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METHODOLOGICAL ISSUES IN LCA OF WASTEWATER TREATMENT COMBINED WITH PHA BIOPOLYMER PRODUCTION

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ABSTRACT

Production of polyhydroxyalkanoates (PHAs) by mixed microbial cultures utilising the organic content of wastewaters is one of the technologies studied in the EU project ROUTES. When comparing the life-cycle environmental impacts of simultaneous wastewater treatment and production of PHA-rich biomass to traditional wastewater and solids treatment, the handling of this multi-functionality is critical for the results. Only one LCA of such a system has been found in the literature. The current paper identifies substitution and allocation based on chemical oxygen demand removal as two possible options to account for the multi-functionality of the system. Examples based on literature data were used to show that for global warming potential, the choice of allocation method can substantially affect the results.

INTRODUCTION

Polyhydroxyalkanoates (PHAs) are thermoplastic polymers of increasing interest since they are biodegradable and can be produced from renewable resources, e.g. crops and organic wastes, which are also cheaper feedstocks. To date, PHA production with pure cultures is the most common approach but the interest in mixed-culture PHA production is increasing due to its lower demands on sterility, equipment and control (Chanprateep, 2010).

In the project “ROUTES – Novel processing routes for effective sewage sludge management” under the EU seventh framework programme, PHA production by mixed cultures in tandem with municipal wastewater (WW) and sludge treatment is one of the technologies under study (Braguglia et al., 2012). Volatile fatty acids, produced from sludge acidogenic fermentation, are utilised for PHA production by activated sludge biomass with increased PHA-accumulation capacity. The PHAs can be recovered from the polymer-rich biomass, either on-site or elsewhere. In the ROUTES project, municipal WWT with simultaneous production of PHA-rich biomass is compared to a reference wastewater treatment plant (WWTP) using life cycle assessment (LCA), in order to gain insights into the potential environmental impacts of the process and its units. However, such a comparison faces methodological challenges, in particular the need to account for the added function of PHA generation. This problem is aggravated by the state of development of the technology, which is currently being prototyped at pilot scale. Full-scale applications are only foreseen in the future. Therefore, the amount of environmentally relevant data available in the literature is limited and actual process designs integrated into local infrastructures cannot be fully specified.

Despite these challenges, doing LCAs on technologies that are under development has a value since environmental hotspots can be identified from which further process development can be optimised and potential areas of application with improved environmental performance can be identified. This work discusses approaches for dealing with the multi-functionality of systems producing value-added by products, such as PHAs, from required waste management services, such as wastewater treatment (WWT).

METHOD

The method applied in this study includes an identification of appropriate allocation and substitution approaches in LCA of PHAs generated in WWT, using inputs from earlier experiences reported in the literature. The importance of the choice of allocation/substitution method is illustrated using an example system of mixed-culture PHA production integrated with industrial WWT.

The functional unit for the example system was chosen to be ‘treatment of 500 kL WW inflow to the WWTP per day’. A gate-to-gate approach was used for the illustrative example, as the generation and collection of the WW and treatment of the residues after polymer recovery are not relevant for the studied allocation/substitution approaches in the illustrative example, nor are in focus in the technical development work in the ROUTES project.

Few LCA studies on PHA production are available in the scientific literature. For mixed-culture PHA production, only one study has been published (Gurieff and Lant, 2007), assessing only global warming potential (GWP). A summary of available literature on LCAs of PHA production can be found in Heimersson et al. (2013). Integrated WWT and PHA production was therefore based on the model system from Gurieff and Lant (2007) with production of inputs modelled for European conditions using Gabi 5 Professional database (PE International). Two alternative substitution products are modelled: (1) PHA-rich biomass from pure culture production from corn as modelled by Akiyama et al. (2003), with input data from Renouf et al. (2008) for monosaccharide production, both with production of inputs modelled for European conditions using Gabi 5 Professional database and (2) High-density polyethylene (HDPE) for German conditions from Gabi 5 Professional database. As the future main application area and actual function of PHA in relation to alternatives are unsure, 1 kg PHA is assumed to replace 1 kg HDPE in the illustrative example, to show the potential of replacing one possible oil-based polymer. Other polymers or PHA-containing products could also be eventually considered.

RESULTS AND DISCUSSION

The issue of multi-functionality in the studied system can be handled in two ways: substitution of additional functions by other means of providing the same function, or allocation of impacts between WWT and additional functions, based on e.g. physical or economic basis.

Substitution was applied by Gurieff and Lant (2007) in their LCA comparison of WWTPs producing either PHA or biogas. They assumed that the produced PHA replaced an equal amount of HDPE. In the study, the PHA recovery process was not modelled specially for mixed-culture PHA production, but instead it was based on simulated data produced for an economic analysis by Van Wegen et al. (1998). The lack of process data on PHA recovery modelled specially for mixed-culture applications adds uncertainty to the LCA.

A review by Heimersson et al. (2013) showed that almost all data on PHA recovery processes in published LCA studies refer directly or indirectly to (often about ten year-old) simulated data. Furthermore, in our study the likely application area for the PHA was not known, adding another level of uncertainty to the assessment. In the ROUTES case, PHA recovery could be placed either inside or outside of the system boundaries. If the recovery is placed inside the system boundaries, recovered PHA is leaving the system and could be assumed to replace another polymer, e.g. the marginal polymer in the studied area based on economic or environmental criteria, often a petrochemical-based polymer. But if the recovery is placed outside of the system boundaries it is the PHA-rich biomass that should be replaced. This could be a reasonable option since data availability on PHA recovery and the use phase of the PHA is low, although this limits the substitution possibilities to other PHA-rich biomass streams, i.e. pure culture production from grain.

Allocation made on a monetary basis should at this stage be avoided, due to the large uncertainty in terms of the value of PHA or PHA-rich biomass on the emerging PHA market. A physical allocation requires a common physical unit for the WWT function and the PHA-production function. No such unit is obvious, but an allocation between the functions of WWT and of production of PHA-rich biomass based on chemical oxygen demand (COD) removal by the processes has been suggested by Heimersson et al. (2013), for a study in which both PHA (main function, reflected in the functional unit) and WWT (by-function) is performed by the system. This way of allocating focuses on the WWT function and in particular the COD removal function of the process.

Figure 1 shows the influence on the results of different choices regarding the substitution or allocation methods. The figure contains just a few examples of possible substitutions; however, more options can be explored, for example PHA-rich streams from other feedstocks and other oil-based and renewable alternatives to PHA. Nevertheless, the results do show that the influence of choice of substitution/allocation approach on the overall result can be substantial. The net impact can even be negative if substitution is applied and the biopolymer recovery is left out of the studied system. In Figure 1, only GWP is shown. The substitution/allocation approach could potentially put focus on the assessment of different impact categories, e.g. as the replacement of a grain-based PHA-rich stream could increase the importance of assessing categories like eutrophication and toxicity that have shown to be significant when assessing agricultural products.

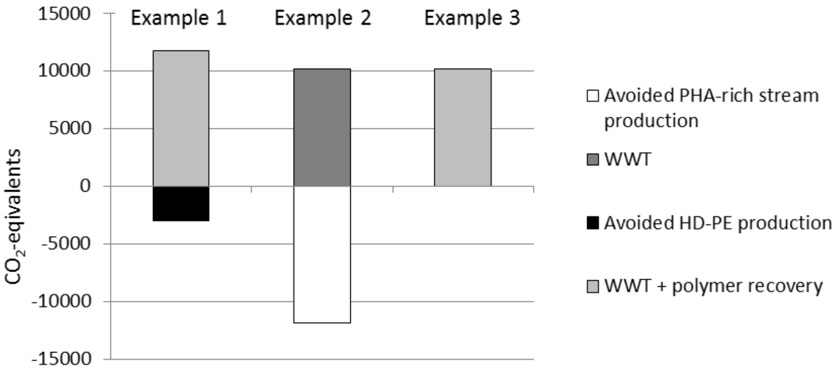

Figure 1. Three different ways of accounting for the additional PHA-producing function of the studied WWT system: (1) PHA substituting HDPE (with polymer recovery included in the system) (2) the PHA-rich biomass substituted by a similar stream from pure culture fermentation of corn (with polymer recovery excluded from the system) and (3) COD allocation with recovery included in the studied system.

CONCLUDING REMARKS

This paper has shown that selecting an accounting approach for additional functions is a delicate issue in the case of simultaneous PHA production and WWT. Accounting for the generated PHA by substitution by polymer or polymer-rich stream or even a COD removal based allocation is shown to be important for the overall results. The influence of the choice of approach should preferably be investigated in a quantitative sensitivity analysis.

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REFERENCES

Akiyama, M., Tsuge, T. & Doi, Y. 2003. Environmental life cycle comparison of polyhydroxyalkanoates produced from renewable carbon resources by bacterial fermentation. *Polymer Degradation and Stability,* 80**,** 183-194.

Braguglia, C., Gianico, A. & Mininni, G. 2012. ROUTES: innovative solutions for municipal sludge treatment and management. *Reviews in Environmental Science and Biotechnology,* 11**,** 11-17.

Chanprateep, S. 2010. Current trends in biodegradable polyhydroxyalkanoates. *Journal of Bioscience and Bioengineering,* 110**,** 621-632.

Gurieff, N. & Lant, P. 2007. Comparative life cycle assessment and financial analysis of mixed culture polyhydroxyalkanoate production. *Bioresource Technology,* 98**,** 3393-3403.

Heimersson, S., Morgan-Sagastume, F., Peters, G., Werker, A. & Svanström, M. 2013. Methodological issues in life cycle assessment of mixed-culture production of polyhydroxyalkanoates using wastes as feedstock. *Accepted for review in New Biotechnology*.

Renouf, M. A., Wegener, M. K. & Nielsen, L. K. 2008. An environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugars for fermentation. *Biomass and Bioenergy,* 32**,** 1144-1155.

Van Wegen, R. J., Ling, Y. & Middelberg, A. P. J. 1998. Industrial production of polyhydroxyalkanoates using escherichia coli: An economic analysis. *Chemical Engineering Research and Design,* 76**,** 417-426.