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Challenges in applying LCA at the research stage: case study on biotreatment of pollutants in drinking water resources

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1. Introduction

Research projects aiming to develop new technologies, products, and services increasingly use life cycle assessment (LCA) as a means of providing information about the potential for sustainability of the technology under development. While using LCA at this early stage clearly provides benefits in terms of steering decisions towards sustainable choices, this collides with the practicalities of LCA, which is a sophisticated and data-demanding method. In this work we give an overview of the main challenges that the LCA practitioner encounters in such prospective assessments and how they can be overcome, with the example of a case study on biotreatment of water resources.

2. Description of the case study and its challenges

2.1. Defining the scope

The EU-funded project BIOTREAT (www.biotreat.org) aimed at developing new technologies for bioremediation of drinking water resources contaminated with micropollutants, such as pesticides, pharmaceuticals, and its metabolites. The basis of the proposed technologies is the introduction of specific degrading microorganisms or microbial consortia into existing sand filters at waterworks. The project included a joint environmental and economic assessment, the former using LCA and the latter using cost-benefit analysis (CBA).

The goal of the LCA was to identify hotspots, and to compare the BIOTREAT concept with currently available market technologies. The first challenge was to identify which options could be replaced with BIOTREAT. Based on discussions with the partners, two alternatives to BIOTREAT were identified: granular activated carbon (GAC) and re-location of the well. Besides, two BIOTREAT scenarios were chosen: direct inoculation of sand filters, and the use of carrier materials to help stabilizing the inoculated bacteria in the sand filter.

After three years of research, mostly lab-scale experiments had been carried out, and some pilot-scale experiments had been performed near Copenhagen, Denmark, to remove 2,6-dichlorobenzamide (BAM), a pesticide metabolite, from a polluted aquifer. It was decided to use the pilot scale experiments as a basis for the LCA, given that they were closer to real full-scale operation. As a consequence, Denmark was established as the geographic context, and BAM as the target pollutant. The functional unit was defined as providing drinking water with BAM concentration under the threshold level of 0.1 µg/L.

Consequential modelling was chosen for the inventory analysis. Consequential LCA was considered more suited to support a prospective assessment. The system boundaries only included affected processes (added activities in the waterworks), whereas common activities such as distribution of drinking water to consumers were excluded. Impact assessment was performed with the Stepwise 2006 method [1].

2.2. Data collection

The life cycle inventory (LCI) analysis was the most challenging stage in the study. For the BIOTREAT scenarios, we collected data about energy use by the pilot plant, as well as data on production of the bacterial inoculum (Aminobacter sp. strain MSH1) as produced in the pilot plant. For the use of carrier materials, the only data available came from lab-scale experiments in test tubes, where bacteria had been inoculated in a mixture of sodium alginate, calcium chloride, and a mineral substrate used in fishkeeping.

In addition, the experiments showed that the bacterial population was not stable and was progressively lost by e.g. wash-out, predation by protozoa, etc. and the degradation capacity of the filter was lost within days/weeks, especially if no carrier materials were used. As a consequence there was a high uncertainty on the frequency with which the filter would have to be inoculated in a real plant. Based on expert judgement, it was assumed to be bimonthly for direct inoculation, and yearly when carrier materials were used.

Another challenge in the LCI was getting appropriate information for the comparison with other technologies. This is especially difficult since within the project there were no experiments with GAC that could be used as basis for the LCI, therefore estimates from literature had to be used. We used data on BAM removal with GAC from pilot-plant tests carried out by DTU [2] and for well re-location we used data from an average Danish waterworks according to Godskesen and colleagues [3].

3. Results and discussion

One of the first lessons learned was the fact that data from pilot- and lab-scale experiments are extremely uncertain. The impact of the BIOTREAT technology was mainly related to the production of the bacterial inoculum, but the methods used in the pilot plant for this production were far from optimized and not realistic for a full-scale plant. It was decided to consider in the LCA industrial-scale production of Aminobacter bacteria, and due to lack of data this had to be done using yeast production as a surrogate. As it can be seen in figure 1 (left) for the climate change impact category, the results dramatically changed, moving the BIOTREAT technology from unsustainable to a competitive technology when compared to GAC.

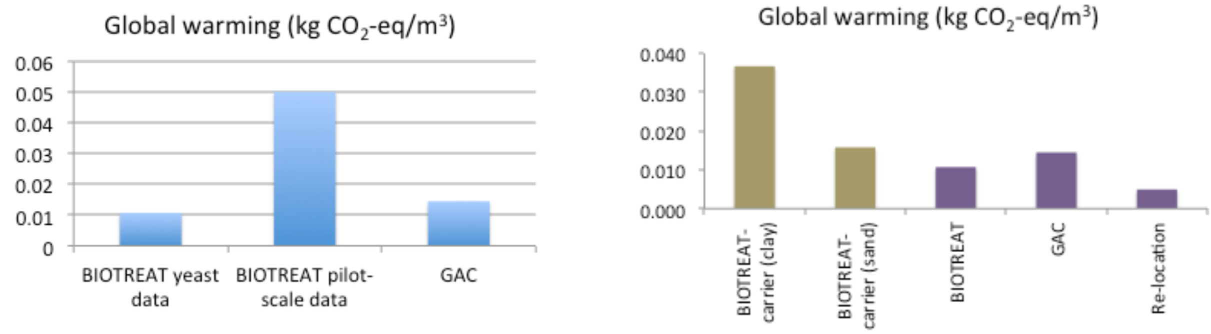

Figure 1. Left: Climate change results for the BIOTREAT technology compared to GAC depending on the data used for bacteria production (pilot plant data or industrial yeast as surrogate). Right: overall comparison of climate change results with a focus on the difference between using expanded clay or quartz sand as carrier material in the BIOTREAT technology.

Similarly, when the BIOTREAT concept was used with carrier materials, the relative impact of this option was very high when considering expanded clay as carrier material (figure 1, right). However, when shifting to quartz sand, the technology performed better from a climate change perspective. In any case the results were highly uncertain as they were derived from lab-scale tests.

The use of LCA led to unexpected results. As an example, it was thanks to the data collection effort in the LCI phase that the consortium realized that a UV system would be needed after the sand filter, to ensure microbiological safety. Also, the most favourable option among those assessed, both from an environmental and economic point of view was not treating the pollution, but shutting down the polluted well and opening a new one elsewhere. This was the case assuming that the new well involves the same material inputs (same distance from the waterworks) and energy used for pumping the water than the replaced one. Nevertheless it is not always possible to open a new well, if pollution it is too widespread in the aquifer.

4. Conclusions

Although it is not possible to go into further details in this short abstract, several sensitivity analyses were carried out both in the LCA and the CBA, and in spite of the high uncertainty, useful lessons were learned on which are the key parameters influencing impacts and costs. We showed that LCA, applied at the research stage, can provide useful information to technology developers, opening their eyes to a completely different perspective that goes beyond their work in the lab. It is our conclusion that the role of LCA in this context is rarely to provide strong claims, but rather to identify hotspots, and to provide a first quantitative impression of relative performance, where what matters are orders of magnitude and not decimal points.

5. References

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