A Review of Life Cycle Assessment Tools

February 2017

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Executive Summary

Sometimes referred to as "cradle to grave" analysis, LCA provides a mechanism for systematically evaluating the environmental impacts linked to a product or process and in guiding process or product improvement efforts. LCA-based information also provides insights into the environmental impacts of raw material and product choices, and maintenance and end-of-product-life strategies. Because of the systematic nature of LCA and its power as an evaluative tool, the use of LCA is increasing as environmental performance becomes more and more important in society.

Despite its power and growing importance, LCA is viewed in some quarters as prohibitively tedious and expensive. However, there are today a number of user-friendly data banks and analytical tools that allow non-scientists to conduct comprehensive environmental assessments of products ranging from a can of beans to automobiles and large buildings. Available LCA tools range from simple, focused spreadsheets to sophisticated software programs with professional support and access to some of the most comprehensive databases available.

In this report, information is provided to assist first-time LCA practitioners in selecting appropriate LCA tools and data sources. Exploration of available resources is important before embarking on any assessment, so as to identify available data (and thus additional data needed), as well as software tools that best fit the needs of those involved.

LCA tools are evaluated herein based on credibility of information, ease of searching for data, understandability of datasets, and available breadth of processes. Three databases from public sources, the US Life Cycle Inventory Database, CPM LCA Database, and the European Life Cycle Database, along with three private LCA tools, ecoinvent 3.0, GaBi, and SimaPro, were analyzed according to these criteria.

Introduction

In the face of increasing interest in determining environmental impacts of business practices, environmental life cycle assessment (LCA) is at the forefront of the sustainability discussion. LCA is a methodological framework for assessing environmental impacts associated with all stages of a product's life, from raw material extraction, through manufacturing, distribution, use, maintenance, and end of useful life. An LCA may cover all of these steps, in which case the assessment is described as "cradle to grave" (Figure 1), or may encompass a subset of the steps in the production and life of a product.

LCA consists of four parts: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation (Figure 2). Goal and scope definition describes the purpose and breadth of an assessment. Conducting a life cycle inventory involves data collection and quantification of inputs and outputs. An impact assessment examines data collected in the LCI stage in the context of specific environmental and human health impacts. Finally, the interpretation stage connects the findings from the LCI and LCIA stages back to the goal of the assessment.

Figure 1
Depiction of "Cradle to Grave" LCA

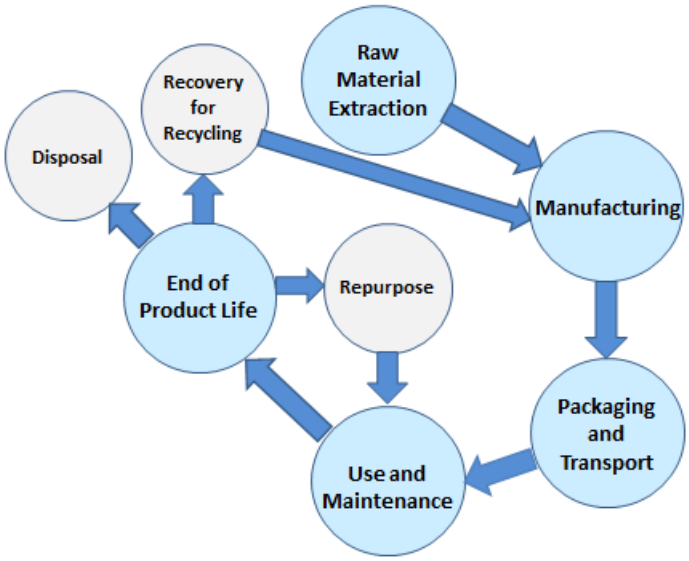
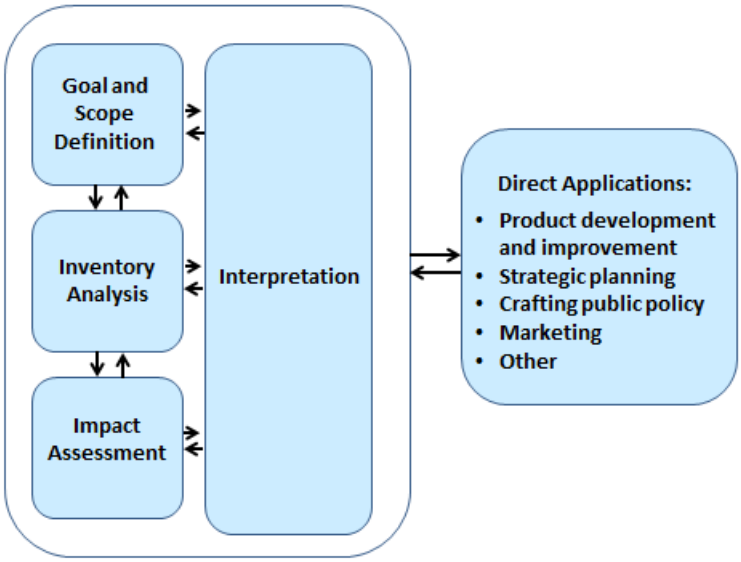


Figure 2
The Four Stages of an LCA



The LCA structure is defined and described by the International Organization for Standardization (ISO) 14000 series. ISO 14040:2006[1] provides a comprehensive standard for the conduct of an LCA. This a good place to start for new practitioners.

The Dovetail report *Life Cycle Analysis: A Key to Better Environmental Decisions* provides a detailed look into how LCAs are done.[2] For those interested in learning how to perform an LCA

[1] ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and framework. 1 July 2006.
[2] (http://www.dovetailinc.org/report_pdfs/2005/dovetaillca0105.pdf)

from the start, *Life Cycle Assessment- Quantitative Approaches for Decisions that Matter*[3] is a free textbook accessible online. Originally designed for use in a college course, this textbook provides a straight forward guide to performing a meaningful LCA. Individual chapters are available for download and are updated by authors regularly.

It is perhaps obvious that the ability to produce a credible LCA relies heavily on the quality of available data. Increasingly, relevant and reliable data can be found in established databases accessible through LCA modeling tools. Public and private sectors alike have amassed a wide variety of data with the sole purpose of use in LCA.

In this report, information is provided to give new LCA practitioners guidance as to how to begin an assessment. Three of the most well-known life cycle inventory databases are identified and briefly discussed, as are three of the most widely used LCA software tools. Exploration of available resources is important before embarking on any assessment, so as to identify available data (and thus additional data needed). Knowledge of software options is also valuable in finding the best fit for the project and those involved in it.

In this report, three public databases and three LCA software tools are briefly described and evaluated based on credibility of information, ease of searching for data, understandability of datasets, and available breadth of processes. Additional commentary is also provided.

Evaluation Criteria

Describing something as "user-friendly" can vary greatly in meaning from person to person. This evaluation is based on specific criteria as outlined below.

- Credibility of data
- Understandability/clarity of data sets
- Ease of using search function
- Selection of processes

Credibility of Data

The execution of a Life Cycle Assessment (LCA)[4] relies heavily on the quality and availability of data. Reputable LCA tools should be able to identify sources of data. Individual data sets may offer citations, and/or an explanation of how data was collected. Beyond source citations, LCA tools should have some kind of standard that data must meet before inclusion in associated databases. A key standard is that of ISO, which has created standards for both the conduct of an LCA and for LCA data, and consequently, ISO compliance is an important measure of any LCA tool.

Another aspect of data credibility is availability of region-specific data. Many LCA tools will have data only for the country or region of origin. Region-specific data is often not recommended for use outside of its specified range. Availability of data for multiple regions and countries, or for the specific region of interest, is an important criterion for selection of an LCA tool.

[3] (http://www.lcatextbook.com/)

[4] For background information about LCA, what it is, how it works, and why it matters, see previous Dovetail Reports at www.dovetailinc.org, including: *Life Cycle Analysis: A Key to Better Environmental Decisions*, available at: http://www.dovetailinc.org/report_pdfs/2005/dovetaillca0105.pdf

Understandability/Clarity of Datasets

Often, data used in LCA will come in the form of a dataset. These datasets present a wide range of data, from technical system details to system boundaries and administrative information. Depending on the tool, datasets can be many pages long. Each database and tool will have a different layout for their datasets.

Whereas all this information is important to understand, some of the most important information will be found in a section titled something similar to "Exchanges" or "Inputs and Outputs." Understandability and clarity of a database is largely dependent on how easy it is to find and interpret this section.

Ease of Using Search Function

One of the more daunting parts in conducting an LCA is finding useful information. Databases can have thousands of datasets available, and consequently finding the right dataset for a study may take some time. A key factor is the usefulness of the search function; some are more straight-forward than others. Not uncommonly, additional information is sometimes required to properly filter results. In any event, there will be a learning curve when any new tool is used for the first time. For this report, "ease" refers to the learnability of the search functions.

Selection of Processes

LCA tools themselves can be sector-specific or broad and generally applicable. The more sector-specific LCA tools have been excluded from this report in favor of the more generalist tools, because they offer the widest variety of systems and processes for the new practitioner.

Within the generalist tools, there is great variation in the breadth of systems and processes available. New practitioners often find it easier to use one tool for an entire study rather than employing multiple tools in order to obtain desired information. Comprehensive generalist tools provide the greatest opportunity for relying on only one tool.

Analysis of LCA Databases and Modeling Tools

As indicated, there are a number of tools available for use by LCA practitioners. There are similarly multiple data sets. Sifting through the sea of available tools and datasets, while considering the selected criteria, resulted in the following short list of tools and databases that may be appropriate starting points for a new LCA practitioner:

Databases

- U.S. Life Cycle Inventory Database
- CPM LCA Database
- European Life Cycle Database

LCA modeling tools

- ecoinvent 3.0
- GaBi
- SimaPro

Each of these is discussed in detail below. Discussion is focused on the selected criteria identified on page two.

Databases

U.S. Life Cycle Inventory Database (USLCI)

The USLCI Database was created through a partnership of the National Renewable Energy Laboratory (NREL) and the Athena Institute[5] under direction of the U.S. Department of Energy.[6] Development of the database began in 2001 and was first made publicly available in 2003. Due to growing demand for LCA and other developments, the database was slated to be expanded and revised in 2008. Revision efforts included a survey sent out to stakeholders with questions about their organization, their use of the database, and desirable features of the new database. Survey results were discussed at a stakeholder meeting in February of 2009 and the updated database was released in 2012. Access to the USLCI Database is free for all users with an option to register for an account.

The USLCI Database offers two types of entries: elementary flows and unit processes.[7] For every unit processes entry, tabs titled *Activity*, *Modeling*, *Administrative*, and *Exchanges* are given in lieu of a spreadsheet-type dataset. Full spreadsheet datasets are available, but require an account to download. Transparency is a high priority for this database. Sources for the data provided can be found under *Modeling*. Although it is not clear what periodic reviews of the database are performed, some of the processes appear to have more up-to-date information than others based on information provided under *Activity*.

One big perk of the four-tab layout is how easy it is to find the appropriate information for an LCA. The *Exchanges* tab holds all the data necessary. Inputs and outputs are clearly labeled and categorized. Information presented under this tab is very readable, featuring the desired product flow in bold font. One downside to this is how the data is organized. Rather than the product flow being located at the top of the list, the entire list is organized alphabetically, so it may take some searching to find the product flow.

This database features a search bar and an advanced search option, but it is almost never necessary to use this. There is a sidebar that lists every category of processes. Each category can be expanded to display the subcategories and collapsed when finished. Categories and subcategories can be selected and every entry contained will be listed on the page. Because it is a U.S. government sponsored database, the data is specific to energy and material flows within the United States. Some entries are classified by region, such as Northeast, Southwest, Alaska, and others. As for selection of processes, the USLCI database contains 1,060 unit processes. Although it covers a variety of categories, the options are limited and a practitioner might not find every process he or she needs at this site.

[5] In February 2017, The Athena Institute announced the release of version 5.2 of the Athena Impact Estimator for Buildings. This free software tool supports LCA for building designers and sustainability consultants. http://calculatelca.com/software/impact-estimator/overview/

[6] National Renewable Energy Laboratory. 2009. U.S. Life Cycle Inventory Database Roadmap. U.S. Department of Energy. (http://www.nrel.gov/lci/pdfs/45153.pdf)

[7] "U.S. Life Cycle Inventory Database." (2012). National Renewable Energy Laboratory, 2012. (https://www.lcacommons.gov/nrel/search)

CPM LCA Database

The CPM LCA Database was developed in 1995 by the Swedish Life Cycle Center, formerly called CPM.[8] They remain the current owners of the database, although it is maintained by the Department of Energy and Environment at Chalmers University of Technology. Access to this database is free for all users. The database was sponsored between 1996 and 2006, but now primarily relies on specific projects and external funding for further development. Despite "LCA" in the name, this is an LCI database tool, and therefore only data is provided.

All data presented in the database goes through a review process and is given one of three marks: Sufficient, Acceptable, or Unsatisfying. By using these marks, CPM adds a level of accountability to their product. Just like the USLCI Database, each entry has individual citations given. Datasets also provide a time frame of validity for their information. It is important to pay close attention to this to avoid using data that may no longer be accurate. There are three formats of dataset available for each entry. The first format is created by SPINE (Sustainable Product Information Network for the Environment). The second dataset available is in ILCD (International Reference Life Cycle Data System) format, which is compliant with ISO 14040/44 standards. The third dataset is in the format of an ISO/TS 14048 report. All datasets provide the same information. Practitioners can choose which format they prefer. All formats are descriptive and easy to follow.

When looking for a process, the user can choose from a list of all processes and transportation options or use an Advanced Search tool. The Advanced Search tool has one section for Processes and a second section for Inputs and Outputs. It is more productive to only use the Process search function and gather input and output data from the datasets. There are 745 entries in the CPM LCA Database, 612 process entries and 133 transportation entries. Data is further limited geographically. The majority of data was collected in Sweden and may not be applicable outside of Sweden and the surrounding area. Individual datasets include discussion of locations in which data is valid.

European Life Cycle Database

The European Life Cycle Database (ELCD) was created by the European Platform on Life Cycle Assessment, part of the Joint Research Centre of the European Commission.[9] First released in 2006, the goal of the ELCD is to provide free background data for LCAs focused on the European market. All data given in the ELCD is compliant with entry-level requirements of the Life Cycle Data Network (LCDN) and is endorsed by the organizations providing the data. Entry-level requirements were established to ensure data quality, extent of documentation, and methodological consistency. The Life Cycle Data Network is a global, web-based system where data developers across the globe can submit data from any sector.

Life cycle inventory datasets are available for free; no account is needed to download a spreadsheet of the data. An ILCD format dataset is available online. This format will provide all the information required. After selecting a process, a page will appear that gives a basic description of the dataset. The description gives important information including location, reference year, expiration date, reference flow, and compliance status. This type of information can help the user decide whether or not a particular dataset will be helpful for their study. A total of 503 process datasets are available for ELCD users, and 190 of these entries are fully LCDN Entry-level compliant, others are partially

[8] Center for Environmental Assessment of Product and Material Systems. About the CPM LCA Database. (http://cpmdatabase.cpm.chalmers.se/AboutDatabase.htm)

[9] Joint Research Centre. European Platform on Life Cycle Assessment. European Life Cycle Database. (http://eplca.jrc.ec.europa.eu/?page_id=126)

compliant. Datasets must be compliant in four categories to be deemed fully compliant: nomenclature, methodological, review, and documentation. Individual datasets will specify which categories it has compliance in. However, it is important to note that a dataset does not need to be fully LCDN Entry-level compliant to be ISO 14040/44 compliant.

The search function for this database can be tricky to figure out. Search categories include name and descriptors, geographical region and time coverage, and classification. Classification may be the most useful of these parameters. It may take a little longer to find a specific desired dataset. As stated before, the goal of the ELCD is to provide LCA data for the European market so the majority of the data available is specific for individual countries or larger areas.

LCA Modeling Tools

Ecoinvent 3.0

The ecoinvent Association is a not-for-profit organization founded as a joint initiative of the ETH Domain and Swiss Federal Offices in the late 1990's.[10] In 2003, ecoinvent 1.01 was launched. The database has been revised multiple times and the latest version, ecoinvent 3.0 was released in 2013. A license must be purchased to access this online database. All revenues from the sale of licenses go directly back into improving the database. One unique characteristic of ecoinvent 3.0 is that it is an LCI and LCIA database. Many datasets are offered in multiple formats. Some formats include impact assessment data, and all include inventory data. Analysis of this database was done based on guest access to the database. Full access will have features that cannot be reviewed in this report.

Ecoinvent accepts data submissions from across the globe. Submissions go through a review process by the ecoinvent editorial board. If published, the submitter will be cited in the resulting dataset. Many other LCA tools will use data from ecoinvent or grant their users access to ecoinvent, which speaks highly of its reputation. With full access, datasets may be viewed in three different formats, whereas guest access only allows one format that provides LCI data. This format of dataset is very readable and offers all necessary information about exchanges and the validity of data. Individual exchanges can be expanded to view more information specific to that value, such as uncertainties and classifications.

The search function is a very simple keyword search bar. Using broad terms like "steel" or "rubber" will return more results than more complicated terms or phrases. This may take a little time to find the desired process. Similar to the previous databases, ecoinvent data covers a wide variety of geographic locations. It is especially important to pay attention to the geography section in this large database as there may be a variety of different regions covered in these entries. Each dataset is coded with the applicable geographic region. The ecoinvent database has a huge selection of processes. Guest access allows the user to use version 3.0 of the database. The latest version, 3.2 was released in 2015. It features new data and updated previous data. Version 3.3 was set to be released in 2016, demonstrating ecoinvent's commitment to providing the best data they can.

GaBi

GaBi is a full service-LCA based software program, meaning that the software assists in performing an LCA in addition to providing data. Data is accessed via Thinkstep, an international company focused on sustainability on multiple levels. GaBi software is available in multiple forms, each

[10] ecoinvent Centre. About ecoinvent. (http://www.ecoinvent.org/about/about.html)

geared for a slightly different purpose. Users are required to purchase a license to download the software and an internet connection is required for updating the software. This analysis is based on the access allowed via a 30-day free trial, so keep in mind having full access will present different features this report won't have considered.

GaBi is one of the most widely used LCA tool across the globe, offering over 8,000 processes reported from a wide variety of industries.[11] Thinkstep reviews all data and methods annually and partners with the global verification company DEKRA to ensure that their data is of the highest possible quality. All LCA related data is ISO 14040/44 compliant. Datasets from the online databases are in ILCD format, identical to datasets from ELCD and the CPM database. The dataset provided by GaBi are far more detailed than ILCD datasets from the other databases. A license is required to view the exchanges section of these databases. The software comes with a pre-loaded LCA study on paperclips and guidance about how to use the program for your own project. Patience is required when exploring the program. The full version may be much more user-friendly than the demo. Some exchange data can be found in the software program for the selected processes.

Online databases, which can be connected to the software program in the full version, offers a keyword search function. Data from around the world is available from GaBi. The USLCI and ELCD databases are included in GaBi along with discounted access to the ecoinvent database. GaBi has many different databases covering a multitude of sectors. Conveniently, if a user cannot find the data they need, data can be requested from Thinkstep that will work to fulfill the request. It would be difficult to identify some shortage in data provided by GaBi. The GaBi team updates their databases annually to ensure accuracy and improve the breadth of their data.

SimaPro

Developed by PRé Sustainability, SimaPro is one of the two most used LCA software programs globally. Like GaBi, SimaPro is a full-service LCA tool. Likewise, multiple versions of the software are available, each catering to different needs. Licenses must be purchased to download the software. A free demo of SimaPro is available, but is extremely limited in nature. The demo is available in three versions that mirror the available full versions. The analysis in this report is based wholly on the demo version.

The library provided by SimaPro is a combination of ecoinvent, USLCI, ELCD, Agri-footprint, and many other databases. Each entry is credited to the database it originates from and who generated the data. SimaPro abides by ISO 14000 standards when performing LCA studies and creating diagrams and other figures. The full version allows the user to select the basis for data representation. Datasets are very comprehensive and offer extensive lists of inputs and outputs. Outputs are divided into three categories, emission to air, emissions to water, and emissions to soil. Such a division makes it easier to understand the effect that outputs will have on the environment. The geographic range of data is also given in these lists.

The library of processes can be searched through by a sidebar of expandable categories, similar to the sidebar of the USLCI Database. It may take a little time to find a desired process using the sidebar. By using "Control+F," a search window appears, allowing a quick and simple keyword search. Users may find this easier to use than rifling through the sidebar.

[11] GaBi Software- to drive product sustainability!. thinkstep. (http://www.gabi-software.com/america/software/gabi-software/)

As noted previously, SimaPro offers an extensive collection of data through inclusion multiple well-known databases. It is important to note, however, that the vast majority of this data is not available through the demo version, which offers access to only 100 processes. The demo is useful for gettting a feel for the program and how it works through exploration of the library, and viewing of an included guided tour. The limited demo aside, SimaPro is a very powerful LCA tool.

Additional Considerations

The LCA tools evaluated and described in this report do not represent an exhaustive list of those available. A more complete listing can be found at (https://nexus.openlca.org/databases). Full-service LCA tools other than those described in this report include Aveny GmbH, Quantis, and Umberto. Most of these are compatible with each other, and with the software tools identified in this report. Other tools are available that focus on specific industries. For example, Athena LCA software is designed for evaluation of whole buildings and building assemblies. The Building for Energy and Environmental Sustainability (BEES) program, of the National Institute of Science and Technology (NIST) is another reputable tool that focuses on building products, including flooring materials. For more information on BEES and a case study using the BEES program, refer to the Dovetail report *Life Cycle Assessment of Flooring Materials: A Guide to Intelligent Selection*.[12] The GREET Model, created by the Argonne National Laboratory, is a software system focused on LCA of fuels and vehicles.[13] Additionally, a well-known U.S.-focused source of information is the Franklin Associates LCI database.

One factor that may impact selection of an LCA tool or database is whether it was publicly or privately developed. On the one hand, publicly sourced information and tools are often available free of charge, whereas licenses to gain access to private tools may cost thousands of dollars. On the other hand, public entities tend to have more limited resources for creating and maintaining their products. This can result in databases that are limited in size and scope. Public tools may have a few hundred datasets available whereas private databases may have thousands of datasets at their disposal. Public sponsored tools may also have difficulties keeping their data updated. For example, the US LCI database has been updated only once since being released in 2009, but ecoinvent has updated its database three times since the third version was released in 2013.

The Bottom Line

There is no shortage of tools available to LCA practitioners, a reality that has allowed the use of LCA to flourish. Both public and private sectors have created resources to help LCA practitioners complete accurate and meaningful studies. As a result, LCA practitioners have a variety of tools available at their disposal, ranging from comprehensive databases to sophisticated software programs. As LCA continues to grow in importance, the availability of LCI databases will grow as well, reducing the costs and time required to complete an assessment.

Those looking to conduct an LCA would be wise to explore as many tools as possible before initiating work as to find the tools and data sources that best fit the needs of the project team and those involved.

[12] (http://www.dovetailinc.org/report_pdfs/2009/dovetailfloors0809.pdf)

[13] The GREET Model can be accessed here: (https://greet.es.anl.gov/)

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