according to the decisions adopted during the definition of the goal and scope of the systems under study.

The application of LCA to analytical procedures is a field seldom studied. Rynja and Moy (2002, 2006) developed an approach adapting LCA to evaluate the environmental performance of analytical laboratory services and their associated supply chains. However, they proposed a general theoretical framework that enables the application of LCA methodologies developing a Laboratory Product Model, being a representation of a generic laboratory service output. Other studies stated a set of good practices for materials and energy reduction, based on average purchases of laboratories provided in public registers, but without calculating environmental indicators (Mathew, 2003; Ray et al., 1999; Thurston and Eckelman, 2011). There are LCA studies applied to laboratory procedures but they measured the environmental improvements derived from the use of specific technology advances, for example, new solvents that allows for less environmentally damaging extractions (Pena-Pereira et al., 2015). The vast majority of publications found in the search with the terms LCA and laboratory are focused on the environmental evaluation of upcoming products or processes based on the results at laboratory scale.

By contrast, in the LCA herein presented the Carbon Footprint (CFP) of novel analytical products for the detection of pathogen in drinking water was calculated. Two types of analytical products were assessed: two qPCR kits with materials ready to use in quantitative polymerase chain reaction analyses, and one on-line monitoring device using fluorescence measurements. The scope of the models describing the three systems was based on specific real data retrieved from the project's partners, considering the whole life cycle. Special attention was given to the use phase that entails the sampling and laboratory work of the analytical methods where the novel products are used. This included materials and energy consumption, transport activities and waste generation associated to the determination of the presence of pathogens in water. The results were compared to the conventional water analysis methods taking into account different scenarios and the variability of the main parameters of the system, i.e. quantities of different products and materials used in the procedure, duration of use of equipment, distance of transport, among other.

2. Methods

2.1. Data provision

As mentioned, the analytical methods developed in the project as well as the conventional methods for their comparison, where modelled based on the information retrieved from the partners. Particular remarks were done about the necessity of reliable and representative data to obtain accurate outcomes. To facilitate the data acquisition from partners the request went on in two campaigns, first to partners being the developers of the new methods and secondly to partners in charge of field application of these methods for the analysis of water. Fig. 1 shows the flow of actions followed and the interaction with partners for data provision.

The manufacturing of three different analytical products were computed with the information reported by three manufacturer partners. After receiving general information about their features and use, specific questionnaires were sent to obtain the necessary data related to materials and energy involved in the manufacturing, paying special attention to the packaging as main difference between different product presentation formats.

Regarding the use phase of the new analytical products, up to seven partners provided information about their application for the monitoring of the presence of pathogens in large, small and food production water systems from different European locations. With the general idea from the previous phase on how the analytical products are used, a general questionnaire was delivered to partners to obtain information divided in four blocks: activities during sampling campaign and particularly the transport, materials and products involved in the processing of a sample when using the studied analytical products, energy consumption by equipment, and the wastes generated and their management.

2.2. System scope and assumptions

Three different waterborne pathogen analytical methods were assessed: two qPCR (quantitative Polymerase Chain Reaction) kits and one online monitoring device. The Carbon Footprint was calculated for the functional unit of one analysis, meaning the use of the method to produce information about the presence of pathogens. The outline of the scope of these systems, divided in product production and product use, is shown in Table 1. The activities considered in the evaluation of the kits production include the manufacturing, validation and packaging of the substances needed to conduct the qPCR assay. In these assays the DNA of the targeted pathogen is amplified in the way that its presence can be detected and quantified. The materials needed to produce the qPCR are