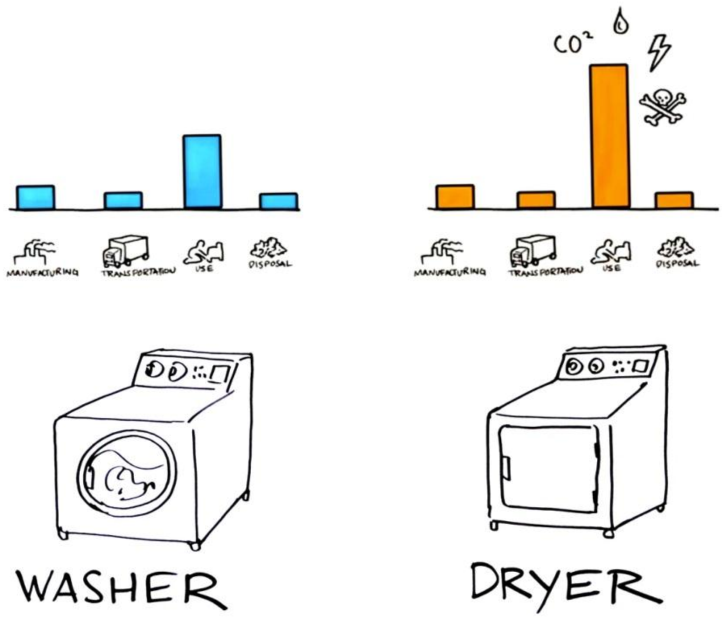
Lifecycle Assessment

An introduction for students



Lifecycle Assessment (LCA) is a foundational tool for sustainable design. It is a way of quantifying the environmental impact of your designs so that you and your customers can make more informed decisions. This brief primer introduces the basic terms, methodologies, and tools of LCA. It is a resource for designers looking to follow a design process that incorporates Whole Systems and Lifecycle Thinking.

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Introduction

Lifecycle assessment (LCA) is a method to quantify the environmental impacts of a product or service, such as greenhouse gas emissions, water pollution, land use, toxins, and more. These impacts can be measured for any or all phases of a product’s lifecycle, including manufacturing, distribution, use, and disposal. LCA can be used for many purposes, from helping inform the early stages of the design process to providing detailed data for environmental reporting. The depth and breadth of analysis can vary greatly; take care to match the sophistication of the analysis to its intended purpose. A rough assessment can take less than an hour, while a full assessment performed to international standards may take hundreds of hours. Many methodologies and software tools are available for LCA, and these should also be matched to the intended purpose.

Uses of Lifecycle Assessment

The most common uses for LCA are internal decision making and external reporting.

For internal decision making, LCA is useful to identify the product's biggest environmental impacts and to provide a benchmark for further analysis. Both of these are useful for guiding product development and are best performed early in the design process. While more detailed analyses always provide deeper understanding, they may not always be time and cost-effective.

For external reporting, LCA is useful to prove that a product is environmentally preferable to its competitors or to verify that the impacts of the product meet governmental or third-party standards. Both of these uses require that lifecycle assessment be as accurate as possible, using standardized methodologies and boundaries.

Scope and Boundaries

How much should you include in your assessment? There are direct impacts, such as resource use and waste during manufacturing. But there are also many indirect factors, such as emissions of the power plant that generated electricity for the factory; impacts from mining and refining of raw materials; transportation; energy use during the product's life; and the product's end of life. The more factors you include, the more complete your assessment will be, but the more time and money it will require. Also, when you include factors that are out of your direct control, such as supplier and user behavior, your results will be less certain and precise.

Boundaries define what your assessment will include, both in terms of lifecycle stage and what’s considered within each stage. For lifecycle stage, some analyses (called “gate to gate”) only consider impacts from manufacturing. Some consider impacts from material extraction until the final product leaves your factory (“cradle to gate”). Others consider impacts until the end of a product’s life (“the grave”). The most widely useful assessments use “cradle to grave” boundaries, including all stages of your product's lifecycle, from resource extraction to end of life.

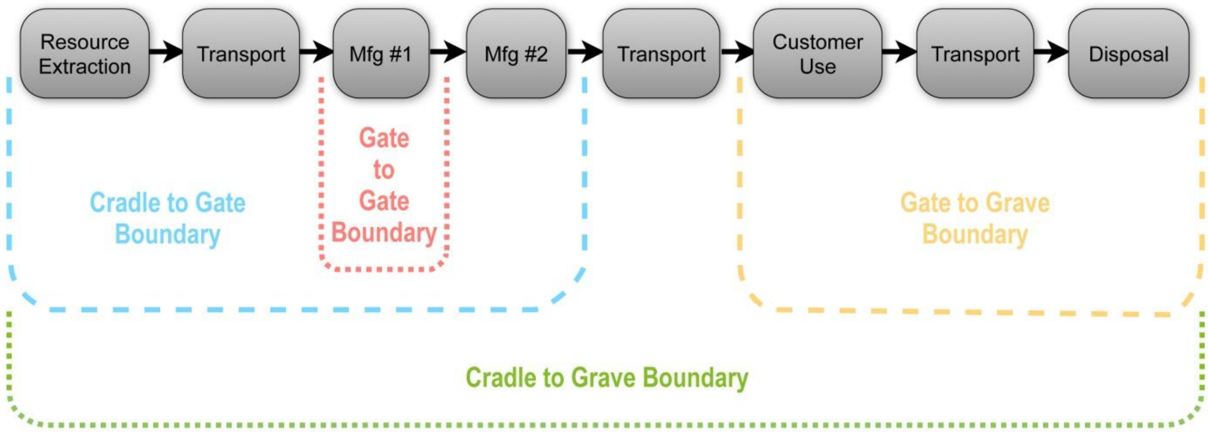

Figure 1. Common boundaries for lifecycle assessment.

In terms of breadth, analyses can include your factory's direct impacts, your suppliers' impacts, transportation, customer usage, and end of life. Enterprise carbon accounting has three standards for this: scope 1, scope 2, and scope 3, shown in the following diagram. Scope 1 boundaries only include emissions produced by your manufacturing plant. Scope 2 boundaries also include impacts from the upstream supply chain and energy generated offsite. Scope 3 boundaries add the downstream supply chain. The most widely useful assessments for product design use scope 3 boundaries.

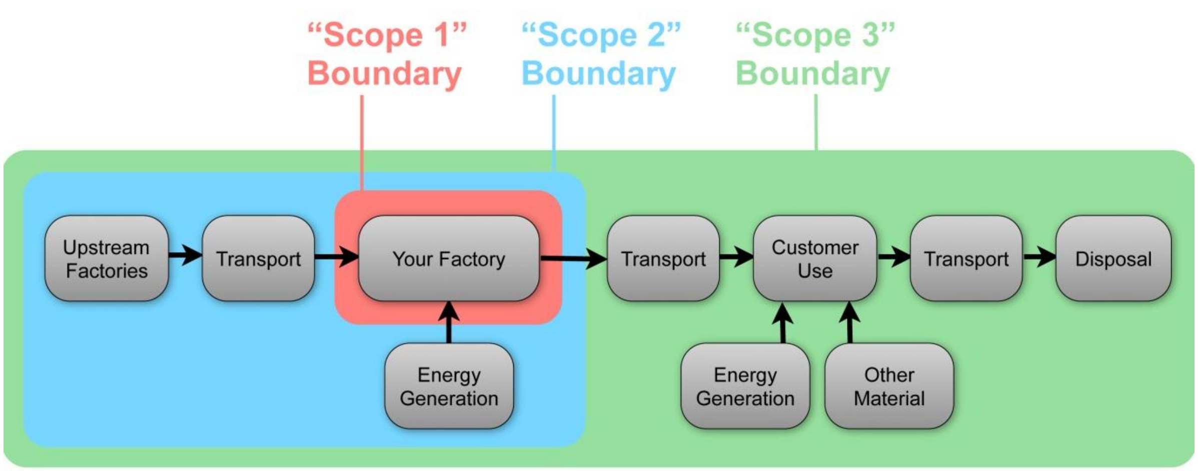

Figure 2. Standard options for the scope, or breadth, of lifecycle assessment.

Functional Units

Most LCAs do not simply list the environmental impacts of a product; instead, they list impacts per unit of service. If you compare the environmental impact of a disposable paper coffee cup to a ceramic mug, the paper cup has a lower impact to manufacture. This is misleading, however, because the ceramic mug lasts much longer. This makes its environmental impact per liter of coffee consumed much lower than that of the disposable cup. Other products will have different units of service. When selecting functional units, be careful to choose one that allows fair comparisons between your product and other alternatives.

Figure 3. Which is more sustainable? Your choice of functional units, and your assumptions about product use, may change your answer.

Inventory

To sum up all the impacts of your product's lifecycle, you must create an inventory of everything within your chosen boundaries that causes an environmental impact.

Materials and Processing

To determine the impacts of your product, you must know all your product's components and how they were processed. This includes knowing, for example, not only what kind of plastic was used for a certain part, but the mass of that part and whether it was formed by injection molding, extrusion, or other process. For assemblies from suppliers, you may need to get information from them, disassemble a unit and weigh its parts, or estimate in other ways. Often there will be some materials or processes in your product's lifecycle that you do not have data for. In this case, you often have to use the data available and estimate the best item or combination of items as a substitute. It is good practice to run multiple analyses with different substitutions to see how sensitive the results are to your assumptions.

Transportation

Transportation of finished goods and component parts should be factored in as well. Often design engineers won't know these figures with certainty, so you may want to try several alternatives to see how much it changes the results. Average transportation impacts from mines to material factories are already included in the material properties data of some databases.

Energy and Resource Use During Life

Energy use during the product's life must be estimated, as well as other resource use (water, paper, or other materials). You can do this by estimating both the usage profile and the lifetime of the product, and multiplying them. (For instance, a laptop might use 25 W of power for eight hours per day for four years, for a total lifetime energy use of 292 kWh.) Because there can be a high degree of uncertainty in these estimates, be sure to run multiple analyses with different estimates to see how sensitive the results are to your assumptions.

End of Life

You must also estimate your product's end of life impacts. Will it be sent to the landfill? Recycled? Incinerated? The ends may vary from one material to another within your product. It is good practice to run multiple scenarios to see how results change, and it is probably safe to assume that a certain percentage of your products will meet different ends.

Methodologies and Units

There is no perfect way to measure environmental impacts. Some measure only a single kind of impact (such as greenhouse gas emissions), while others are more comprehensive. Each of these impacts will be measured in different units, for example, greenhouse gases may be measured in kg of CO2 equivalents, while carcinogens may be measured in Disability-Adjusted Life Years (a World Health Organization standard), and land use may be measured in hectares. Most LCAs track these impacts by the mass of the product's ingredients and kWh (or other units) of energy used, but an economic input-output LCA instead tracks impacts by dollar value of each ingredient and energy input.

Some lifecycle assessments show the results of each impact category separately, while others combine many different kinds of impacts into a single score. To convert many different kinds of impacts into a single score, you must first normalize and weight them. Normalizing translates all the different units of measurement into a single generic unit (such as "points"), while weighting multiplies different impacts by different amounts to scale them by importance. Even within a single methodology, there may be multiple weighting schemes.

Single-score analyses can be controversial because of the value judgments inherent in normalizing and weighting (how many kg of CO2 emissions equal one hectare of land use?), but single-score results are generally the easiest for designers to use in decision making for product development. Figures 4 through 6 show the results of a single product analysis in three different formats.

Eco-Indicator 99 methodology measures greenhouse emissions, fossil fuel depletion, ozone layer depletion, two kinds of air pollution, water acidification, water eutrophication, mineral depletion, land use, ecotoxicity, ionizing radiation, and carcinogens.

By contrast, **IPCC Global Warming Potential** methodology only measures emissions of greenhouse gases such as CO2, methane, and nitrous oxide.

For more in-depth explanations of these, see the "Eco-indicator 99 Manual for Designers" listed in the Resources section.

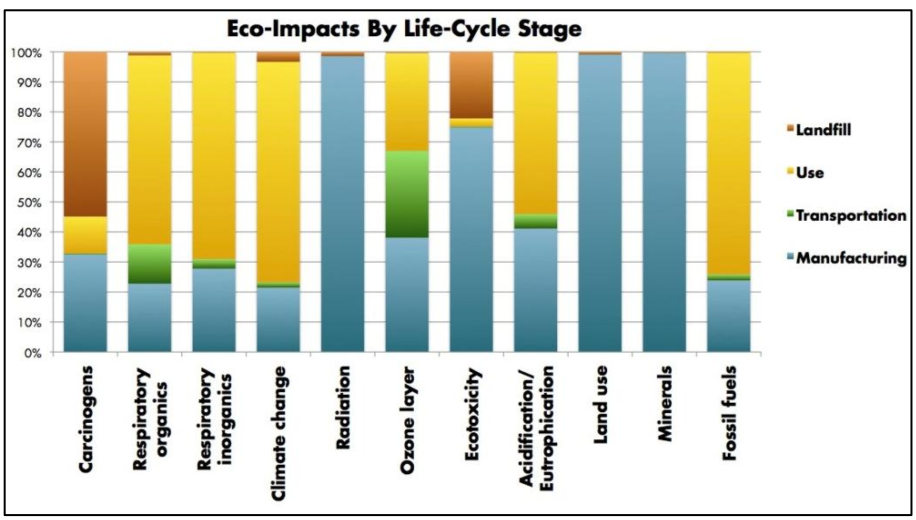

Figure 4. Each impact category shown separately, relative % by lifecycle stage.

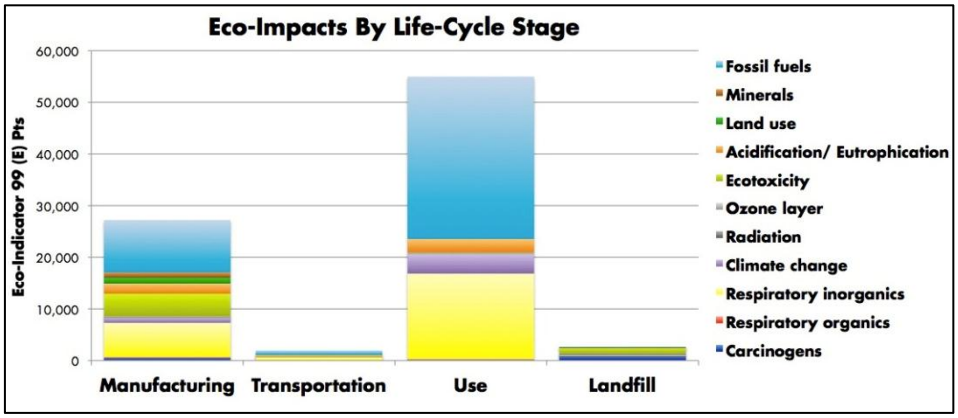

Figure 5. Impacts shown with points that have been normalized and weighted.

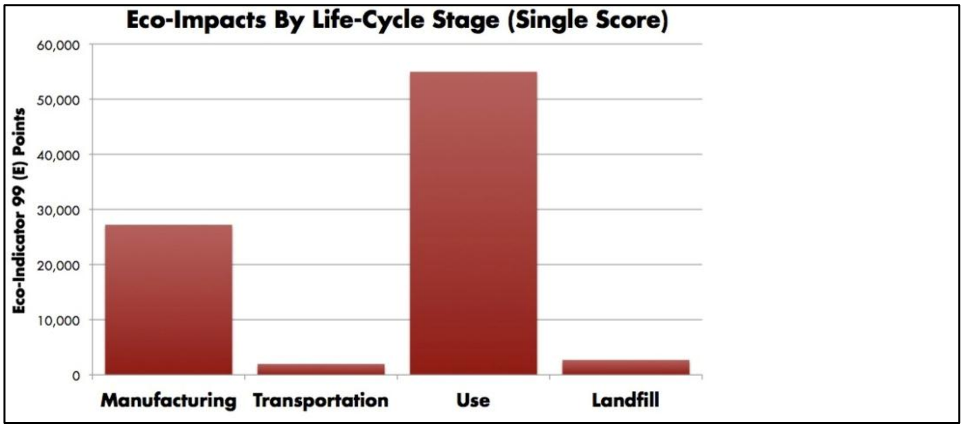

Figure 6. Normalized and weighted points wrapped up into single scores.

Interpreting Results

Once you have analyzed your inventory, you will get a series of charts or tables of numerical results. It is up to you to turn those numbers into meaningful strategies to improve environmental performance. Remember that the way you present the data (such as grouping several components into one bar in the graph) can affect the conclusions it suggests. Your initial results may suggest different scenarios for analysis as well (such as greater customer energy use or a longer life). Running multiple scenarios like this and comparing them is called *sensitivity analysis*. Seeing your results may even cause you to rethink your boundaries or functional unit or other aspects of the analysis.

Based on what you learn from doing an LCA, you can make more informed choices about the design strategies that will reduce your product’s environmental impact. For example, if the use phase dominates, you could prioritize energy efficiency or reduce the use of consumables. Or if disposal has the most impact, you may want to focus on recycling or repair.

Tools

There are many tools available to perform LCA, ranging from paper pamphlets with tables of eco-impact scores, to databases, to desktop software, to web-based software, to plug-ins for CAD programs. Generally, the web-based and plug-in software is the most convenient for designers but the least detailed in results. Desktop software is currently the most powerful tool for sophisticated analysis. It is the best tool for detailed LCAs for external reporting, but it may be too cumbersome for simple analyses. Most simple tools have just one analysis methodology built in, while advanced desktop tools generally allow users to choose their methodology.

Regardless of the tool, the analysis is driven by a database of environmental impact factors for various materials and processes. These come from previous studies done within academia or industry. Using this industry-average data greatly simplifies and accelerates the work of LCA, though it is less accurate than directly measuring emissions in your own factory.

Performing Lifecycle Analysis

The process of performing an LCA is generally as follows:

1. Determine system boundaries.
2. Determine product lifetime and functional unit.
3. Gather inventory
    a. Materials
    b. Manufacturing processes
    c. Transportation
    d. Energy and other resource use during life
    e. End of life
4. Compute impacts (often with several variations)
5. Interpret results

This process is not always linear. Your interpretations of one analysis may cause you to run different scenarios or change assumptions, or data difficulties may cause you to change boundaries. But in the end, you will go through all these steps, emerging with a greater quantitative understanding of the environmental impacts of your product and enabling you to make informed decisions to make it more sustainable.

Resources

Further Reading

"Life Cycle Assessment: Principles And Practice," a report for the U.S. Environmental Protection Agency: www.epa.gov/ORD/NRMRL/lcaccess/pdfs/600r06060.pdf

U.S. Environmental Protection Agency's listing of LCA resources: www.epa.gov/ORD/NRMRL/lcaccess/resources.html

Eco-indicator 99 Manual for Designers: www.pre.nl/download/ei99_manual.pdf

Journal of Industrial Ecology: www.wiley.com/bw/journal.asp?ref=1088-1980&site=1

The International Journal of Life Cycle Assessment: www.springer.com/environment/journal/11367

International Standards Organization, ISO 14044 "Environmental management—Life cycle assessment—Requirements and guidelines": www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=38498

Tools

EcoInvent database (data for use with software tools): www.ecoinvent.org/database

GaBi software (desktop-based, in-depth analysis): www.gabi-software.com

Granta Eco-Audit (desktop-based, based on in-depth materials data): http://www.grantadesign.com/products/ecoselector/

SustainableMinds (web-based, single score analysis): www.sustainableminds.com

Okala Guide (pamphlet with single-score LCA impact tables): www.idsa.org/okala-ecodesign-guide

SimaPro software (desktop-based, in-depth analysis): www.pre.nl/simapro

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These types of data and tools are now also being integrated into the CAD environment. For example, the **Eco Materials Adviser in Autodesk Inventor 2012** is focused on materials and process selection based on embodied CO_2, energy, water, and cost (inventor.grantadesign.com).