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Commentary: Non-linearity in LCA – What are we talking about?

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A Commentary on

A more basic modeling framework for life cycle methods to cover non-linear, dynamic, and integrated effects. Looking beyond linear inverse modeling

by Schaubroeck, T. (2022). *Front. Sustain.* 3, 957017. doi: 10.3389/frsus.2022.957017

In a recent Opinion, Schaubroeck (2022) argues that the methodology for life cycle assessment (LCA) should be reconstructed, allowing for "non-linear, dynamic, and integrated effects", moving away from "linear inverse modeling," as it "impede[s] more accurate quantification". Schaubroeck (2022) extensively refers to our book *The Computational Structure of Life Cycle Assessment* (Heijungs and Suh, 2002) and suggests that our book presents the "linear inverse modeling" as the only conceivable approach to LCA computation.

In this response, we address three topics: (1) we clarify that our aforementioned book does not preclude other approaches to LCA computation than the linear approach, (2) we highlight other non-linear approaches to LCA in the existing literature, and (3) we comment on the proposed set-up by Schaubroeck (2022).

First, our book did not claim that "linear inverse modeling" is "*thé* mathematical framework." Schaubroeck (2022) writes that the equation like $h = QBA^{-1}f$ in Heijungs and Suh (2002) "should never have been introduced as *thé* mathematical framework" (italics and accent in original). We believe that this rendering is a simple misunderstanding.

- Our book is indeed entitled as "The Computational Structure of Life Cycle Assessment." But we were convinced that few, if any, would regard the use of "the" in the title as an indication that the book was presented as the only conceivable approach in the universe to LCA computation. Many books have titles that start with "The", while their authors were of course aware of that they only described a transient state of insights. Just think of John Maynard Keynes (*The General Theory of Employment, Interest and Money*), Sigmund Freud [*Die Traumdeutung* (meaning *The Interpretation of Dreams*)] or René Descartes [*Les Passions de l'âme* (meaning *The Passions of the Soul*)]. Did these authors impede, rather than promote,

the advancement of employment economics, psychoanalysis, and metaphysics, respectively, because they happened to use "the" in the title of their books? We will leave this to the readers to decide.

- Our book puts the emphasis on a "simplification" (see p. 11), while noting that "approaches toward accounting for non-linearities and dynamic situations are discussed in Chapter 9". We admit that non-linear and dynamic approaches are not elaborated at the same level of detail as the linear non-dynamic case. As we clearly stated in the book, however, the matrix-based approach should be regarded as a convenient and simplified approach, which is subject to further innovation and added complexity as necessary.

We therefore disagree with the view by Schaubroeck (2022) that our book impeded the advancement of the field by presenting the matrix-based approach as the only conceivable approach to LCA.

Let us also add that the term "linear inverse modeling", which Schaubroeck (2022) uses to describe our approach does not occur in Heijungs and Suh (2002). As far as we know, its first occurrence is by the author himself in Schaubroeck et al. (2013), citing Suh and Huppes (2005), who in turn do not use the term.

Second, non-linear LCA is not at all new. As a matter of fact, we contributed to the development of non-linear LCA. One of us (Suh) co-authored a recent paper on "Non-linearity in marginal LCA" (Qin et al., 2021) and the other (Heijungs) published another recent paper with an explicit section on "Nonlinear LCA" (Heijungs, 2020). Further, this journal (of which we are associate editor and chief editor) has an ongoing research topic "Non-linearity in Life Cycle Assessment", which has so-far featured several interesting articles that discuss approaches for developing non-linear LCA (e.g., Li et al., 2020; Pizzol et al., 2021). We believe that it would be important to understand the contribution by Schaubroeck (2022) in the context of these ongoing contributions to non-linearity in LCA rather than as a lone Copernican Revolution as the author seems to suggest.

Third, the proposed approach by Schaubroeck is unclear. Schaubroeck (2022) presents a "basic framework". The "basic general equation of a process" in Schaubroeck et al. (2021) is reproduced here:

$$\{F_x, F_v, \ldots\} = p_p\left(\{F_y, F_z, \ldots\}, t, OC\right)$$

in which the F-terms are flow amounts, t is time and OC are "other condition parameters that in this case might influence the process". Further, p_p is "a function that represents a certain process p (which may also be abstract)," according to Schaubroeck et al. (2021). First about the mathematical conventions in this notation: brackets, like $\{F_x, F_v, \ldots\}$ and $\{F_y, F_z, \ldots\}$, indicate sets, and the idea of having a function that takes a set as an argument and returns a set as a function value is completely unknown to us. It would help if just a small example would have been given. We are afraid that the expression is incomprehensible due partly to the 'unconventional' use of mathematical notations. Second, the function presented above is too abstract to be meaningful in our view. It was the British writer, Clive Staples Lewis, who famously said "You can make anything by writing." Likewise, we suppose that one may well define an abstract function as the function that governs how the entire universe operates given the set of all relevant inputs. How useful it is to merely define such a function, however, is the core of the issue.

We hope that this commentary helps clarify some of the misunderstandings and confusions that readers of Schaubroeck (2022) may have encountered.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

Publisher's note

References

Heijungs, R. (2020). Is mainstream LCA linear? *Int. J. Life Cycle Assess.* 25, 1872–1882. doi: 10.1007/s11367-020-01810-z

Heijungs, R., and Suh, S. (2002). *The Computational Structure of Life Cycle Assessment*. Dordrecht: Kluwer Academic Publishers. doi: 10.1007/978-94-015-9900-9

Li, D., Tao, M., Vieira, J., and Suh, S. (2020). The effects of incorporating non-linearity in LCA. Characterizing the impact on human health. *Front. Sustain.* 1, 569385. doi: 10.3389/frsus.2020.569 385

Pizzol, M., Sacchi, R., and Köhler, S. (2021). Non-linearity in the life cycle assessment of scalable and emerging technologies. *Front. Sustain.* 1, 611593. doi: 10.3389/frsus.2020.611593

Qin, Y., Yang, Y., Cucurachi, S., and Suh, S. (2021). Non-linearity in marginal LCA. Application of a spatial optimization model. *Front. Sustain.* 2, 631080. doi: 10.3389/frsus.2021.631080

Schaubroeck, T. (2022). A more basic modeling framework for life cycle methods to cover non-linear, dynamic, and integrated effects. Looking beyond

linear inverse modeling. *Front. Sustain.* 3, 957017. doi: 10.3389/frsus.2022.957 017

Schaubroeck, T., Alvarenga, R. A. F., Verheyen, K., Muys, B., and Dewulf, J. (2013). Quantifying the environmental impact of an integrated human/industrial-natural system using life cycle assessment. A case study on a forest and wood processing chain. *Env. Sci. Technol.* 47, 13578–13586. doi: 10.1021/es4046633

Schaubroeck, T., Gibon, T., Igos, E., and Benetto, E. (2021). Correction. Sustainability assessment of circular economy over time. Modelling of finite and variable loops and impact distribution among related products. *Resour. Conserv. Recycl.* 172, 105675. doi: 10.1016/j.resconrec.2021.105675

Suh, S., and Huppes, G. (2005). Methods for life cycle inventory of a product. *J. Clean. Prod.* 13, 687–697. doi: 10.1016/j.jclepro.2003.04.001