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Review article

Type and number of environmental impact categories used in livestock life cycle assessment: A systematic review

S.C. McClelland[a,b,*], C. Arndt[a], D.R. Gordon[c,d], G. Thoma[e]

[a] Environmental Defense Fund, 123 Mission Street, San Francisco, CA 94105, USA
[b] Colorado State University, Fort Collins, CO 80523 USA
[c] Environmental Defense Fund, 1875 Connecticut Ave, NW, Washington, DC 20009, USA
[d] Univeristy of Florida, Gainesville, FL 32611 USA
[e] University of Arkansas, Bell 3149, Fayetteville, AR 72701, USA

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ABSTRACT

Life cycle assessment (LCA) is an important tool to evaluate environmental 'hot spots' in livestock systems and recommend production improvements. However, it is common for livestock LCA to investigate only a narrow subset of environmental impacts to simplify results for decision-makers, which makes it difficult to fully understand the tradeoffs among environmental impacts and identify the most relevant mitigation options. We completed a systematic review of the livestock LCA literature to better understand the impact categories included and the progress made towards more comprehensive LCA. Our search of publications between 2000 and 2016 identified 173 relevant peer-reviewed papers. Nearly all the publications (98%) included climate change as an impact category and almost one-third of the publications (28%) focused solely on that one category. Biodiversity, ionizing radiation, and particulate matter were the least common categories addressed. Cattle LCA, including dairy or beef, were the livestock species most frequently evaluated. Our analysis shows that while the number of multi-category livestock LCA (LCA with 4 or more impact categories) increased over time, LCA including 1–3 impact categories (which we define as "simplified LCA") increased at a higher rate than multi-category LCA. Simplified LCA therefore remain the most prevalent in the literature. Publications that included multiple impact categories were better able to identify environmental impact tradeoffs among livestock production systems and management scenarios. To compare results across livestock LCA studies, it is necessary to increase the standardization of system boundaries, functional units, impact frameworks and mandatory inputs. The optional steps of normalization and weighting in the life cycle impact assessment can also help decision-makers prioritize which environmental impacts to address. More work that includes a greater number of impact categories in livestock LCA is sorely needed to more fully understand and to harmonize the communication of the environmental performance of livestock production systems.

1. Introduction

The global demand for livestock products is expected to increase by 70% by 2050 (Opio et al., 2013), underscoring the importance of minimizing environmental impacts incurred during livestock production. These impacts are well documented: livestock production is a major contributor to greenhouse gas emissions (GHG) (Steinfeld et al., 2006), water consumption and pollution (Mekonnen and Hoekstra, 2012), land-use and land-use change (FAO, 2009), and loss of biodiversity (Herrero et al., 2009). However, livestock production systems are a critical source of protein and socio-economic income in much of the developing world (Randolph et al., 2007) and in developed regions (White and Hall, 2017). Additionally, under certain management practices, livestock may increase soil carbon sequestration potential (Reeder and Schuman, 2001; Rowntree et al., 2016), promote bird habitat (Derner et al., 2009), and improve grassland heterogeneity (Wrage et al., 2011).

Substantial efforts in the public and private sector are underway to increase the sustainability of livestock production. Policies aimed at improving environmental performance can be found in California – the United States' leading milk producer – which recently passed legislation to adopt regulations "to reduce methane emissions from livestock manure and dairy manure management operations by up to 40% below the dairy sector's and livestock's sector's 2013 levels by 2030 (SB-, 1383,

* Corresponding author at: Environmental Defense Fund, 123 Mission Street, San Francisco, CA 94105, USA.
E-mail address: shelby.mcclelland@colostate.edu (S.C. McClelland).

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2016; http://www.leginfo.ca.gov/). Australia and Canada have also taken steps to reduce livestock's climate impact through the Carbon Farming Initiative (C2011A00101, 2011) and Alberta's Greenhouse Gas Reduction Program (Alberta and Alberta, 2017), respectively. In Europe, the European Commission established the Product Environmental Footprint, which includes livestock products, as a method to communicate environmental performance throughout a product's lifecycle (European Commission, 2016a). Other initiatives include the Livestock Environmental Assessment and Performance (LEAP) partnership, a multistakeholder group focused on improving the environmental, economic, and social viability of livestock supply chains (FAO, 2017).

Policies and supply chain initiatives are increasingly based on whole-farm or life cycle assessment (LCA) in order to identify environmental 'hot spots' and improve production (UNEP/SETAC, 2012). Life cycle assessments quantify the potential environmental impact of a product from the raw materials' extraction to final disposal, including direct and indirect effects of production and consumption on issues like land and resource use. The practice of LCA is guided by standards published by the International Organization for Standardization (ISO, 2006a, 2006b) and includes four main steps: (1) goal and scope definition, (2) life cycle inventory analysis (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation of results. Optional steps in the LCIA include normalization and weighting, which can help decision-makers interpret LCA results and determine where to prioritize efforts aimed at reducing a product's environmental impact (Laurent and Hauschild, 2015). The final interpretation step summarizes and discusses the results of the LCI and LCIA (ISO, 2006a, 2006b).

Life cycle assessments are widely used across the livestock industry. De Vries and de Boer (2010) reviewed 21 LCA that examined the environmental impacts of pork (five studies), chicken (two studies), beef (three studies), milk (nine studies), and egg production (two studies) in different countries. More recent work investigating LCA of global beef production (de Vries et al., 2015) identified 16 different studies in North America (six studies), Europe (eight studies), and Oceania (two studies). The growing prevalence of livestock LCA in the peer-reviewed literature has led to greater acceptance of this methodology as a means of accounting for the full scope of environmental impacts from the livestock sector (Roy et al., 2009). The European Commission, for example, established the European Platform on Life Cycle Assessment, which recommends the use of LCA for measuring and communicating the life cycle environmental performance of a product (EU, 2015, 2016). Unlike other efforts, the guidance provided by the European Commission requires that at least three impact categories be included in the LCA (European Commission, 2016b).

The inclusion of livestock LCA studies in regulatory or other decision-making frameworks is based on the underlying assumption that the methodology captures the entirety of the product's environmental impact. However, it is common for livestock LCA to investigate only a narrow subset of environmental impacts in order to simplify results for decision-makers (Van Hoof et al., 2013). In their review of beef LCA, de Vries et al. (2015) found that all studies included the midpoint impact climate change in the LCA, but only half the studies or fewer examined land-use, energy use, eutrophication potential, and/or acidification potential. In LCA, a midpoint category describes a proximate impact along the environmental chain that can be measured before the endpoint impact is realized (e.g., GHG emissions are a midpoint indicator for average global temperature changes) (Jolliet et al., 2003).

In the absence of clear communication and justification for simplified LCA (e.g., carbon and water footprints or single attribute LCA), a narrow focus leads to the oversimplification of results and makes it difficult to determine the full scope of a product's environmental impacts. While simplified LCA, i.e., LCA with 3 or fewer impact categories, are valuable tools to conceptualize specific environmental impacts, they cannot accurately reveal the trade-offs that exist among different impacts and mitigation options, introducing the possibility of shifting environmental burden from one impact to another (Teillard et al., 2016).

The surge of simplified LCA publications in the livestock literature has led to calls within the scientific community for more comprehensive livestock LCA and greater transparency when interpreting study results (Roy et al., 2009; Teillard et al., 2016; Thoma et al., 2013a, 2013b). To date, most reviews of the livestock LCA literature focus on one livestock species (de Vries et al., 2015), recent methodological advances (Roy et al., 2009), or review and compare the results for a few environmental impacts (de Vries and de Boer, 2010; Garnett, 2009; Nijdam et al., 2012). We address this gap in the literature by completing the first systematic review of all livestock LCA to characterize the inclusion of environmental impacts. The objectives of our review were to: (1) quantitatively characterize the impact categories in the livestock LCA literature, (2) identify and review studies that examine 10 or more impact categories, and (3) evaluate the livestock LCA literature to benchmark the progress made towards more comprehensive analyses. We hypothesized that the attention given to this topic would have resulted in an increase in the numbers of impact categories in published LCA over time.

2. Methods

2.1. Literature search

We searched for articles using the terms "livestock" AND "LCA" or "livestock" AND "life cycle assessment" or "livestock" AND "life cycle analysis" in the 'topic' fields on the Web of Science and EBSCO database. In both databases, we searched for papers published between January 1, 2000 and December 31, 2016 (inclusive). Furthermore, we supplemented our results with papers included in a previous livestock LCA review that spanned 2000 – 2013 (Thoma, 2015). We also cross-checked references in papers we categorized as "reviews" and included the publications that were not captured if they met our inclusion criteria (see below).

2.2. Screening process

Our systematic review process closely followed Gurwick et al. (2013) and the guidelines in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (Moher et al., 2009). We excluded search results that were published in languages other than English and results where only an abstract was included. The remaining results were placed into one of two categories. The first category included papers that appeared in peer-reviewed publications and reported original data or results from observations, experiments, or models. These papers were LCA or partial LCA with minimum system boundaries from cradle-to-farm-gate with a livestock product (e.g. "1 kg of energy-corrected milk" or "1 kg of beef") as the functional unit. We excluded papers based on a footprint analysis (i.e., carbon footprint, water footprint, energy footprint) unless the study methodology explicitly mentioned undertaking an LCA, rather than a footprint, approach. Footprint analyses, by their very nature, focus on only one impact category, and excluding them in our inclusion criteria reduced the potential for introducing bias into our results.

The second category included all the publications that did not meet our inclusion requirements. We did not include in this analysis other publication types like news stories, book chapters, or editorial notes. Additional results excluded were papers that did not include a livestock LCA despite being identified in our search, papers that evaluated or described an improved method for analyzing the life cycle of livestock but did not contain an LCA, or papers that did not meet the system boundary requirements listed above, e.g. conducted an LCA for livestock feed or manure handling for energy production.