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7 Conclusions and Recommendations

Based on the evaluation, none of the existing methods can be recommended as optimal in their present form. Different directions for improvement and further development of existing approaches, and development of new ones, exist as well. There seems to be at least three main directions to go:

- Improving the assessment factor-based PNEC approaches making them less risk assessment-oriented and more suitable for LCIA. The goal involves development of non-conservative assessment factors including uncertainty estimates (confidence limits), and, if possible, taking toxic mode of action into account. However, the problem with instability of the indicator due to its dependence on the choice of the database still remains.
- Improving the chemical coverage and the environmental relevance of the 'PAF related' approaches. The main problem here seems to be the lack of data and the fact that the way these approaches have been used till now does not reflect effects on the ecosystem in a more accurate way than the assessment factor-based PNEC approaches. The goal will be to make procedures for a more environmentally relevant application (e.g. more realistic, not haphazard representation of species on each trophic level). There is also a need to improve the chemical coverage by fitting the approach to a low data availability, and further to utilize, improve and develop the inclusion of mixtures and damage modelling.
- Further development of the 'media recovery' damage approach or development of new damage-based indicator based on the 'time to extinction' approach or 'changes in genetic diversity'.

For damage modelling, the 'media recovery' approach seems to be the most realistic way to go if a method is to be functional for LCIA within the near future. The media recovery approach can be coupled with the PAF approaches, but, for example, needs further development on the connection between media recovery and recovery/recolonization of species populations. Taking into account that the two other damage approaches are at an even earlier developmental stage than the 'media recovery' model, and that the availability of the needed data is very poor, it is probably not realistic to attain practical, useable methods based on these approaches in the near future. However, from a theoretical point of view, the approaches based on mean extinction time and genetic diversity are very attractive.

For the assessment factor-based PNEC approaches; the main problem is that they are founded in the first tier of a multi-tiered risk assessment and therefore conservative, which is not compatible with the comparative framework of LCIA. A way to deal with this problem could be to try to develop non-conservative assessment factors taking the huge work on acute to chronic ratios already done (e.g. Chapman et al. 1998, Solbe et al. 1998, Länge et al. 1998, Forbes and Calow 2002) as a starting point, and maybe trying to differentiate the assessment factors by TMOA. However, as the PNEC approach is no-effect based (i.e. NOEC based), it will still suffer from the uncertainty of measured NOEC values due to variation in test design, and the potential dependence of the lowest toxicity value on the choice of database to characterize the toxicity of the substance.

If we accept using a fixed β value in Eq. 6, which is the most appropriate if the method is going to be functional in a normal LCIA context, then, despite the described differences in theoretical foundation, all PAF approaches described here lead to the following general characterisation factor equation:

$$CF = dPAF = EEI \cdot dC = \frac{k}{HC50} \cdot dC \quad (8)$$

(Eq. 8 was lacking on p. 32)

The constant k in Eq. 8 may be 0.59, as in the Eco-indicator 99 method (Goedkoop and Spruiensma 2001a, 2001b), 0.5, as in the average HC50-based approach or 0.2–43, as in the average HC5-based approach (Pennington et al. 2004). So, in the comparative approach applied in LCIA, there is no difference in practise between the PAF approaches, as long as the same value for HC50 and the same value for change in concentration (dC) are used. The key element in the effect indicator part ($k/HC50$) of Eq. 8 therefore becomes HC50.

The crucial point in the determination of a PAF-based ecotoxicity effect indicator is thus the data used and the principles applied for determining the HC50 value of each toxicant. As mentioned above, the HC50 may be estimated by use of e.g. NOEC values or EC_{50} values and based on the non-parametric median or the parametric geometric mean. Furthermore, the actual data used may, for example, reflect haphazard representation of species on each trophic level or a more realistic and consciously chosen representation of the structure of the ecosystem/community in question. The choice of data and estimation principle may therefore have significant influence on the outcome, especially when the amount of available data on each toxicant is low, which is the typical case within LCIA handling many chemical emissions. These issues are addressed in a second paper by the authors Larsen and Hauschild (2007).

Acknowledgement. Thanks to the two anonymous reviewers for extensive and constructive comments which have been incorporated. Also thanks to Jérôme Payet, EPFL, for stimulating discussions and comments on the draft paper. The authors also gratefully acknowledge the financial support of the Danish Ministry of Science, Technology and Innovation given to KEMI (Centre for Chemicals in Industrial Production).

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