Letter to the Editor

Response to Comments on "Using Attributional Life Cycle Assessment to Estimate Climate-Change Mitigation . . ."

We thank the authors of the three letters (Hertwich 2014; Brandão et al. 2014; Dale and Kim 2014) for taking time to respond to our article (Plevin et al. 2014). Although the letters raised numerous interesting issues worthy of discussion, we found that many of the critical comments addressed issues outside the scope our article. Rather than exhausting our limited space arguing against what we did not write, we focus here on issues discussed in the article. We leave it as an exercise for the reader (and perhaps the letter writers) to compare the original article to the claims made in the letters.

It is Useful to Distinguish Attributional Life Cycle Assessment from Consequential Life Cycle Assessment

The attributional and consequential life cycle assessment (ALCA/CLCA) dichotomy continues to be described and defined in recent articles and standards. The literature is quite clear on this distinction: CLCA attempts to estimate the net change of an action or decision; ALCA does not. The problem is not the dichotomy per se, but rather that these two quite distinct approaches are treated as alternative means to the same end. Our article shows that ALCA often is applied and interpreted as if its results represented the *consequences* of an action, and that this interpretation is incorrect.

For the purpose of estimating climate-change mitigation potential, only a change-based analysis is relevant. To mitigate climate change is to reduce climate change relative to some baseline case without the activity. This is essentially the definition of CLCA. ALCA cannot perform this task, unless one assumes that ALCA is a good proxy for CLCA. Therefore, in this application, CLCA clearly is superior methodologically, though, as we have written, there are important implementation challenges.

Attributional Life Cycle Assessment Does Not Estimate Effects; It *Attributes* Them

ALCA does not "identify the share of total pollution *caused* by a specific product," as Hertwich stated (emphasis added) (Hertwich 2014). ALCA is an accounting system that *attributes* a share of total pollution to a specific product. To estimate the effect of an action (including changing the quantity produced from some product system) requires a comparison of a baseline world without the action to a world with the action (WRI 2013). This describes CLCA, not ALCA. Again, if by ALCA one means a certain set of simplifying assumptions within a consequential framework, then the issue becomes the validity of those assumptions, which is an empirical and analytical question to be considered case by case. In any case, the fact that ALCA, as it normally is understood, does not even attempt to estimate change—and, more specifically, climate-change mitigation—was the main point of our article.

Mixing Attributional and Consequential Life Cycle Assessment Produces an Analysis that Has No Clear Meaning

We recognize that, in practice, many studies mix elements of ALCA and CLCA, but we find these mixtures incoherent. The hybridization of process-based LCA with environmental input-output (EIO) LCA is coherent because both methods are based on physical input-output relationships and rely on a linear, static framework devoid of market feedbacks. Conceptually and structurally, EIO is a version of ALCA, with an expanded, more interconnected set of processes than in what might be called "traditional" once-through process-based LCA.

In contrast, as we point out in the article, if CLCA answers the question "what is the net effect of an action" and ALCA answers the question "what portion of total pollution can I attribute to product *system X*," then ex hypothesi combining ALCA and CLCA does not provide a coherent answer to the question of interest, which, for us, is the climate-change mitigation potential of particular actions. If, however, what one means by ALCA is, for example, the use of average values to approximate marginal effects, then this is no longer a problem of the incoherence of combining ALCA and CLCA because they are traditionally understood, but rather a question of the validity of certain simplifying assumptions within a "consequential" framework. In general, this is an important question for another article; here, we reiterate the importance of distinguishing between the inappropriate application of ALCA as recognized in the literature and the question of the appropriateness of certain (ALCA-like) simplifying assumptions in CLCA.

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Consequential Life Cycle Assessment, Completeness, and Uncertainty

In our article, the value of discussing *ideal* CLCA is that it offers a benchmark against which simplifications can be compared. We believe it is better to first recognize and account for all potential real-world complexities, then determine which are likely to be important to the metric of interest, and then figure out how best to represent the important ones. There is no theoretical or empirical basis for assuming a priori that all of the complexities left out of traditional ALCA are unimportant.

We emphasize here the point made in our article that excluding uncertain elements of an analysis does not increase certainty; it sweeps it under the rug. We have argued before that a more complete description or modeling of an open system does indeed entail a loss of precision and an increase in uncertainty (Creutzig et al. 2012). But, the uncertainties imposed by the nonlinear, nondeterministic, nonstationary, global economy are present whether they are included in a model or not. Recent scholarship suggests that capturing these effects in our estimates of climate-change mitigation is important; omitting them risks producing very misleading results.

Hertwich asks whether CLCA should be product or policy focused. In our view, it can be either, so long as the product-focused analysis is about a change in production volume. CLCA cannot address a static system, but either a change in production (for whatever reason) or a policy that affects production can be analyzed. When analyzing the effects of an increase in production of biofuels, the effect on the gasoline or petroleum market is part of the analysis rather than simply an assumption of perfect replacement.

Integrated Assessment Models are Helpful, but They Do Not Offer a Complete Solution

Hertwich argues that LCA should stick to the analysis of the product system, but refrain from analyzing a complete set of consequences, which, as he rightly points out, would involve taking myriad effects into account. His basic claim is that this is not necessary because established integrated assessment models (IAMs) already deal with these effects. We disagree. As we have argued before (Creutzig et al. 2012), IAMs and ALCA occupy opposite poles. At one extreme, ALCA offers detailed process and technology representation, but its description of product systems remains insufficient for understanding overall climate impacts. At the other extreme, IAMs offer a more complete representation of complex market and ecological interactions, but lack the process detail of LCA, often lack technological detail, and generally do not investigate all of the relevant consequential effects. Thus, significant disjunctures remain between the space covered by ideal CLCA as we define it and the space covered by IAMs.

We agree with Hertwich that there is no reason to reinvent the wheel. To estimate climate-change mitigation effects, a change-based analysis is required; whether we call this CLCA with broad market linkages or integrated assessment modeling with improved technological detail is immaterial.

Economic Models Are Indeed Far From Perfect

Dale and Kim (2014) wrote that the economic assumptions underlying some CLCA models are not grounded in reality. Though it is true that some of the structural assumptions of economic models can be unrealistic (e.g., the assumption that utility and profit maximization alone determine the relevant human decision making in the economic/environmental/technological systems of interest), and that the empirical bases for specifying economic models often are poor, these are reasons to develop better models of human economic decision making and get better data, not reasons to ignore such decision making altogether. ALCA essentially assumes that consequential economic effects are zero, which is certainly a worse estimate than using whatever data and tools are available to estimate a broad range of plausible consequential effects as done in CLCA.

We want to emphasize that we agree with Dale and Kim when they point to the importance of constantly scrutinizing the structure and empirical foundation of economic models. Taken one step further, we argue that the debate should shift toward identifying the most plausible assumptions for consequential modeling. As we wrote in our article, we believe the best use of consequential analysis is to illuminate the plausible range of outcomes, and to achieve this, a large number of scenarios and models should be employed.

Falsifiability is Not the Only Measure of Value

Dale and Kim argue that attempts to model unintended consequence are "not based on science" because they cannot be tested and falsified. It is well known that models of open systems cannot be verified (Oreskes et al. 1994), although there are methods of validating the performance of some individual components. Regardless, if one believes we have a responsibility to consider the consequences of our actions, then we must use the methods available to do this, whether or not they are verifiable or falsifiable as a whole. As we wrote, one rational way to do this is to examine a large number of plausible scenarios, using multiple methods. This provides information that can guide action, and this informed guidance is better than no guidance at all.

We agree with Brandão and colleagues (2014) that modeling climate mitigation effects fits the definition of "postnormal science" in which uncertainties and stakes are high, and decisions must be made despite imperfect knowledge (Funtowicz and Ravetz 1994). Analysis supporting decisions about mitigating climate change—the focus of our article—is perhaps the classic example of postnormal science.

Summary

The main point of our article was to caution against using ALCA to estimate climate-change mitigation effects. "Mitigation" implies a reduction from a baseline, and ALCA is not designed to estimate change. ALCA also omits critical features relevant to estimates of climate change mitigation effect, namely, market-mediated effects and emissions therefrom. We argued that using ALCA to estimate mitigation can therefore produce misleading results. We argue instead for acknowledging complexity and uncertainty, incorporating these into the analysis, and being clear about these when communicating results.

We acknowledge that modeling complex systems, such as the global economy, poses many challenges. However, if our goal is to understand and compare the efficacy of alternative climate-change mitigation strategies, we must choose between attempting to model reality—if coarsely—and ignoring the challenging aspects of reality in the hope that this does not produce misleading results. If we recognize the limitations of the models we use—and the resulting uncertainties—we provide policy makers with a better understanding of what is known or unknown and how this uncertainty translates into risk. We believe that this approach, rather than presenting the false precision of oversimplified models, will produce better-informed decisions.

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