New LCA Theses

Assessing Toxic Impacts on Aquatic Ecosystems in LCA

Jérôme Payet

GECOS-ENAC Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne. Switzerland (jerome.payet@epfl.ch)

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Over the last decade, several Life Cycle Assessment (LCA) methods for assessing impact of products on living resources have been developed. Beyond the quantified assessments of impacts on living systems, researchers have also checked the feasibility of the impact assessment on human health and ecosystem quality and helped to identify the limits of such methods. Among the different impact categories, the impact of toxic substances on ecosystems occupies an important position. The extent of these impacts has been stressed on many occasions and the necessity of preserving ecological areas and biodiversity has become a major issue on an international level.

By focussing on aquatic ecosystems, this thesis aims at identifying constraints connected with the assessment of the impact of chemical substances on ecosystems in LCA and at setting up a method for assessing impacts of toxic substances on aquatic ecosystems, which meets the requirements of a comparative approach like Life Cycle Assessment. The overall purpose of the thesis is to propose a comparative method for Life Cycle Impact Assessment of toxics in aquatic ecosystems. With that aim, the dissertation provides a guide through 6 major issues:

1. The feasibility of the comparative impact assessment on ecosystems and the identification of associated constraints.
2. The development of a statistical method for comparing impact on ecosystems;
3. The review of data availability for the calculation of Effect Factors.
4. The choice of the most relevant ecotoxicity measure (ECxs[1], NOECs[2] and LOECs[3]) for a comparative purpose.
5. The development of best-estimate extrapolation factors for assessing chronic effects based on acute data.
6. The analysis of the ecological realism of the comparative assessment method.

These points are analysed throughout the 7 chapters of the thesis.

The main purpose of the thesis is to present the parametric version of the AMI method (Assessment of the Mean Impact) which has been developed for the assessment of impacts on aquatic ecosystems during the course of the PhD. The Hazardous Concentration of a toxic affecting 50% of the species over their chronic EC50 (Effect Concentration affecting 50% of tested individuals), also known as $HC50_{EC50}$, is selected for the calculation of Effect Factors to be implemented in current LCIA methods. The Confidence Interval on the $HC50_{EC50}$ is provided, enabling a comparison between the impact values obtained as results of a Life Cycle Assessment study. Furthermore, a detailed review of the existing methods has been performed. It concerns the parametric version of AMI based on $HC50_{EC50}$s; the Eco-Indicator based on $HC50_{NOEC}$s; USES-LCA based on both $HC5_{NOEC}$s and the Most sensitive species, and the PNEC (Predicted No-Effect Concentration) based on the Most sensitive species. Particular attention is paid to possible bias and uncertainty, highlighting the following findings: (1) $HC5_{NOEC}$s are on average 50 times higher than the most sensitive species, and this difference in conservatism introduces a bias in the analyses for the method mixing $HC5_{NOEC}$s and most sensitive species. (2) Effect Factors based on the most sensitive species increase the relative weight of the most toxic chemicals by two orders of magnitude, depending on whether the study is based on US or European ecotoxicity databases. (3) the methods based on $HC50_{EC50}$s and $HC5_{NOEC}$s are the only ones able to provide a Confidence Interval on the Effect Factor, but the Confidence Interval on the $HC5_{NOEC}$s can be more than 10 orders of magnitude greater than that of the $HC50_{EC50}$s. (4) compared with the Confidence Interval on the $HC50_{EC50}$s, the most sensitive species cannot be distinguished from $HC50_{EC50}$s for chemicals characterised by fewer than 5 species, and the $HC5_{NOEC}$s cannot be distinguished from the $HC50_{EC50}$s for chemicals characterised by fewer than 8 species.

A part of the thesis focusses on the analysis of two statistical estimators, aimed at calculating the average toxicity of substances on biological species. The two methods provide an estimation of the $HC50_{EC50}$ and the associated Confidence Interval. On the one hand, a parametric method using the geometric mean and a calculation of the confidence interval with Student's t-test is considered. On the other hand, a distribution-free method calculates the $HC50_{EC50}$ based on the median response of species and the confidence interval based on bootstrap. A detailed application of the two methods is done with the comparison of two herbicides, the Sulfosulfuron and the Prosulfuron, where the distribution-free method appears to be more powerful than the parametric for a substance-to-substance comparison. Nevertheless, the distribution-free method requires a minimum of 5 chronic EC50s, that cannot be satisfied in most cases.

A substantial effort has been put in the review of existing aquatic toxicity databases which can be used for the calculation of Effect Factors for Life Cycle Impact Assessment (LCIA). Six ecotoxicity databases available in an electronic format are analysed, especially focussing on the identification of the substances and organisms, the definition of the test conditions, and the control procedure of the database. A selection of tests is carried out, retaining a dataset of 128,864 test results, acute, sub-chronic and chronic. On that basis, an estimation of the maximum number of possible Effect Factors is performed. The results highlight the discrepancy between the large number of test results available (128,864), and the relatively restricted number of Effect Factors (between 34 and 4959, depending on the method) that can be calculated for a comparative purpose like LCIA.

After a general conclusion, the AMI $HC50_{EC50}$ database is presented. It provides acute and chronic $HC50_{EC50}$ data calculated with the parametric version of AMI (geometric mean of the EC50s and confidence interval based on Student's t-test) for 522 substances.

The PhD is available by email at jerome.payet@epfl.ch

[1] ECx: concentration of substance that affects 50% of the individuals tested for a given effect
[2] NOEC: No Observable Effect Concentration
[3] LOEC: Lowest Observable Effect Concentration