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Editorial: Non-Linearity in Life Cycle Assessment

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Editorial on the Research Topic

Non-Linearity in Life Cycle Assessment

Life Cycle Assessment (LCA) can provide a quantitative assessment of the environmental performance of an analyzed product or service. Traditionally, many underlying assumptions within LCA are linear in nature while the environmental mechanisms are not. Although these assumptions offer a pragmatic approach to conducting the LCA (i.e., simplifying the modeling framework and data requirements), a careful examination of their impact on the results of an LCA is warranted to better understand the applicability to real-world issues. In this Research Topic, six groups of authors presented their work on non-linearity in LCA from different aspects, ranging from considering various non-linear phenomena in predictive validity of models, developing methodologies for non-linear human health impact assessment, assessing the non-linear marginal impacts due to scaling emerging technologies and spatial characteristics, and quantifying use phase impacts of battery electric vehicles with non-linear consequential LCA.

In their Review article, Huppes and Schaubroeck focused on the qualitative predictivity of different models regarding novel technologies with a long-term horizon. At the core, the pathways from current assumptions to future realities are uncertain and dynamic, which creates the challenge for models built "now" to predict relevant environmental consequences in the "future." The authors compiled a checklist involving real-world relevancy of analyzed technology/product, model complexity, and feedback from the real-world due to the technology/product. The authors then examined how valid the predictivities of nine types of models of different combinations of characteristics in sequential modeling of processes, period of processes, scale level of the study, futures, and choice systems.

In their article, Li et al. explored the differences in calculating human health toxicity in LCA when using conventional steady-state models versus other dynamic and non-steady-state models. Specifically, the authors evaluated the exposure and impacts due to different emissions scenario such as (i) constant emissions, (ii) workday emissions, and (iii) pulse emissions. The results demonstrate obvious differences in the way environmental concentrations, exposures, and impacts can be estimated under these scenarios, particularly for non-constant emissions. Pulse emissions, for example, are interpreted by steady-state models as low exposures since the single pulse is averaged over time, while the dynamic model can capture these large spikes in concentration, exposure, and risks. Ultimately, this paper demonstrates the caution that LCA practitioners need to take when interpreting their results, particularly for non-constant emission sources. Traditionally, characterization factors are used to linearly scale chemical emission to human health impact, by assuming a homogeneous exposure and toxicological susceptibility for the entire population. Li and Li explored the interactions between inter-individual variabilities in human exposure and toxicological susceptibility affect the estimated overall health impacts on the population. The PROTEX model was used to simulate the exposure of a population to dieldrin and heptachlor,

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which tend to accumulate in food items. By considering variations in anthropometrics and dietary patterns between ages, sexes, and racial groups, the authors assessed the overall health impact on the population in five scenarios, which contain different combinations of assumptions in exposure (homogeneous/ heterogeneous) and the dose-response relationship (linear/non-linear, homogeneous/heterogeneous susceptibility). They found that human exposure can vary by a factor of six among the different demographic groups. Specifically, they found that with a non-linear dose-response relationship with heterogeneous susceptibility, the estimated overall health impact is substantially higher than when the susceptibility is assumed to be homogeneous.

Pizzol et al. focused on how life cycle inventory could change non-linearly as emerging technologies scale up. In their article (add link later), a computational simulation based on ecoinvent database was first performed to theoretically explore the effects on life cycle inventory from increased efficiency from technology upscaling or learning effects. The authors then conducted two case studies to further illustrate the differences in results using linear and non-linear life cycle inventories. The first case study considered the load factors and drive train technologies for freight transportation. The second case study investigated the change in environmental impact due efficiency improvement in Bitcoin mining from both mining equipment and location changes.

Qin et al. demonstrated a spatial optimization technique for modeling marginal responses of a multi-producer, multi-consumer system. In essence, their model determines the optimal production-by-location mix and associated environmental stressor at minimum systems cost for a case study on blue water consumption by potato. The authors found that, based on 2016 demand, the cradle-to-gate blue water consumption of potatoes was 96 m^3/ton potato, and the volume of water consumption increases non-linearly with the growth in potato demand. When they modeled the marginal impacts when there is higher fuel tax and higher water price in a particular scenario where the dietary demand adheres to USDA's recommendation, they found that water price is more effective in reducing marginal blue water consumption of potato.

In their article, Rovelli et al. use couple consequential LCA and non-linear inventory modeling to better expose the links between increased use of battery electric vehicles and the marginal electricity supply and its influence on LCA impact calculations. By using dynamic models, the authors were able to capture differences in the electricity mix depending on the amount of BEV penetration in the market as well as the time of day of charging. This contrasts with conventional consequential LCA which would assume that the grid mix does not respond to these differences. The results highlight several important non-linearities in the LCA results, such as the assumed change in electricity mix depending on the time of day of charging a BEV and perhaps more notably the increase in climate change impacts if additional renewable sources are not added to the grid to account for the increased charging demand.

The body of work presented in this Research Topic provides a discussion non-linearity in LCA. Addressing non-linearity is particularly important when the analyzed technology/product is an emerging one, temporal fluctuation of emissions is substantial, scaling of production has large influence on the life cycle inventory, and diversity of impacted population is considered. Challenges remain in data availability for adopting non-linear assumptions in LCA, while new methodology development is also needed.

AUTHOR CONTRIBUTIONS

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

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.