Consequential LCI modeling of chemicals in wastewater: including avoided nutrient treatment

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1. Introduction

Treatment of organic chemicals in urban wastewater treatment plants (WWTP) through biological treatment requires availability of nitrogen (N) and phosphorus (P), among other nutrients, in order for microorganisms to build up their biomass. However many chemicals do not contain in their molecules these nutrients (consider a chemical with the formula $C_xH_yO_z$). In this case microorganisms need to obtain the nutrients from an alternative source, mainly NH_4-N and PO_4-P already available in wastewater. In consequential life cycle inventory (LCI) modelling terms, these nutrients present in wastewater constitute non-fully utilised materials, and thus their consumption from wastewater should be credited with the avoided treatment they would have otherwise been subject to. To our knowledge these credits are not quantified by current WWTP models used in LCA and the objective of this work is to quantify their magnitude, taking into account the variability induced by differences in wastewater treatment levels in different countries.

2. Materials and methods

Wastewater treatment of chemicals and the credits induced by nutrient consumption have been modelled with the WW LCI v2 model (1, 2). Figure 1 shows an overview of the model's concept. A chemical substance's properties are used to predict its fate in a municipal WWTP as well as in the environment. Based on the predicted fate factors, the model calculates an LCI including the operation of the WWTP and sludge disposal processes, as well as emissions from degradation in the environment of any fraction of the chemical directly released to the environment. The model includes four levels of wastewater treatment: septic tanks, WWTP with primary treatment, WWTP with primary and secondary treatment including N removal, and WWTP with primary, secondary and tertiary treatment, the latter consisting of P removal and sand filtration. Sludge is subject to anaerobic digestion and disposal routes include landfarming, landfilling, incineration and composting. In order to reflect current wastewater treatment scenarios, the model includes a database with statistics on wastewater treatment levels and sludge disposal practices in 57 countries. The model is programmed in Excel, accommodating simultaneous calculations for 30 chemicals, either individually or as a mixture.

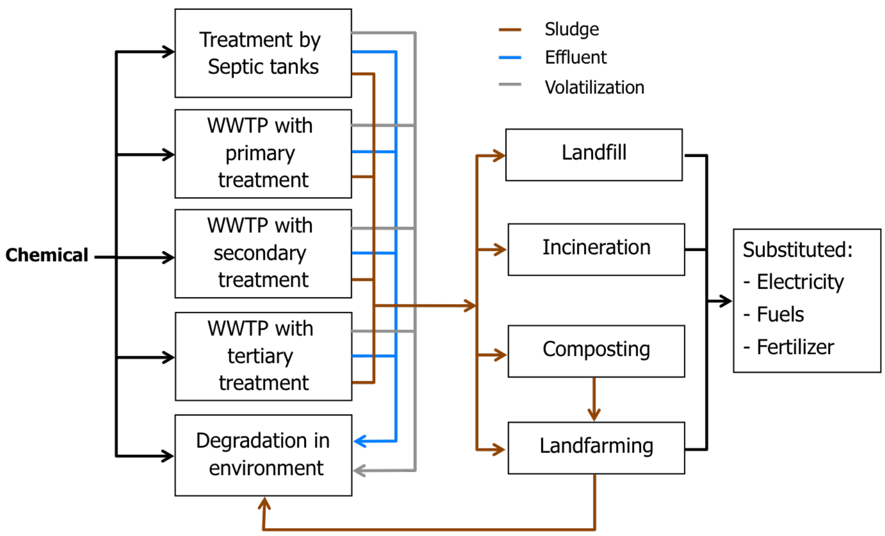

Figure 1. Conceptual diagram of WW LCI v2.

As an example, we illustrate the quantification of nutrient credits for the chemical ethanol (C_2H_6O) in two countries with substantially different wastewater treatment realities: Denmark and India (Table 1). We use WW LCI v2 to obtain an LCI for discharging ethanol to wastewater in these two countries, and we extract from the model's mass balances the amounts of NH_4 and PO4 consumed in the different treatment levels. In Denmark, for example, 68 g ammonium and 27 g phosphate are consumed per kg ethanol discharged to the sewer.

WW LCI v2 does not currently provide a systematic calculation of credits associated to consumption of nutrients, but these credits can be calculated by:

1. Obtaining from WW LCI v2 the LCIs for treating ammonium and phosphate, in the two countries, for each treatment level: septic tanks, primary treatment, secondary treatment and tertiary treatment.
2. Linking to the LCI of ethanol obtained from WW LCI v2 the inputs of -X g ammonium and -Y g phosphate consumed in each of the above-mentioned treatment levels.

Wastewater treatment and sludge disposal scenario		DK	IN
Wastewater treatment scenario	Connection to WWTP - primary treatment	2%	0%
	Connection to WWTP - secondary treatment	3%	21%
	Connection to WWTP - tertiary treatment	84%	0%
	Connection to septic tank	11%	39%
	Direct discharge (no treatment)	0%	39%
Sludge disposal scenario	Composting	6%	0%
	Landfarming	50%	100%
	Landfilling	0%	0%
	Incineration	44%	0%

Table 1: Wastewater treatment and sludge disposal scenario in Denmark and India based on WW LCI v2 database.

3. Results and discussion

The output of WW LCI v2 is a comprehensive inventory linked to ecoinvent v3 data sets, that can be imported to LCA software. Impact assessment calculations are then easy to perform for different impact categories.

Figure 2 shows the impact assessment results for the chemical ethanol in Denmark and India, for three impact categories assessed at mid-point level: greenhouse-gas (GHG) emissions, freshwater eutrophication and marine eutrophication. We can see that the avoided treatment of ammonium and phosphate have outstanding effects on the ethanol's marine eutrophication and freshwater eutrophicaton scores in both countries, where the overall result for discharging ethanol to wastewater becomes a beneficial one. For GHG emissions the relative magnitude of the nutrient credit is substantially lower than for eutrophication, especially when ethanol is assumed to contain fossil carbon. Still, for ethanol containing fossil carbon and discharged in Denmark, the GHG emissions are reduced by 16%, and by 45% when ethanol contains biogenic carbon.

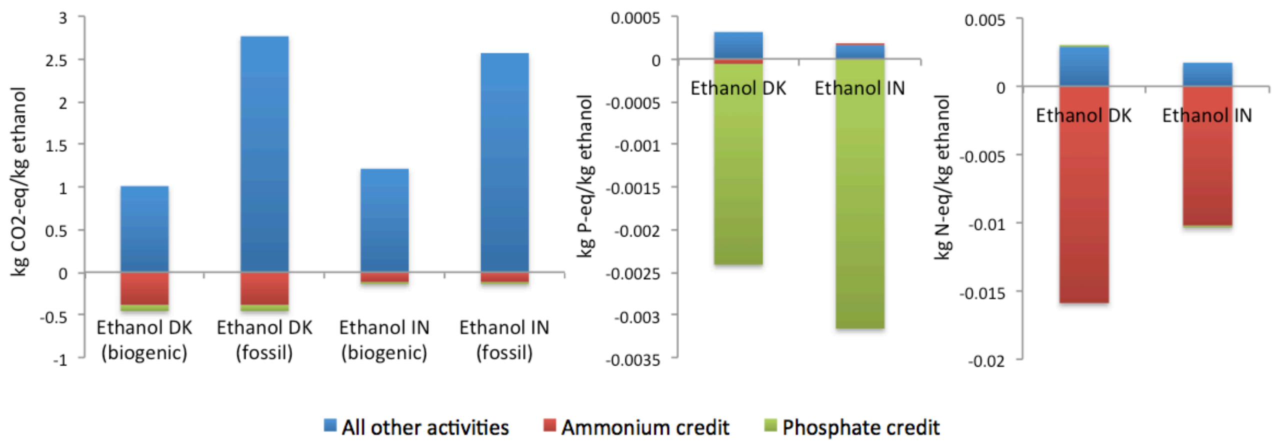

Figure 2: GHG emissions (left), freshwater eutrophication (centre) and marine eutrophication (right) results per kg ethanol discharged in wastewater in Denmark (DK) and India (IN). Impact assessment calculations carried out in the software SimaPro. GHG emissions assessed with global warming potential (GWP) for a time horizon of 100 years, with biogenic CO_2 assumed to have a GWP-100 = 0. Both eutrophication impact categories modelled with the ReCiPe method.

4. Conclusions

Our results show that consequential LCI modelling of organic chemicals in wastewater needs to account for credits associated to consuming nutrients available in wastewater, since this consumption leads to the nutrients being incorporated in sludge rather than treated in the WWTP. These credits should be considered in the models in the same way as those from e.g. energy recovery from sludge incineration or from displacement of mineral fertilisers when sludge is applied in agriculture. The results also show that the magnitude of these credits is closely linked to the regional or country-specific wastewater treatment realities.

Finally it must be highlighted that these credits only apply to organic chemicals that 1) are expected to degrade in WWTPs and 2) do not contain N and/or P in their molecules.

5. References

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