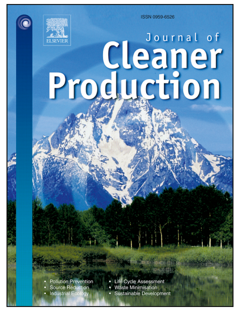

LCA data quality: A management science perspective

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LCA data quality: a management science perspective

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Highlights

- From a management perspective, LCA constitutes a passive user-based tool.
- The current prevailing LCA approach of data quality assessment is inadequate for enterprise-specific data.
- Concrete suggestions for consistent LCA data quality assessment are provided.

Abstract

Companies represent essential sources of data for Life Cycle Assessment (LCA). However, management systems and management approaches are rarely informed by LCA data developments, and vice-versa. The present paper focuses on the role of the company in the LCA data collection process. The objective is to investigate the adequacy of the current LCA data quality assessment approach from a management perspective. This is accomplished by applying the ecoinvent Data Quality System (DQS) to a primary LCA data collection project, including an immersion within the organisation and taking subjective experiences into account during the data collection process. Our analysis relies on two theoretical fields in management sciences: first, management tools and second, environmental accounting. The study demonstrates that the current prevailing LCA data quality assessment approach is inadequate for enterprise-specific data because it focuses uniquely on industry average data. The study also indicates that LCA constitutes a passive user-based tool. Hence, the drawbacks related to data management and control within the organisation are completely neglected in LCA developments. Finally, our analysis provides concrete suggestions for allowing consistent data quality assessment that would ensure the usefulness of LCA information.

Keywords

LCA, data quality, environmental accounting, management tools

1. Introduction

Life cycle assessment (LCA) is a methodology used to quantify the environmental impacts of products by taking into account all the production and consumption stages, from the production of raw materials to the end of life, including all intermediate steps. Companies can rely on LCA to identify, assess, consolidate, interpret and disseminate data on the environmental impacts generated by their activities. Hence, in management sciences, LCA is commonly known as an environmental management accounting (EMA) tool (Burritt *et al.*, 2002; Antheaume and Christophe, 2005; Richard, 2009, 2012).

According to Schaltegger and Burritt (2000), environmental accounting can be defined as a subset of accounting that addresses "activities, methods and systems as well as recording, analysis and reporting of environmentally induced financial impacts and ecological impacts of a defined economic system (*e.g.*, firm, plant, region, nation, etc.)" (p.63). Environmental management accounting (EMA) implementation usually refers to the tools that should allow: *i)* "(…) to complete what "counts" in the management accounting by considering the physical flows and the costs that the company causes to others due to its activities; and *ii)* to expand the categories of actors to whom the business is accountable" (Antheaume and Christophe, 2005, p.3). From this perspective, LCA can help to ensure better internal management and decision-making (*e.g.* promoting cleaner production, improving eco-efficiency and calculating savings within organisations), and also serve as a basis for external accounting (*e.g.* providing necessary data for environmental regulatory agencies) (Jasch, 2005). From a broader perspective, LCA constitutes a management tool. Moisdon (1997) defines management tool as "a formalization of organised activity, (…) any system of reasoning that formally links a certain number of variables within an organisation, designed to provide information for the different acts of management, which can be grouped under the terms of the trilogy: plan, decide, control".

Life Cycle Inventory (LCI) requires extensive quantities of data from companies. Activity data is necessary for the assessment of foreground processes (*i.e.*, core processes, directly related to the product system at stake) and background processes (*i.e.*, not specifically related to the product system). These processes comprise input and output flows. Input flows include consumed products (*e.g.*, materials, services, consumables, etc.), input of wastes (in the case of waste management services) and resources from nature (*i.e.*, from ground, water, air, biosphere, land, etc.). Output flows comprise wastes (*e.g.*, solid, liquid and gaseous waste for waste management), emissions to air, water and soil as well as the final goods and services being produced. Each of these flows includes several variables (*e.g.*, productivity, distance travelled, types of transport used, quantities of materials and energy used, etc.) that might be taken into consideration during the data collection (European Commission, 2010b). Background processes' data related to basic commodities are common secondary data sources for LCA practitioners. These data can be found in LCA databases and their availability is essential for the creation of LCA studies. Also, their use in parts of the core processes (foreground system) can reduce the cost and minimise the time and effort required to conduct LCA studies (Zimmermann *et al.*, 1996). In some cases, industry average data related to the core system can be even preferable to specific data (*e.g.*, systems including purchases from multiple sources). In contrast, when average values are incompatible with LCA applications of particular production systems (*e.g.*, for a situation where specific supplier is used), enterprise-specific data should be collected, at least for the foreground processes.

Figure 1. Common approach of data collection in LCA

Data quality may largely determine LCA results (Guinée *et al.*, 2002). Data quality management based on the application of data quality indicators (DQIs) is strongly recommended in the literature in order to ensure LCA usefulness and reliability (Weidema and Wesnaes, 1996; Finnveden, 2000; Guinée *et al.*, 2002). LCA data quality assessment on the basis of DQIs constitutes a semi-quantitative evaluation of LCA data. In general, it describes the aspects of data affecting the reliability of a LCA study's result and assigns scores (typically a range of 1-5) as a quality index (Figure 1). A pedigree matrix with DQIs was first proposed by Weidema and Wesnaes (1996, p.169). Since then, this approach has been used as the main reference for data quality assessment in LCA guides (Guinée *et al.*, 2002; European Commission, 2010b; UNEP, 2011; Weidema *et al.*, 2013) and LCA standards (ISO, 2006a).

Although companies are the source of essential LCA data, it seems that there is a mismatch between LCA and environmental accounting. Even if managers normally prefer to use other EMA tools to generate the sustainability information they need, the physical and environmental information required for LCA is fundamental in several management roles (*e.g.* finance, marketing, process, etc.) (Schaltegger *et al.*, 2015). In addition, management accounting studies are rarely informed by LCA data developments and vice-versa. Indeed, the LCA community rarely addresses issues related to enterprise data[1]. LCA databases have been widely developed but they are based primarily on industry averages. Furthermore, work on LCA data improvements are specifically related to harmonisation of background information, in which a discussion of enterprise-specific data does not take place, but rather addresses issues such as how to deal with uncertainty and aggregation (European Commission, 2010b;

[1] A recent publication of the UNEP/SETAC Life Cycle Initiative addresses issues related to enterprise data based on current practices of organisational LCA (O-LCA) (UNEP, 2015). Though it does not include new insights in terms of LCA data quality, it does raise awareness on the issue.

UNEP, 2011; Weidema *et al.*, 2013; European Commission, 2012). Correspondingly, very few in-depth assessments related to LCA have been undertaken in the management accounting literature[2] and they have not investigated LCA implementation to see how LCA data quality management could be improved at the organisation level (Schaltegger, 1997; Bicalho *et al.*, 2012).

This paper focuses on the role of the organisation in the LCA data collection process. The objective is to analyse the foreground LCA data collection process from a management perspective with the purpose of highlighting gaps in the current LCA data quality assessment approach. This is accomplished by applying the current prevailing data quality assessment approach to a primary data collection project, which includes an immersion in the organisation during the data collection process. Accordingly, we take an interpretive position (David, 2001a, 2001b; Hatchuel and David, 2008) – coherent with management sciences' methods for studying management tools – by observing and analysing the LCA data collection process while considering subjective experiences within the organisation. In our analysis, we rely on two theoretical fields in management sciences: first, management tools (Moisdon, 1997), and second, environmental accounting (Schaltegger and Burritt, 2000; Gray and Bebbington, 2001).

2. Material and methods

2.1. Data quality indicators (DQIs)

[2] We observe a certain number of conceptual frameworks relating LCA and environmental accounting (*e.g.*, Schaltegger and Burritt, 2000; Gray and Bebbington, 2001; Antheaume and Christophe, 2005; Richard, 2009, 2012) as well as studies where the relevance of data quality becomes apparent in environmental accounting (*e.g.*, Gale, 2006; Jasch, 2006; Stechemesser and Guenther, 2012). A few studies in management have questioned the quality and relevance of LCA information within the context of regulatory frameworks (Schaltegger, 1997; Bicalho *et al.*, 2012). However, they do not include the investigation of LCA data quality through LCA implementation.

Table 1. Pedigree matrix with data quality indicators (DQIs)[3]

In this study, the pedigree matrix presented in Table 1 is applied to assess the quality of enterprise-specific data (related to the inputs in the foreground system) used to quantify GHG emissions of a specific oil palm production.

2.2. Interpretive intervention-research

It is possible to distinguish two fundamental epistemological positions in management science: positivism and constructivism (Usunier *et al.*, 2007). They are characterised by two opposing ways of seeing reality. Positivists tend towards objectivity and consider that reality can be explained objectively. Positivist researchers have no interest in social and organisational constructs (Wacheux, 1996). Conversely, constructivism is based on the idea that one universal reality does not exist; rather it is built, invented, and interpreted differently by different social actors (Glaserfeld, 2001). Within the constructivism paradigm, we can make a distinction between a radical position (described above) and a moderate position, called interpretivism. Supporters of interpretivism leave the issue of reality unresolved because they consider that the essence of the object cannot be reached. They usually emphasise the understanding of a phenomenon, which is, moreover, developed from within the phenomenon (Perret and Seville, 2007; Allard-Poesi and Marechal, 2007). In our interpretivist approach, we use the case study to understand the process of gathering LCA data within an organisation. This epistemological choice is coherent with typical intervention research applied in management science to investigate management tools development and/or implementation within organisations (Hatchuel, 1994; Landry *et al.*, 1996; David, 1998; David, 2001a, 2001b; Hatchuel and David, 2008).

[3] Weidema *et al.*, 2013, published a new matrix (based on Weidema and Wesnaes, 1996) with slightly updated fields. The main modification is related to the completeness indicator, which is better defined in the new matrix. Table 1 presents the completeness indicator as it is presented in the new version of the pedigree matrix.

We conducted participant observation during the data collection. Participant observation is a qualitative research method that is well suited to situations where the researcher wishes to understand a social environment. It goes beyond the descriptive (objective) aspect of the research to seek to discover the meaning, dynamics and process of a phenomenon (Lessard-Hébert *et al.*, 1997). In this study, participant observation was necessary to identify and examine the sources of LCA data within the company, as well as the actions performed and the difficulties encountered when gathering it. Qualitative face-to-face interviews were conducted with nine employees of the company. In most cases, these interviews were followed by additional discussions and email exchanges. In addition, the lead researcher also integrated a self-reflection element regarding her role and activities within the company and data-gathering context to complement the study's findings.

2.3. Case study

2.3.1. Background, goal and scope definition

The case study presented in this paper makes use of information from a LCA study (*i.e.*, parts of the scope definition and the inventory analysis) conducted in 2010 in the context of a thesis in management sciences[4]. The motivation for the original study was to generate knowledge about the palm oil produced in Brazil, at that time, a little-known biofuel source. The study applied the "attributional" LCA approach[5] (*i.e.*, a summation of the emissions resulting from the production of all the inputs used in the fuel manufacturing process together with the emissions from producing the fuel itself) and calculated only the climate change related GHG emissions impact. The objective of the original LCA was to compare the environmental impact of the GHG emissions of a biodiesel produced from Brazilian palm oil with conventional diesel fuel within the framework of the Renewable Energy Directive.

The agricultural phase is the key source of GHG balances of biofuels, and this differs widely depending on the crop type, location and feedstock production (Edwards *et al.*, 2008). Thus, the original LCA placed particular emphasis on the agricultural stage. The foreground data for the oil palm production in the product system is site specific and was collected directly on site. As the objective in the present study is to analyse the foreground data collection process of LCA from a management perspective, we only took into account enterprise-specific data related to the foreground system for the oil palm production.

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[4] Les limites de l'ACV. Etude de la soutenabilité d'un biodiesel issu de l'huile de palme brésilienne. (Bicalho, 2013). The LCA is presented in Chapter V. This work was co-financed by the French Environment and Energy Management Agency (ADEME) and the French Development Agency (AFD), and was intended for a wide audience, ranging from researchers, international agencies and organizations to anyone interested in issues related to GHG emissions from palm oil and biofuel sources.

[5] It is common to distinguish between attributional and consequential LCA. This paper is focused on the attributional approach, which is the most traditional form, and makes use of site-specific and/or average data. In contrast, the consequential approach involves comparison of emissions in some policy scenario with a baseline case and uses marginal data representing the effects in the output of goods and services.

2.3.2. Data quality goals (DQGs)

Data quality assessment depends on DQGs that are defined according to the goal and scope of a given LCA study. For example, a LCA study for long-term strategic use would consider different geographical and technological levels and would place emphasis on obtaining recent data rather than verified data (Weidema and Wesnaes, 1996). ISO 14044 (2006a) defines data quality as "characteristics of data that relate to their ability to satisfy stated requirements". In other words, the quality of a LCA dataset depends on what users require from it.

DQGs in the original study differ between the different stages of the biofuel life cycle. For the oil palm production considered in the present study, DQGs are:

1. to use enterprise-specific data as much as possible for the foreground system. This methodological choice is consistent with the fact that the impact generated in agricultural operations of oil palm plantations can vary significantly between producers and between regions, depending on soil and climate conditions (Corley and Tinker, 2003);
2. to use representative data of an oil palm production located in Para, Brazil[6] that applies modern farm techniques;
3. to use recent data, preferably corresponding to the crop year 2009 (recall that the original study was conducted in 2010). The data should be based on a one year average;
4. to consider qualified expert judgement[7] on data related to fertilisers. This is suitable in order to improve the credibility of the study as the GHG emissions impact of fertilisers in oil palm production is usually substantial (Schmidt, 2007).

[6] Pará is the largest palm oil producer in the country and represented 80% of the production in 2009 (Agrianual, 2010).

[7] The expert needs to have detailed technical expertise on the item and the process in question (Chomkhamsri *et al.*, 2011).

2.3.3. System boundaries and data collection

The foreground system evaluated is an agricultural process under the operational and management control of Agropalma, a conventional commercial farm located in the Brazilian State of Para, where the firm has been in operation since 1982. At the time of the survey, the company was the largest[8] and most modern agro-industrial palm producer in Brazil (César and Batalha, 2013).

Oil palm is a perennial crop with a life cycle lasting between 25 to 30 years under standard plantation conditions (Corley and Tinker, 2003; Choo *et al.*, 2011). The agricultural production consists of several stages: seedling production in nurseries (in poly bags for thirteen to sixteen months); immature plantations (young palms up to four years old with reduced yields) and mature plantations. The foreground system includes immature and mature plantations, whereby seed production and nursery stages are excluded[9]. Details on oil palm agricultural management can be found in Corley and Tinker (2003). The product system evaluated and data collection aspects are shown in Figure 2.

Figure 2. Data collection related to the system boundaries

The data collected include the amount and type of fertilisers and pesticides, as well as fuel used by machinery to establish the plantation and transport the seedlings, field inputs, and the fruit bunches. Each piece of data relates to the specific amount of material and energy used by

[8] In 2009, the company was responsible for 75% of the Brazilian oil palm production and its total planted area was 39,115 hectares.

[9] The GHG emissions of seed production and nursery processes are minor over the whole cycle (nursery accounted for 0.01% of GHG balance at farm gate in Choo et *al.*, 2011). Since the study focuses on GHG assessment, irrespective of other environmental impact categories, these missing processes do not alter the results and conclusions in the impact evaluation. On the other hand, the overall agricultural system includes relevant background processes for the agricultural system, including production and transport of inputs to the fields and use of fossil fuels (see figure 2). In the original study, secondary sources (which are not considered in this study) were used for background processes.

the firm to produce 1 tonne of Fresh Fruit Bunches (FFB) per hectare[10]

The period considered in the study is the year 2009 (January 1 to December 31). The study took into account the average production per hectare over the whole plantation (mature and immature) of the firm in 2009 (expressed in tonnes of FFB per hectare). Fertiliser inputs were considered for immature and mature plantations together. The input of organic fertilisers includes N and P from empty fruit bunches (EFB).

3. Results and Discussion

Our analysis focuses on the production of LCA information within the organisation and the process of assessing data quality, rather than the results of data quality assessment. In this sense, the data quality indicators are presented (see section 3.1), but are not interpreted with uncertainty calculations. The production of LCA information is specifically addressed in section 3.2, with a particular focus on the problems encountered during the data collection process. Upon this basis, the analysis on LCA data quality assessment from a management perspective is provided in Section 3.3.

3.1. Results of the data quality assessment

The results of the quality assessment are presented in Table 2.

Table 2. Data quality indexes attributed to the enterprise-specific data assessed

[10] In the original study, the functional unit is one unit of energy content – 1 megajoule (MJ) – of fuel. This functional unit enables the biofuel system and the conventional fuel system to be treated as functionally equivalent and, thereby, establish a basis for comparison of the two products. However, for this study, we take into account the production of 1 tonne of Fresh Fruit Bunches since only the production of biomass – not the entire biofuel system – is considered

The data quality indexes for each data unit presented in Table 2 correspond to the following criteria: reliability, completeness, temporal correlation, geographical correlation and technological correlation, respectively. The specifics of each criterion are described in the following sub-sections.

3.1.1. Reliability

According to Weidema and Wesnaes (1996), the reliability indicator *"relates to the sources, acquisition methods and verification procedures used to obtain data"*. Reliability is independent of the data quality goals. In other words, *"a decision made under the goal definition does not change the reliability of the data, and the score should be identical if the data is used in another study"* (Weidema and Wesnaes, 1996, p.169).

A score of 1 was attributed to yield data, which was based on physical measurements. This data, provided by the CSR manager, was well documented in the management system. Data on mineral and organic fertilisers correspond to the full amount of fertilisers effectively applied to the field. The information was organised in Excel files elaborated within three different departments: fertilisation, R&D, and agricultural maintenance. Since fertilisers and their related field emissions have a large GHG emissions impact (Schmidt, 2007; Choo *et al.*, 2011), we conducted a review of these data with help from oil palm production specialists[11]. The score of 1 attributed to all the information on fertilisers is justified, first, because these data are based on physical measurements and, second, because we conducted a review process on relevant data based on experts' feedback.

Data on pesticides and fuels (*e.g.*, for machinery used to establish the plantation and transport the seedlings) also correspond to measured quantities. However, the diesel used for land preparation corresponds to estimates from subcontractors responsible for providing this service. Neither the information on pesticides nor on fuels were verified. Therefore, based on the pedigree matrix, these data have been given a score of 2.

[11] In short, the amounts of phosphorous (P) and nitrogen (N) showed especially weak quantities compared to similar production in Asian countries (Schmidt, 2007). Several combined factors explain these low fertiliser rates: 10% of the total area was not fertilised (because the palm trees were over 23 years old), but amounts were averaged over the whole plantation. Moreover, 16% of the plantation area only received organic fertilisers, which have a lower amount of nutrients than mineral fertilisers.

3.1.2. Completeness

Completeness is also independent of the DQGs. It relates to the statistical representation of the data and the representativeness of the period of data collection. In the case in question, we gathered enterprise-specific data from 2009 corresponding to 95% of the total production (5% is outsourced). The most relevant data was considered as representative when compared with a three-year average. For example, data on fertilisers represents 95% of the overall amount of fertilisers used in the palm plantations in 2009. However, data on N fertiliser is not exactly representative of the evaluated system because the firm had decided, for strategic reasons, to reduce N applications by 25% in 2009 compared to its standard procedure[12]. With the exception of data on N fertilisers, which is given a score of 2 for completeness, other data points are considered "representative data from a sufficient sample of sites over an adequate period" (*i.e.*, a score of 1).

3.1.3. Temporal, geographical and further technological correlations

Temporal, geographical and further technological correlations are dependent of DQGs. According to Weidema and Wesnaes (1996), these criteria represent *i)* the time correlation between the year of the study and the year of the obtained data; *ii)* the geographical correlation between the defined area and the obtained data; and *iii)* all aspects of correlation other than temporal and geographical aspects.

As specified in section 2.3.2., DQGs included the use of representative data of an oil palm production applying modern farm techniques located in the Brazilian state of Para. All the data considered in the study are enterprise-specific from a modern agro-industrial palm

[12] In order to show the usual scenario, a sensibility analysis was conducted in the original study by adding 25% to the amounts related to mineral fertiliser N.

production in Para and thus represent the geographical area, the technology and the materials under study. So, each piece of data is given a score of 1 for geographical and technological correlations. In addition, DQGs specified the preference for the use of recent data. As the data collected is from 2009 and the year of the study was 2010, the data are also given a score of 1 for temporal correlation.

3.2. Problems encountered

We carefully observed the data collection process in order to identify and examine the variables influencing data quality at the organisation level in the creation of the LCI. In this section, we describe the problems and difficulties encountered during the process, detailing seven documented variables: departments involved (number and specificity); number of participants; data format; method for producing data; data availability (period-years); time needed for data collection; verification (independent review). Table 3 shows the characteristics of the data collected according to these variables.

Table 3: Characteristics of the enterprise-specific data assessed

Gathering company data was a challenge. Based on the characteristics presented in the table above, we discuss three significant well-known barriers in the LCA community that were encountered during the creation of the LCI: the significant investment of time for collecting and treating data, the restricted availability and/or access to LCA data, and the absence of formal independent verification.

3.2.1. A significant investment of time for data collection

The company uses a traditional management information system called *SIGLA* that gathers financial, industrial and accounting information in one database, and makes this information accessible to the company's users. This system is based on four integrated information management modules (*i.e.*, commercial, financial, industrial and accounting), and provided certain environmental information (*e.g.*, mineral fertilisers used in immature plantations and diesel used for transportation). Nevertheless, because environmental data are aggregated in the system, the required data do not exist in a format that is useful for the creation of the LCI. Indeed, the utility of this management information system for data collection was quite limited. Most of the information was collected from multiple sources, mainly specific Excel files, derived from different departments. Data collection involved the participation of nine people from six of the firm's departments. Figure 3 puts into perspective the magnitude of the involvement of the company's departments during the data collection.

Figure 3. Company's structure and departments involved in the LCA data collection

In this context, the data collection process took about a week; about a month when considering the waiting time for people to produce/find the requested data. Also, it required the complete cooperation and significant effort of the company employees that participated in the process. The CSR manager commented that the unexpected time and effort required to be invested was problematic for them and if the company had previously imagined the time required for LCA data collection, the collaboration for the study would probably not have taken place. Moreover, several days were needed to transform flow names, quantities and units into appropriate LCA data for the creation of the LCI. This was particularly the case for fertiliser use, for which five years of raw data was in the form of lists with fertiliser formulae. Table 4 provides an example of the raw data collected.

Table 4. Example of raw data collected

It should be noted that the data gathering and processing for this study were undertaken in the context of a thesis project (see section 2.3.1), which allowed for a very generous allocation of time. Under normal business conditions, it would be difficult, if not impossible to undertake a data collection process with the same degree of specificity.

3.2.2. The difficult access to, and limited availability of, LCA data within the company

The difficult access to LCA data is, in part, related to the time required to obtain useful data. In this case, some data were available for several years of the period being examined, while other years were not, and this limitation was often due to the extensive time required to find the information within the company archives. Originally, the study intended to consider actual activity data for five years (*i.e.*, from 2005 to 2009), but given the difficulty to access the information, the company was unable to meet our demand. However, since it was possible to compare relevant data with a five-year average (particularly related to fertilisers), this limitation did not compromise the completeness attribute of the data (recall from 3.1.2: data on N fertilisers was given a score of 2 and all other data points are given a score of 1 regarding the completeness attribute). However, one could easily imagine a scenario where a lack of relevant data, due to the reasons stated above, does hinder a study result.

Data availability also posed significant challenges. For example, quantities of effluent applied on the field as organic fertiliser were unavailable for any year, but were able to be estimated from the literature. As we focused the LCA data quality assessment on enterprise information and applied it only to data collected directly within the organisation, this aspect is not shown in Table 3.

3.2.3. The absence of independent verification

Verification is a term originally coined for Quality Management Systems (QMS) and applied for Environmental Management Systems (EMS). ISO 9001 defines verification as a process that "uses objective evidence to confirm that specified requirements have been met". Verification can be done in several ways, for example by tests, calculations, documents examination, etc., Third party verification guarantees the external and independent nature of the registration process (ISO, 2005). Grahl and Shmincke (2012) highlight that, transferred to LCA, the term "verification" has been transformed by into a pseudo synonymous for critical reviews, but this is a misinterpretation. Although critical review in LCA implies an independent process by an outside organism (*i.e.*, ISO 14044 requires a third party critical review "for LCA studies used to make comparative assertion that is disclosed to the public"), the objective evidence, which is "data supporting the existence or verity of something" cannot be attributed to the criteria of a critical review[13].

In the case study presented in this paper, two aspects were observed when applying the reliability indicator as proposed in the pedigree matrix. First, a reliability score of 1 was attributed to yield data and to all the information on fertilisers. This is justified by the fact that those data are based on measurements and that they underwent an expert review. Based on the pedigree matrix, these two characteristics combined correspond to the score 1 (the strongest score) for data reliability. However, no data collected underwent "verification", but rather a "critical review". An attempt was made to partially address verification of the

[13] According to the ISO standard 14040 (2006), the critical review process shall ensure that "the methods used to carry out the LCA are consistent with this International Standard; the methods used to carry out the LCA are scientifically and technically valid; the data used are appropriate and reasonable in relation to the goal of the study; the interpretations reflect the limitations identified and the goal of the study; and the study report is transparent and consistent".

relevant data on fertilisers with significant climate change impact with a review, supported by experts (*i.e.*, oil palm cultivation specialists provided judgments based on their knowledge and experience). Although expert judgment on data is considered highly valuable to assure the credibility of LCA studies[14], this practice differs completely from a formal verification through the provision of objective evidence involving an outside organism. Secondly, a reliability score of 2 was attributed to data on pesticides and fuels, but these data did not undergo verification or critical review. Based on the pedigree matrix, a score of 2 is assigned to non-verified data based on measurements on the reliability indicator. Since scores can range from 1 to 5, a score of 2 can be interpreted, at the very least, to be "good reliability data". In other words, based on the pedigree matrix, the absence of verification does not compromise the reliability attribute of the data.

3.3. LCA data quality assessment from a management perspective

We can draw from two major research approaches related to management tools to explain the limitations of LCA data collection within organisations. The first focuses on the physical dimension (technical substrate) of the tool and is based on the passivity of the users. The second, more critical approach perceives the management tool through the prism of all its components: the physical, social and organisational dimensions (Lorino, 2002; David, 1996a, 1996b; De Vaujany, 2005). The case study will be discussed from a management-based perspective by taking into accounting these two opposed approaches in management sciences.

3.3.1. LCA: a tool based on the passive user[15]

[14] Expert judgment is generally considered as a good method to apply to achieve a good LCA data review (Chomkhamsri *et al.*, 2011).

[15] The term "passive user" is employed to designate users that are passive to a tool already designed with a set of standards to be applied.

The approach based on the premise of passive organisation users assumes a positivist view of the management tool, and accordingly, assumes the existence of an objective reality, independent of the user's perception (Simon, 1991). Essentially, the management tool is conceived without considering the context in which it is introduced (Berry, 1983; Moisdon, 1997). This approach is supported both by a representationist conception of reality and a conformation conception that coexist in most cases. According to Lorino (2002), the representationism corresponds to a view centred on the ability of the tool to represent reality based solely on its intrinsic qualities. From this perspective, the organisation actor is without desires, strategies, goals or identities (Grimand, 2006, p.15).

Two major facts provide evidence for this approach when considering the problems encountered in the LCA data collection process presented in the previous section. First, the availability of environmental information was inextricably tied to financial management. The financial nature of the information can, in fact, only partially respond to environmental information needs. As described in the case study, the utility of the firm's traditional management information system for LCA data collection was very limited. According to Christophe (1995), traditional management systems are unsuitable for environmental management accounting either because we come up against limits well known in traditional accounting (which is the case of individualised expenditure account)[16] or because the environmental assessment goes beyond the scope of traditional economic analysis. In the context of the present study, only data related to elements with considerable financial impact to the firm are easily accessible (*e.g.*, information on the yield, available for several years, or data on mineral fertilisers, which represents 30% of the company's production costs). In sum, this aspect explains both the issue of restricted access to/availability of environmental

[16] In accounting, it is not always easy to individualise costs. It is not because they are recognised as costs that they constitute "information". To become *information* they must be recognisable (Christophe, 1995).

information issue, as well as the extensive time required for the LCA data collection process. Furthermore, environmental information was not produced and verified on the same basis as financial information. Management and financial accounting involves compulsory calculations, with data that are externally audited according to generally accepted standards and have their costs financed by the firms.

Second, DQIs do not capture pertinent data quality information related to data management and control. Current DQIs are actually used *i) "to revise the data collection strategy to improve the quality of data collection"* and *ii) "in combination with uncertainty estimates give a better assessment of the reliability of the result"* (Weidema and Wesnaes, 1996). However, data representativeness is the key to obtaining good results in LCA data quality assessment (Leroy, 2009). In other words, if the goal of the study is a specific LCA, the use of enterprise-specific data qualifies the information as excellent or, at least, very good. From this perspective, in the prevailing approach of LCA data quality assessment, only the quality of industry average data (usually background inventory data) appears to be questionable. Furthermore, the LCA community tries to bridge data gaps by concentrating research efforts on centralised information-based solutions, such as the development and harmonisation of LCA databases (usually based on industry average data) without addressing solutions related to site-specific data collection (European Commission, 2010b; UNEP 2011; Weidema *et al.*, 2013; European Commission, 2010b).

The previous approach by which we characterise LCA practice and data collection is often criticised in management sciences, especially in view of the differences that may exist between the expected and the actual use of the tool (Moisdon, 1997; Berry, 1983; De Vaujany, 2005, 2006; Grimand, 2006). Therefore, many authors discuss the role of stakeholders in the implementation of the tool (Lorino, 2002; David, 1996a, 1996b; De Vaujany, 2005) and advocate a broader view of management tools in which they are seen beyond the technical substrate.

3.3.2. LCA through the prism of all its components – a broader approach

Like any tool introduced in organisations, it is possible to interpret LCA in different ways. LCA maintains a dual relationship with the organisation: first, it brings the company a new way to organise, communicate, and manage its business, etc. (normative dimension); and second, the company provides information about its daily activities allowing further development of the tool while also interpreting and adapting the tool according to the company's characteristics and needs (adaptive dimension). Although it is argued in the LCA literature that data quality management must be an integrated part of a LCA (Weidema and Wesnaes, 1996), the study indicates that good quality LCA studies also require data quality management to be integrated at an early stage at the organisation level. In other words, when performing the LCA study, the data to be collected must first have passed through a quality management process within the company. Based on the analysis provided above, we identify three ways that, combined, would allow LCA to progress in this direction: 1) the development of a more flexible pedigree matrix, 2) policy support, and 3) the inclusion of appropriate environmental systems at the level of the organisation.

3.3.2.1. The development of a more flexible pedigree matrix

One explanation for the data management and control difficulties encountered during the LCA data collection process lies in the fact that the company does not have a dedicated structure that can accommodate and organise environmental data in a uniform, on-going basis. In order to ensure the usefulness of LCA as a decision-support tool, the pedigree matrix should capture data management and control aspects. Here, it is imperative that the data quality system distinguishes between industry averages and enterprise-specific data. In addition, when applied to enterprise data, the pedigree matrix should:

i) classify the organisations that are able to provide valuable LCA information[17]. This implies, for example, the need for a dedicated structure or, at least, an appropriate environmental information system. As noted in the case study, a discrepancy exists among different company departments in terms of their environmental information management because different actors require different kinds of environmental information to fulfil their different management roles. This suggests that companies need to consider embracing transdisciplinary information systems to support managers. (Schaltegger and Csutora, 2012; Schaltegger *et al.*, 2015).

The implementation of such a system would have a positive influence on the completeness attribute of the data. As illustrated in the case study, some data were available for several years of the period being examined, while other years were unavailable; some data was nonexistent (*e.g.* quantities of effluent applied on the field). An appropriate environmental accounting system would, theoretically, provide accurate site-specific information on a periodic basis, and would reduce the problem of limited LCA data availability, allow for better completeness of the information and enable high-quality LCA studies. In addition, selecting the organisations that are able to provide adequate LCA information would improve the efficiency of the data collection processes. Although the efficiency aspect is not directly related to data quality, it promotes good practice since LCA data collection depends on the resources available, especially time and money;

[17] This could be done, for example, through a short questionnaire applied using inexpensive means (mail or telephone) to the companies concerned. Note that this "classification" shall not be considered for the cases where the LCA study requires data from a particular company.

ii) ensure the reliability of LCA studies through stricter specifications on LCA data *verification*. Although, in principle, verification procedures are reflected in the reliability indicator, data verification is not clearly addressed in the pedigree matrix. When applied to enterprise-specific data, clear requirements for objective evidence should be provided and be reflected in the reliability indicator scores. In this regard, as observed earlier in this paper, "verification" and "review process" (*e.g.* peer review, expert review, stakeholder review) cannot be used synonymously (Grahl and Schmincke, 2012): verification includes objective evidence, involves a third-party organism and occurs at the management level; the review process can be described as a "supervision" of the LCA study and does not include objective evidence. It is worth pointing out that, in the context of management and financial accounting, companies are already familiar with formal procedures involving the provision of objective evidence, where data is verified through external audit processes in accordance with international accounting standards (*e.g.*, International Standards on Auditing IAS) and whose costs are borne by the firms. In a similar fashion, well-designed environmental management accounting tools enabling the provision of reliable LCA information could also be established. Although there still is no global consensus with regard to external assurance standards for sustainability (WBCSD, 2016), the existing standards applied for QMS and EMS that are based on the provision of objective evidence (*e.g.*, ISO 9001 and ISO 14001), may be helpful in providing the baselines for such implementation at the company level in a LCA data quality context.

3.3.2.2. Policy support for further guideline development

Environmental accounting needs to be taken seriously at the policy level. In fact, the lack of regulation and standardisation may largely explain inadequate environmental information in management (Bicalho *et al.*, 2012). As highlighted in the section above, the current standards must be further developed to be more helpful for LCA data verification in corporate practice. Public policy instruments that directly require the application of LCA[18] could be powerful mechanisms to promote LCA data quality in terms of data management and control by introducing relevant specifications.

3.3.2.3. The inclusion of appropriate environmental systems at the organisation level

Combined with policy support, new LCA data quality management and control developments (*e.g.*, development of a more flexible pedigree matrix) may create an appropriate normative dimension for LCA in the management context. In turn, new environmental information systems compatible with the collection of LCA data at the business level[19] may appear, resulting from the interpretation of the tool by the organisation. This phenomenon corresponds to the concept of appropriation, which is mainly based on the idea of "design for the use", where the design and use phases are intertwined in an iterative and continuous cycle. From this perspective, the management tool assumes its normative and adaptive dimensions. The normative dimension constitutes the rules or the objectives determined by designers (*i.e.*, all the guidelines issued by the designers on the contents of the tool, characteristics and terms of use), while the adaptive dimension comes from the interpretation of the tool by the users. The latter can encourage new design phases based on recommendations expressing the point of view of the users in the organisation, as well as their perceptions and attitudes towards the tool.

[18] LCA is increasingly important in policy making especially in the European context. The Renewable Energy Directive (RED) (European Commission, 2009a), the Ecodesign Directive (European Commission, 2009b), the Energy Labeling Directive (European Commission, 2010a) and environmental product declarations (EPDs), are some examples of recent EU public policy instruments that directly require the application of LCA.

[19] To our knowledge, few LCAs conducted to date have been supported by appropriate information systems, but some environmental information systems specifically designed for such purpose are already available (see, for example, Eun *et al.*, 2009).

4. Conclusion

Data quality issues have been addressed in the LCA literature since a long time ago, but research and corporate practice are still challenged to find good solutions to solving problems with regard to LCA data quality. The current approach to assess LCA data quality neither encourages data quality management at the organisation level nor ensures the usefulness of LCA as a decision-support tool. This study demonstrates that basic limitations inherent to the data collection process are neglected by the use of the current prevailing data quality assessment approach. The case study revealed that this is the case, reflected in the extensive amount of time spent to collect and treat data, the restricted access to and limited availability of LCA data, and the absence of formal independent verification.

From a management perspective, common problems encountered during the LCA data collection as described in the case study are overlooked because LCA constitutes a passive user-based tool (*i.e*, the LCA is typically performed outside the organisation's operational context). The LCA community tries to overcome data collection problems by concentrating research efforts uniquely on centralised information-based solutions, such as the development and harmonisation of LCA databases established from industry average data. As a consequence, DQIs are not conceived to assess the quality of enterprise-specific data derived from established management systems. But if we look "outside the box", it is possible to see LCA as a management tool in a different light, in which it opens up new perspectives for the organisation . First, LCA provides the company a new way to organise, communicate, manage its business, etc. Second, through the on-going provision of information on its daily activities, the company can develop, interpret and adapt the tool according to its characteristics and needs. This is supported by the main observations of the case study: LCA quality requires active, integrated data quality management at the organisation level and not just passively and periodically, as part of a LCA study.

Our analysis suggests that LCA data quality assessment should, in a preliminary stage, classify the organisations that are able to provide valuable LCA information. By identifying firms with a dedicated structure, the completeness attribute of the data would be better assured while the extensive amount of time required for LCA data collection could be greatly reduced. Also, the reliability criterion should be more explicit and strict regarding verification. If these aspects were taken into account by regulatory frameworks, LCA could better support economic actors to reduce their environmental impact while promoting environmental accounting. In turn, firms would play a role in enabling LCA progress as a management tool: this appropriate normative context would create more favourable conditions for the establishment and implementation of new environmental information systems, compatible with the collection of LCA data at the company level.

Finally, the present study has two important limitations. First, the scope is limited to the application of the current data quality assessment approach to a case study conducted in a Brazilian oil palm producer. Although the findings are relevant, more study is needed for more generalised conclusions. Second, DQIs were applied only to enterprise-specific data for inputs in the foreground system. As systematic errors can significantly influence LCA results, LCA data quality assessment is relevant to any piece of information used in a life cycle inventory.

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Table 1: Pedigree matrix with data quality indicators (DQIs)

Indicator score	1 Excellent	2 Very good	3 Good	4 Fair	5 Poor
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non verified data based on measurements	Non verified data partly based on assumptions	Qualified estimate	Non qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<50%) relevant for the market considered or> 50% of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from shorter periods	Representative unknown or data from a small number of sites and from shorter periods
Temporal correlation	≤ 3 years of difference to year of study	3 to 6 years difference	5 to 10 years difference	10 to15 years difference	Unknown or ≥15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Source: Weidema *et al.* (2013). Updated from Weidema and Weasnaes (1996).

Table 2. Data quality indexes attributed to the enterprise specific data assessed

INVENTORY OF INPUTS (2009)	
Enterprise specific data	**Data quality indexes**
MINERAL FERTILISERS	
N (kg N/ha)	(1, 2, 1, 1, 1)
P (kg P2O5/ ha)	(1, 1, 1, 1, 1)
K (kg K2O/ ha)	(1, 1, 1, 1, 1)
Mg (kg MgO/ha)	(1, 1, 1, 1, 1)
ORGANIC FERTILISERS	
N (kg/ha)	(1, 1, 1, 1, 1)
P (kg P2O5/ ha)	(1, 1, 1, 1, 1)
PESTICIDES	
Glyphosate	(2, 1, 1, 1, 1)
Acephate	(2, 1, 1, 1, 1)
DIESEL	
Mecanisation	(2, 1, 1, 1, 1)
GASOLINE	
Gasoline.	(2, 1, 1, 1, 1)
Ethanol	(2, 1, 1, 1, 1)

Table 3: Characteristics of the enterprise specific data assessed

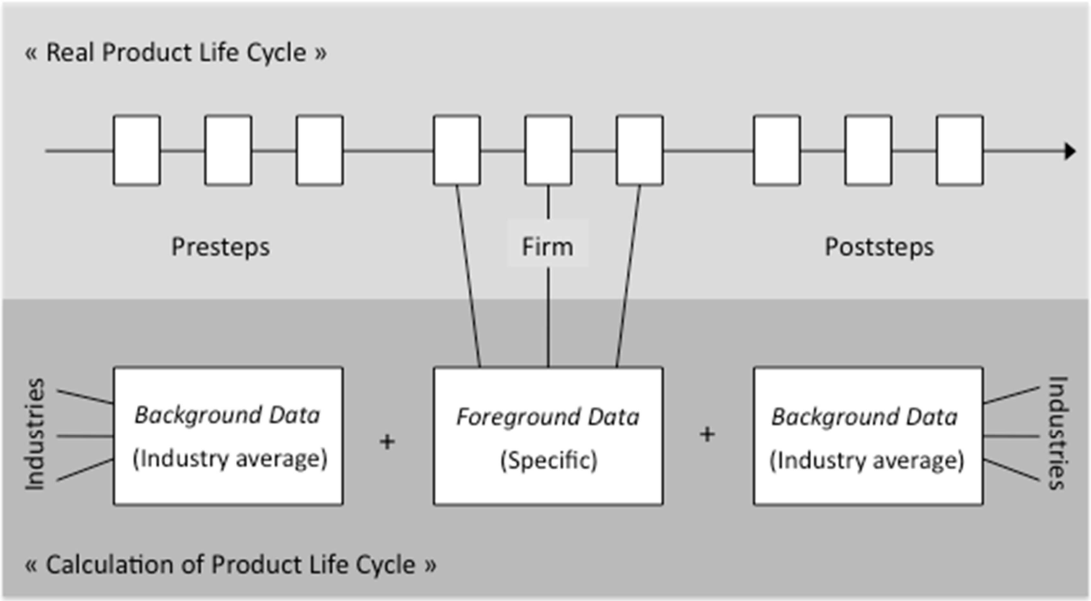
DATA	YIELD	MINERAL FERTILISERS	ORGANIC FERTILISERS	PESTICIDES	DIESEL	GASOLINE
DATA (processed)	17,72 t/ha	N (Kg N/ha): 45,82 P (Kg P2O5/ha): 81,62 K (Kg K2O/ha): 185,3 MG (Kg MgO/ha): 19,3	N (Kg/ha EFB): 18,67	Glyphosate: 0,63 kg/ha Acephate: 0,12 kg/ha	78,02 kg/ha	1,79 kg/ha
a. Provider/ dept.	CSR	AC, AP, R&D	CSR and R&D	AI and ChC	AI and AP	AI
b. People involved	a	b,c,d,e and f	a and f	g and h	g and i	g
c. Method	Physical measurements	Physical measurements	Physical measurements	Physical measurements	Data generated by calculations based on expenditures	Data generated from calculations based on expenditures
d. Data format	Excel list (from database)	Lists with the amounts of NPK contains of each fertiliser applied	Excel list (from database)	Lists of the name and amounts of applied pesticide products	Data displayed in a table format (derived from contracts with suppliers)	Data displayed in a table format ((derived from contracts with suppliers)
e. Data availability	More than ten years available	One year data (2009) available for immature plantations; Five years available for mature plantations	Not applicable for immature; One year data (2009) available for mature plantations	One year data (2009) available Five years available for mature plantations	One year data (2009) data available	One year data (2009) available
f. Required time	Less than one hour	More than one day for immature plantations and few hours for mature plantations	Not applicable for immature; Few hours for mature plantations	More than one day for immature plantations and few hours for mature plantations	More than one day for immature and mature plantations	Not applicable for immature; more than one day for mature plantations
g. Audited	No	No	No	No	No	No

In order to facilitate the reading of the table, the names of the departments (a) have been replaced by the initials of the departments (see Figure 3); and the names of the participants (b) have been replaced by lowercase letters. The required time (f) includes the time spent during the interviews with the participants and the effective time needed to produce the information.

Table 4. Example of raw data collected

Fertiliser	2009	AMOUNT	DATE
(03-09/02-24) + 2,8 Mg c/ Kieserita		1.533 t	07/09/10 provided by R. C. Amaral
06-05/01-28 + 1,2% Mg c/ kieserita		3.204 t	
05-10/03-19 + 2% Mg c/ kieserita		4.211 t	
05-08/02-20 + 2,08 Mg c/ kieserita		1.355 t	
07-05/01-25 + 1,36 Mg c/ kieserita		1.956 t	
04-08/02-24 + 2,19 % Mg c/ kieserita		647 t	
00-16/04-00 + 8,16% Mg c/ kieserita		550 t	
08-00-23 + 2,1 % Mg + Micro c/ kieserita		582,08 t	
07-00-24 + 2,6 % Mg + Micro c/ kieserita		836,20 t	
05-00-28 + 2,5 % Mg + Micro c/ kieserita		412,07 t	
03-00-31 + 3,5 % Mg + Micro c/ kieserita		648,68 t	
08-00-28 + 1,2 % Mg + Micro c/ kieserita		2.690,82 t	
07-00-28 + 1,5 % Mg + Micro c/ kieserita		3.156,15 t	
15-09-20 + 1,2% Mg + Micro c/ kieserita		2000 t	
TOTAL		23.882 t	

Figure 1. Common approach of data collection in LCA



Source: Schaltegger (1997)

Figure 2. Data collection related to the system boundaries

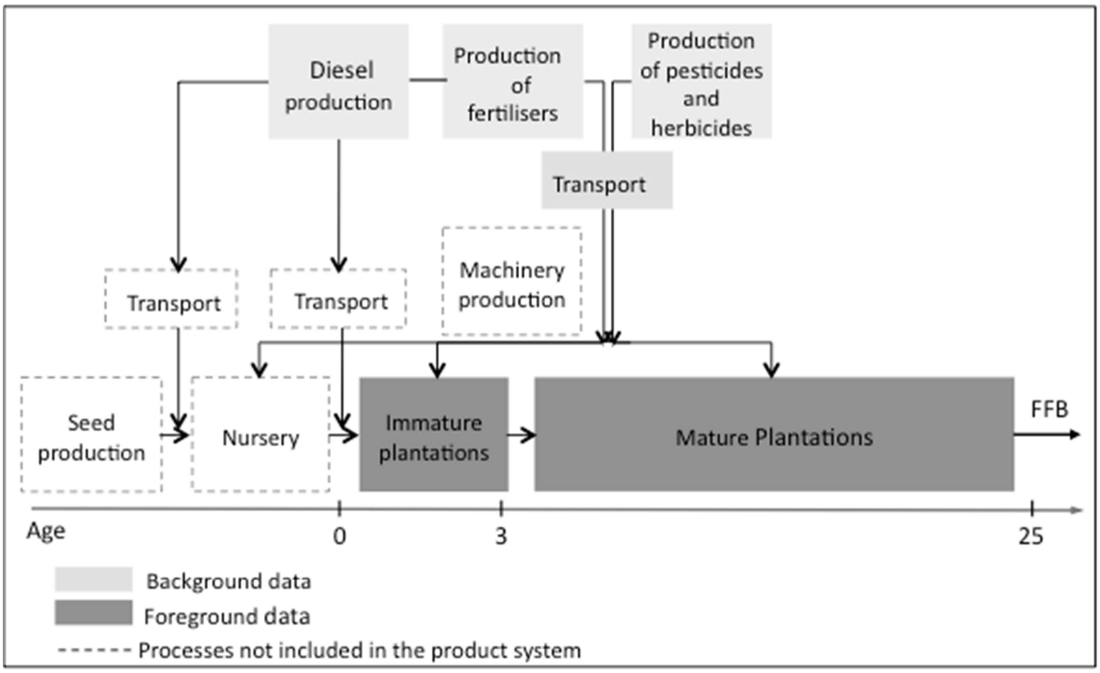


Figure 3. Company's structure and departments involved in the LCA data collection