New LCA Theses

Uncertainty and Variability in Environmental Life-Cycle Assessment *

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Environmental life cycle assessment (LCA) is a tool for the assessment of the environmental impact of product systems. Although the framework itself is well established, its usefulness is still limited due to the fact that uncertainty and variability is often neglected. The aim of my thesis is to contribute to a quantitative evaluation of uncertainty and variability in LCA. It also intends to improve the characterisation factors used for the evaluation of toxic, acidifying and eutrophying emissions.

My thesis starts with a framework to classify types of uncertainty and variability in LCAs. Uncertainty is divided in parameter uncertainty, model uncertainty, and uncertainty due to choices, while variability covers spatial variability, temporal variability, and source and object related variability. The comparison of two exemplary types of roof gutters shows how the effect of combined parameter uncertainties in the inventory and in the characterisation factors for global warming and acidification may be evaluated by means of Monte Carlo simulation. To illustrate the influence of choices, the effect on the comparison is shown using two different allocation procedures in open loop recycling and three time horizons for global warming potentials.

For the evaluation of toxic substances, the global nested multi-media fate, exposure and effects model USES-LCA was developed to calculate toxicity potentials over an infinite time horizon for six impact categories (fresh water aquatic and sediment ecotoxicity, marine aquatic and sediment ecotoxicity, terrestrial ecotoxicity and human toxicity) after initial emission to five compartments (air, fresh water, seawater, industrial soil and agricultural soil), respectively. The model was used to calculate toxicity potentials for 181 substances. Analysing the correlations between the toxicity potentials revealed (1) that the impacts on aquatic and sediment ecosystems can be clustered for the marine and fresh water environment without significant loss of information, and (2) that differentiating between initial emission compartments is important for all the toxicological impact categories identified, except for the assessment of ecotoxicological impacts after emissions to industrial and agricultural soil.

Various types of uncertainty and variability were assessed in the calculation of toxicity potentials. The variance in toxicity potentials resulting from input parameter uncertainties and human variability was quantified for three substances (atrazine, dioxin and lead) by means of Monte Carlo simulation. The variance, expressed by the ratio of the 97.5%-ile and the 2.5%-ile, ranged from about 1.5 to 6 orders of magnitude. The major part of this variance stems from parameters that describe transport mechanisms, substance degradation, indirect exposure routes and no-effect concentrations. In addition, the variance in toxicity potentials resulting from choices in the modelling procedure was quantified by means of scenario analysis. A first scenario analysis showed to what extent potential impacts in the relatively short term are obscured by the inclusion of impacts on the very long term. Toxicity potentials representing potential impacts over time horizons of 20, 100 and 500 years were compared with toxicity potentials representing potential impacts over an infinite time horizon. Time horizon dependent differences up to 6.5 orders of magnitude were found for metal toxicity potentials, while for toxicity potentials of organic substances under study, differences remain within 0.5 orders of magnitude. The second scenario analysis addressed to what extent potential impacts on the continental scale are obscured by the inclusion of impacts on the global scale. Exclusion of potential impacts on the global scale changed the toxicity potentials of metals and volatile, persistent halogenated organics up to 2.3 orders of magnitude.

For the calculation of acidification and terrestrial eutrophication potentials of ammonia (NH_3) and nitrogen oxide (NO_x) emissions to air and acidification potentials for sulfur dioxide (SO_2) emissions to air, the spatially explicit model RAINS-LCA was developed. Taking fate, background depositions and effects into account, the model calculates acidification and terrestrial eutrophication potentials for Europe and a number of European regions. Two impact definitions are explored in the calculations: (1) the marginal change in the hazard index of all ecosystems in Europe and (2) the marginal change in the hazard index of ecosystems in Europe where the critical load is actually exceeded. Using RAINS-LCA as opposed to simpler models, it was found that region-specific differences in terrestrial eutrophication and acidification potentials range up to 1.5 and 3.5 orders of magnitude, respectively.

Aquatic eutrophication potentials for N and P agricultural emissions to air and NO_x and NH_3 emissions to air were improved by using fate models on three different geographical scales: the global, European and Dutch scale. It was found that the inclusion of fate factors decreases the importance of N emissions to agricultural soil regarding aquatic eutrophication by a factor of 2.5 to 7.5 and P emissions to agricultural soil by a factor of 25 to 35. Fate factors for NO_x and NH_3 emissions to air decrease the aquatic eutrophication potentials of these emissions by a factor of 2 to 3.

Finally, three different types of uncertainty were evaluated in the environmental comparison of insulation thickness in buildings. Parameter uncertainties in the functional unit, the inventory analysis, and the impact assessment were assessed with help of Monte Carlo simulation. The influence of choices concerning the allocation of environmental burdens in recycling processes, future waste scenarios, and the timing, geographical scale and definition of environmental impacts were addressed by means of scenario analysis. Model uncertainty due to the lack of spatial and temporal differentiation and due to the lack of suitable characterisation factors for sum emissions was assessed by comparing the outcomes of using different model assumptions. It was found that parameter uncertainty was the most important source of the uncertainties evaluated in this case study.

Substantial effort has been spent on the improvement of current life cycle impact assessment methods and the development of procedures to deal with uncertainty and variability in LCAs. Nevertheless, still much work remains to be done. Various recommendations for further research are given in my thesis. These include the development of publicly available databases with up-to-date inventory data and corresponding uncertainty estimates, and ways to further improve the fate and effects analysis of emissions causing toxicity, acidification and eutrophication.

* Huijbregts MAJ (2001): Uncertainty and variability in environmental life cycle assessment. PhD thesis. Institute for Biodiversity and Ecosystem Dynamics. University of Amsterdam. The thesis can be downloaded from the following website: http://www.uba.uva.nl/nl/publicaties/huijbregts/