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Review

Streamlining life cycle inventory data generation in agriculture using traceability data and information and communication technologies – part I: concepts and technical basis

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ABSTRACT

Quantitative environmental assessment methodologies such as life cycle assessment demand significant time and resource inputs during the data acquisition and life cycle inventory (LCI) phase. Approaches to streamline the LCI data collection process without degrading data quality are therefore required. This requirement is especially true for agricultural products, as agricultural systems are inherently 'open' and complex. We present a two-part paper on this topic. In this first part, we examine streamlined methods for LCI data collection in agriculture by using today's voluntary or compulsory farm traceability information systems and related information and communication technologies (ICTs), with the aim of later converting them into LCI data. The second part is to examine the application of these technologies in a case study.

Our hypothesis is that both traceability data and ICTs could be major drivers for generating accurate, relevant and low-cost LCI data for use in quantitative environmental assessments of agricultural product performance. To that end, we identified the types of data being collected in agriculture as a part of current business practice, especially those with relevance to LCA studies. We also examined the status and current trends in ICTs in use in agriculture to identify the potential for automating LCI data generation. The review identified considerable potential to piggy-back current trends in ICTs in agriculture with the goal of simplifying LCI data collection.

This study concludes that given the increasing need to collect traceability data in modern agriculture and the parallel growing adoption of information and communication technologies, it is likely that ICTs and associated information systems will represent an important potential route for the acquisition of future LCI data.

1. Introduction

The global push to achieve sustainability in agricultural practices during the coming decades is a primary driver of change for agriculturalists and policy-makers alike (Tilman et al., 2002). To this end, there is growing demand worldwide for information on the environmental performance of agricultural products. Life cycle assessment (LCA) (ISO, 2006) is an internationally-recognised method for evaluating the environmental performance of products and/or services, first standardised in 1997; however, the extent to which LCA is actually applied by small- to medium-scale enterprises (SMEs) remains limited (Ansems et al., 2005). The main

Abbreviations: LCA, Life Cycle Assessment; LCI, Life Cycle Inventory; ICT, Information and communication technology; tr-data, Traceability data.

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obstacles for wider application of LCA in SMEs continue to be the amount of resources and level of operator competence required to conduct LCAs (Gonzalez et al., 2002; Ansems et al., 2005; Zackrisson et al., 2008). Indeed, this issue in the agricultural and food production sectors was highlighted in the introduction to the Second European Invitational Expert Seminar on Life Cycle Assessments of Food Products (Weidema and Meeusen, 2000) which suggested that the important future challenges for LCA relate not so much to methodological issues, but rather to furthering its practical application.

To address this challenge, the simplification of LCA is viewed as a necessary, ongoing step among the LCA community. A "Streamlined LCA" group was created by SETAC in Europe and in the US in the mid-1990s and a conference on the issue was held in 1995. In spite of the various suggestions offered by Todd and Curran (1999) for streamlining LCA, more than a decade on, issues surrounding how best to simplify the most demanding life cycle inventory (LCI) phase still remain. For example, an assessment of recent developments in LCA (Finnveden et al., 2009) highlighted the fact that LCI data acquisition remains one of the most labour- and time-intensive stages of LCA and is often complicated by the lack of appropriate data for the product system under study. In the context of agricultural systems, LCI data collection is further complicated by the inherently 'open' nature of system activities wherein processes are generally much more diverse and multifaceted than in the industrial world (Lewis et al., 1999) and highly influenced by uncontrollable external factors such as soil and climate conditions. This susceptibility of agricultural systems to natural stochastic variability makes system generalisations difficult and reliable emissions data hard to collect (Lewis et al., 1999).

Accordingly, the aims of this paper are: (i) to explore ways of streamlining LCI data collection in agriculture; (ii) to consider farm traceability and information systems and demonstrate how they could potentially contribute to the objective of streamlined LCI database development; and (iii) to show how today's innovative information and communication technologies (ICTs) could facilitate LCI data collection by expediting and simplifying the process. Additionally, the general concepts of LCI data generation based on ICTs as well as the potential overlapping interests this may present for these two communities (LCA and ICT ones) are discussed. This paper is to be followed by Part II which is dedicated to the application of these principles to a viticultural case study.

2. Generating LCIs in agriculture

LCI is the second phase of the internationally standardised ISO 14040 LCA method (ISO, 2006) listing inputs and outputs to and from a given system. Different types of data can serve as LCI data for LCAs, for example, primary data (emissions/consumptions directly related to a specific process), secondary data (aggregated data), process data (related to a specific process), input–output data, extrapolated and proxy data (WRI and WBCSD, 2010). This data categorisation reflects previous work (Finnveden et al., 2009) that defined two types of data: aggregated and unit process data. Unit process data corresponds to primary and process data, while the aggregated data corresponds to the secondary and input–output data types (WRI and WBCSD, 2010). Unit process data are considered the most preferable if the LCA is related to that particular process; they can be in the form of either direct environmental emission measurements (e.g., greenhouse gas production) or activity data such as a quantitative measure of a level of activity that results in emissions or consumptions (e.g., volume of fuel used etc.). Activity data are then multiplied by an emission factor, generally with generic default values (e.g., IPCC emission factors) to derive the emissions associated with a process or an operation.

Unlike industrial systems, the 'open' nature of agricultural systems, combined with their susceptibility to uncontrollable soil and climatic variables (Langevin et al., 2010), presents problems for measuring environmental emissions and balancing system inputs and outputs (Lewis et al., 1999). For these reasons, the most commonly applied strategy is to collect on-farm activity data (e.g., crop density, fertiliser and pesticide application regime, hydrological conditions, machinery use, etc.) and to convert these into emissions data using emission factors. A farm activity inventory can be made either top-down by allocating farm-scale aggregated data, activity by activity (where the farm has multiple product outputs), or bottom–up by collecting on-farm activity/process data, process-by-process. The top-down approach has been achieved using farm accounting data that every European farmer compulsorily records (Eide and Ohlsson, 1998; Poppe and Meeusen, 2000; van Lierde, 2000; Dalgaard et al., 2006) and which may be aggregated at regional or national levels by Farm Accountancy Data Networks (FADNs) (van Lierde, 2000). LCI and farm accounting data share a common requirement for enumerating production system inputs and outputs and therefore, farm accounting data could potentially be exploited to generate agricultural LCIs. However, because farm accounting data only details bulk material and energy inputs and outputs, and since farms generally produce a range of different outputs, time-consuming allocation of resource inputs and waste emissions among the different co-products is required, with dubious results (Poppe and Meeusen, 2000). Other researchers (Poppe and Meeusen, 2000; Mourad et al., 2007) have compared this "farm accountancy" approach (also called "the survey approach") for generating LCI data with what they called the "engineering approach". The latter is based on the definition of technical activity coefficients for the processes on an average farm in a given region. Coefficients are provided by experts based on experience and on a one-off questionnaire among farmers who are required to remember details of their 'normal' yearly practice. Aside from these approaches, which are considered relatively time-consuming and potentially erroneous, we propose another approach, the "traceability approach", using on-farm "traceability data" (hereafter "tr-data") collected via ICTs, that would allow emissions computation from "activity" data collected for traceability purposes and has the potential for rapid application in agricultural LCAs.

3. Farm traceability systems for generating LCI data

Traceability is defined by the International Organization for Standardization as the "ability to trace the history, application, or location of *that which is under consideration*". A distinction has to be made between so-called "internal" and "external" traceability. External traceability refers to the ability to keep track of what happens to a product, its ingredients and packaging throughout the *entire supply chain* or part thereof. Internal traceability is the ability to keep track of what happens to a product, including ingredients and packaging *within* a company or production facility. We consider internal traceability systems to be most reliable and appropriate for generating LCI data, as they gather data on the processes the product has been submitted to. Therefore, and throughout the following, "traceability data" (tr-data) encompasses all data that is recorded on the farm for *internal* traceability purposes.

Tr-data are not LCI data as such, but rather "activity" or "process" data. Such data, however, can easily be converted into LCI data by using: (i) LCI databases (e.g., EcoInvent®) to make the inventory of consumptions/emissions during the production phase (also called background processes) of the inputs used and; (ii) models of emission and environmental behaviour, which convert the quantity of inputs applied into pollutant emissions reaching the various compartments (Poppe and Meeusen, 2000; Langevin, 2010). For