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Do We Need a Paradigm Shift in Life Cycle Impact Assessment?

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Life cycle impact assessment (LCIA) aims to improve the understanding of the environmental relevancy of emissions and extractions in product life cycles. The approach of "marginal change" is generally advocated in LCIA.[1−3] It assumes that an additional amount of a certain stressor introduces very small changes on top of a ceteris paribus background situation. The change in impact per unit amount of additional "release" represents the relative importance of the stressor toward a specific area of protection, i.e., human health, ecosystem quality, and resource scarcity. This conversion factor is referred to as the characterization factor for the pollutant considered. The reasoning behind working with marginal changes is that in life cycle assessment (LCA) the focus is on small changes via the concept of the functional unit, e.g., what do we add in terms of environmental impact with the consumption of one liter of coffee?

A characterization factor expresses the fate, exposure, and effect of a stressor. For most impact categories, fate and exposure factors are derived with linear environmental models.[1] On the other hand, ecological effect factors are increasingly based on Species Sensitivity Distributions (SSD), expressing the nonlinear relationship between the Potentially Disappeared Fraction (PDF) of species and the concentration of a pollutant in the environment.[1−3] The ecological effect factor can be analytically derived by calculating the derivative of the SSD and depends on the working point and shape of the concentration−response curve.

The virtues of the marginal approach are that it aims to realistically describe the influence of a change in pollution load for that specific situation and that it promotes emission changes with the highest efficiency in terms of effect reduction, i.e., where the slope of the cause−effect curve is steepest. It is, however, the question whether the marginal approach is truly representing what we are looking for in LCA. For instance, the effect factor will approach zero, i.e., the slope of the concentration−response curve approaches zero, in cases of a high potentially affected fraction of species (dashed line in Figure 1 for freshwater eutrophication). This implies that in situations with high environmental pressure any additional input or reduction of pollution load is judged to be virtually irrelevant. This example points to a fundamental weakness in the marginal approach as employed in LCIA. Ultimately, LCAs aim to contribute in the long run to reach a state of the environment in which effect targets set by society are not exceeded. By focusing in LCIA on marginal changes only, there is little benefit in reducing pollution loads in situations with high environmental pressure.

We advocate to further explore the benefits of following an average approach in the derivation of characterization factors. This can be done by calculating the average distance between the current state and the preferred state of the environment per unit of concentration increase. In this case, the calculation of the effect factor still starts with the working point on the SSD which refers to the current state of the environment, but now reflects the average contribution to the preferred change instead of the marginal change as currently employed. As LCA is a source-oriented policy instrument, "zero effect" is also an option to be

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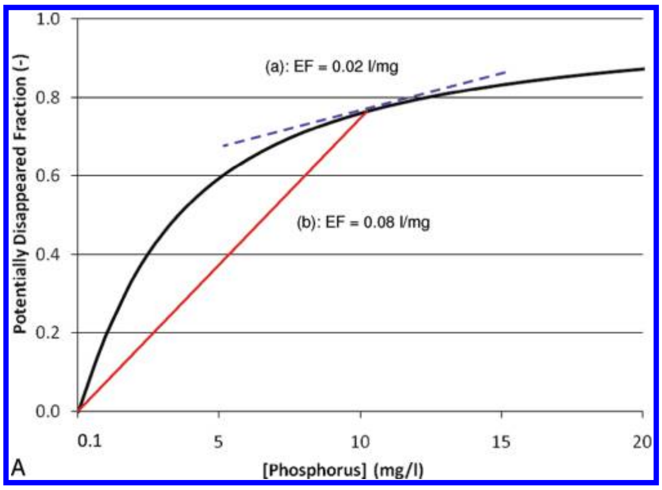

Figure 1. Derivation of effect factors following a marginal approach (a) and an average approach (b), for the impact of total phosphorus concentrations on freshwater macroinvertebrate diversity following a logistic concentration−response curve $PDF = 1/(1 + 4.07 \cdot Cp^{-1.11})$ and working point of 10 mg/L.[4]

used as the preferred state of the environment in the calculation of effect factors. The solid line in Figure 1 shows how to derive the average effect factor for freshwater eutrophication, i.e., calculating the average distance between current and zero effect per concentration unit. As an alternative, an acceptable effect target can also be used in the derivation of effect factors. In this case, the newly proposed procedure remains the same, with the exception that environmental targets defined by society are now taken as the preferred state of the environment instead of "zero effect". For instance, environmental targets, such as a maximum of 5% species affected, can be used for that purpose. Note that in the effect target-oriented approach the effect factor becomes essentially zero in the case that the current state of the environment is equal or below the environmental target. In this context, defining environmental targets can be done on various levels, such as the level of individual stressors, impact categories, or overall ecosystem quality. Following this average line of reasoning, LCIA would focus on reaching the preferable state of the environment defined by society, and not on marginal changes. The advantage of the average approach is that it adopts a long-term perspective, focusing on what society ultimately wants to achieve from an environmental point of view.

We showed how to apply the average method for calculating ecological effect factors of phosphorus concentrations (Figure 1). The differences between the effect factors derived with the marginal vs. the average approach can be larger than a factor of 2 particularly for high concentrations (> 5 mg/l total phosphorus). Although total phosphorus concentrations in surface waters are generally well below the 1 mg/l in developed countries, concentrations above 5 mg/l are occasionally measured.[4] SSDs are, however, not only available for phosphorus, but also for a wide range of other stressors causing ecological effects, including toxicant and greenhouse gas emissions.[1,2] Furthermore, nonlinear stressor-response curves are also applied in the calculation of human effect factors of various pollutants, including toxic chemicals, and for assessing fossil and metal resource use in relation to resource scarcity.[1]

For both marginal and average approaches spatial-explicit models are of high relevance. In a spatial-explicit derivation of characterization factors, the full range of environmental circumstances can be found with potentially relevant consequences for the effect factor calculations. In this respect, a comparison of the marginal and the average approaches is within reach by using spatial-explicit models in the derivation of characterization factors.[5]

To summarize, we recommend that the LCA scientific community reconsider its paradigm to preferably calculate characterization factors with the marginal approach. By using the average method, either following a "zero-effect" or an "environmental-target" approach, the characterization factor represents the average distance between the current and the preferred state of the environment per unit of emission. We consider that the average line of reasoning should receive much more attention and appreciation in prioritizing stressors in product life cycles, as it explicitly reflects the ultimate environmental goals we are aiming for in society.

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