Chapter 4: Putting It All Together

While each of the three environmental assessment choices can be made independently to generate an impact assessment, there are several commonly used approaches. These techniques range from relatively quick, cheap, and low accuracy to much more expensive and time-consuming, but with more rigorous and robust results.

Most sustainability assessments, until relatively recently, were qualitative. Data-driven environmental impact measurements have traditionally been too slow or expensive to acquire. Even today, many organizations find that qualitative assessments are good enough for their purposes. Methods vary from "back of the envelope" to more rigorous, as represented by the following techniques.

Intuition

Most people have a broad-brush sense for the relative impacts of major design choices. For instance, intuition alone will tell you that a lighter version of a product would save on transportation costs or that a more energy-efficient product would have less of an environmental impact. Unfortunately, there are plenty of counter-intuitive trade-offs and costs unknown to the average designer.

Besides often being uninformed, many people are actually misinformed about the impacts of certain materials. Sometimes materials are attacked in the press and public opinion, painted as evil, toxic stuff. PVC has a terrible reputation, even though analysis will show that in certain applications it is the more environmentally responsible choice. In some cases, it is just because they are the most visible that certain components get the brunt of the negative attention. Transportation and packaging fall into this category, even when they might be far from the biggest problem in a given product’s lifecycle.
On the flip side, there are some very significant marketing dollars at work convincing people how “green” some materials are. The cotton industry touts their product as a natural material, “The fabric of our lives.” While it is true that cotton is a product of nature, its environmental impact is pretty substantial, thanks to the amount of water and insecticides used in conventional cotton farming. In fact, cotton uses approximately 25% of the world’s insecticides and more than 10% of the pesticides (including herbicides, insecticides, and defoliants.). Plus, there is the ongoing issue of the increased use of genetically modified cotton. Cotton’s environmental footprint has gotten much better over the years, but the “natural” option might not turn out to be the best sustainable option, despite the hype.

Intuition is fine if that’s all you’ve got, but there are plenty of ways to do better. For example, we’ll test a few of Tom and Priscilla’s intuited assumptions along the way—like her assumption that manufacturing her cups locally would be better.

### Mapping Intuition to the Three Choices

1. Impacts – Any
2. Scope – System boundary is created by areas engineer is directly familiar with; Any life cycle stages, although usually focused on the most visible ones, such as Use
3. Metrics – Usually in the form of comments, although could be checkmarks, or scores

### Product scorecards

Some companies have created scorecards to enable them to evaluate a variety of products with at least some internal consistency. Scorecards of this type are not particularly life cycle-based, but instead focus on the attributes of a product. For example, Norm Thompson Outfitters, with the help of Michael S. Brown & Associates, created a set of 12 scorecards as part of its Sustainability Toolkit, which it uses internally and gives to its suppliers and merchants. The scoring system is a simple 3 (most environmentally responsible) to -3 (least environmentally responsible), with each product element getting a single rating. Each score has examples and criteria listed to help people with their evaluation. For example, in the food category, a 3 indicates a sustainably harvested, organic product, free of toxics in raw material processing. A food is given a score of 0 if it’s on the seafood “watch” list for instance, resulting in moderate ecosystem impacts. Foods scoring -3 would have significant negative ecosystem and human impacts. Fish on the “avoid” list would qualify, for instance. For metal products, recycled gold, silver, and copper would earn a 3, while nickel, lead, and mercury would get a -3. These scores are primarily used to guide sourcing and purchasing decisions.

In another example, the design firm Ximedica (formerly Item Group) created what they call their GreenCard, for internal use. While not a rigorous, in-depth analysis, it is a valuable tool for designers to use in considering product sustainability as they do their work. As its co-founder and Chief Innovation Officer Aidan Petrie put it:
“An awful lot of people are passing very bold statements about the greening of industry, and many of these ideas are big, long-term, transformational, expensive, and complicated. We live in a world of here and now. We have to launch a product next week. We can't wait for plastics that are made out of cornhusks. We have to make plastic parts next year. We have an obligation to that.

“So our GreenCard is a tool that we’ve developed and refined here that informs and influences the design of that plastic product in the very earliest stages. We go through this checklist... You’re making choices all along the way and at the end, you will have a greener product. It may not be that iconic green product, but it would be better than it would have otherwise been, because it had been informed by the GreenCard.”

1 http://www.providenceri.com/CityNews/newsletter2.php?id=191#feature
**Conceptual Life Cycle Thinking**

These approaches consider the life cycle of a product, but tend to have quite qualitative impact evaluations. One of the most popular tools of this type is the Lifecycle Design Strategies (or LiDS) Wheel, also known as the Ecodesign Strategies wheel. It was developed as a part of the United Nations Environment Programme by Hans Brezet and Carolien van Hemel Brezet as a way to evaluate how well a product design reflects the application of eight ecodesign strategies, especially relative to alternative designs. These strategies are usually represented as an eight-axis radar chart, with each design option plotted as overlays, as in the figure below.²

Note that there are no scales defined, plus this reflects the use of strategies, which does not necessarily translate into specific environmental impacts. As stated in the University of Michigan’s EcoDesign and Manufacturing materials, “Because the LiDS Wheel Analyses are inherently qualitative, and based on an arbitrarily defined system of evaluation, it is not a method that can be

used to determine the actual environmental impact of a product. It is, however, an excellent method for evaluating environmental tradeoffs between two similar or evolutionary designs.”

**Mapping Conceptual Life Cycle Thinking to the Three Choices**

1. Impacts – Any, although not always broken out into specifics
2. Scope – All lifecycle stages (or the ones we’ve chosen to focus on)
3. Metrics – Generally scores

**Qualitative Matrix Life Cycle Assessment**

Life Cycle Assessment (LCA) describes the process of evaluating the environmental impacts of a product at each stage of its life and overall. While full LCAs can be intensively data-driven, as will be described in the following sections, sometimes a qualitative assessment is all that is required. Such evaluations can be used as stand-alone decision tools, but often they serve to identify the design options worth more detailed analysis. Evaluations can be text-based or scored, but there are no standard axes or rating systems so organizations can adopt whatever metrics work for their purposes. This figure shows an example of one such matrix used by 3M.

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Please enter the following marks as appropriate:

- √ - Impacts understood and Risks adequately addressed
- * - Impacts understood but Risks require further attention
- ? - Impacts/Risks not completely understood
- + - EHS Advantage

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3 [http://www.engin.umich.edu/labs/EAST/me589/ecodatabasefinal/design/lids/concepts.html](http://www.engin.umich.edu/labs/EAST/me589/ecodatabasefinal/design/lids/concepts.html)

Evaluation approaches become even more effective when adopted by more than one company, or even by a whole industry. One example of this is the apparel industry’s Eco Index, created through the collaborative efforts of over 100 producers and retailers and coordinated by the Outdoor Industry Association. The resulting software application guides its users through a set of questions for each of six life cycle stages, focused on seven key areas of impact.

The scoring system is based on points awarded based on meeting various criteria. For example, in the Packaging area, Post Consumer Recycled (PCR) Content scores range from 0 for “unknown or 0-29% post consumer recycled content” to a maximum of 8 for 100% PCR content. Such scoring systems try to reflect the scale of impact somewhat quantitatively, although the direct impact of changes is hard to see. The scorecard’s guidelines state that use of PCR leads to resource conservation such as less energy used, less waste produced, and less virgin raw material extracted, but does not say how much. Therefore, it is not easy to tell whether it makes a big or small difference changing from, say, 29% PCR to 30% PCR to get an extra point on the scorecard, something product designers may want to know. Plus, a one point change due to PCR use may

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5 Eco Index website: [http://www.ecoindexbeta.org/](http://www.ecoindexbeta.org/)
6 Image from: [http://www.ecoindexbeta.org/content/index-tools](http://www.ecoindexbeta.org/content/index-tools)
have very different environmental impacts than a one point change in raw material input use efficiency. Results are in the form of points, not impacts.

Qualitative impact assessments tend to be quicker, less expensive, and easier for non-specialists to participate in and understand than quantitative ones. Their lack of precision can be acceptable for many high-level decisions, or for indicating when it is worth investing the time and effort required to generate a more detailed understanding of the environmental impacts that many quantitative methods can provide.

<table>
<thead>
<tr>
<th>Mapping Qualitative Matrix LCA to the Three Choices</th>
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<tbody>
<tr>
<td>1. Impacts – Any</td>
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<tr>
<td>2. Scope – All lifecycle stages (or the ones we’ve chosen to focus on)</td>
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<td>3. Metrics – Generally scores</td>
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**Life Cycle-Based Design Assessment**

There is an impact evaluation approach that reflects life cycle thinking and is more quantitatively rigorous than the techniques described above, but is still useful for design-stage evaluation. Life cycle-based design assessments reflect many of the attributes of full life cycle assessments, but are based on product models and not on full studies of a product’s actual environmental impacts. Because they usually draw upon one or more existing impact data sets, they have the advantage of being useful in making data-driven design decisions while still at the drawing board. Most are software applications, allowing fast data search and impact calculations.

**Industry-specific**

Some approaches of this type are focused on particular industries or applications. The Comparative Packaging Assessment (COMPASS)\(^7\) is an online tool developed by the Sustainable Packaging Coalition (SPC), a project of the nonprofit institute GreenBlue. Drawing upon life cycle impact data from the U.S. Life-Cycle Inventory (LCI) Database and Ecoinvent (a Swiss LCI database), it allows engineers and packaging designers to model the impacts of their choices while still in the design phase. It calculates profiles of product life cycle impacts in three main categories.

**Consumption Metrics**
- Fossil Fuel
- Water
- Biotic Resource
- Mineral

**Emission Metrics**
- Greenhouse Gas
- Clean Production: Human Impacts

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\(^7\) See [https://www.design-compass.org/](https://www.design-compass.org/)
Guide to Sustainable Design

- Clean Production: Aquatic Toxicity
- Eutrophication

**Packaging Attributes**
- Content (Recycled or Virgin)
- Sourcing
- Solid Waste
- Material Health

**Industry-agnostic**

Other tools, such as SolidWorks Sustainability, don’t focus on one particular design domain, but allow modeling of a wide range of products. SolidWorks has chosen its approach specifically to meet the needs of designers and engineers who want to incorporate pre-production modeling of environmental impacts into their product development process.

Like other tools of this type, SolidWorks Sustainability uses secondary LCA data to develop a quick, robust assessment, which could be called a “screening LCA” or an LCA-based design assessment. But because it doesn’t use the company’s own primary data, SolidWorks Sustainability shouldn’t replace comprehensive LCA software, such as PE International’s GaBi software.

SolidWorks Sustainability should be used as an environmental impact dashboard, giving immediate feedback on the impact of design decisions. Although it may be considered LCA “light,” it is powered by PE International’s LCA database (confusingly also called GaBi), and uses a general process model made using the GaBi LCA software. This powerful engine provides designers with the tools appropriate for creating comparative models and making educated trade-off decisions. Its integration with SolidWorks’ 3D modeling suite enables real-time impact analysis during the design process.

In SolidWorks Sustainability, impacts are represented in several categories. It assumes that designers benefit from more granularity than a single number score can give, but that environmental impacts can easily be understood and estimated by using a small set of key environmental indicators. It currently shows four types of environmental impacts:

- Natural resource depletion: **Non-Renewable Lifecycle Energy Demand**
- Impact to the air: **Air Acidification**
- Impact to water/earth: **Water Eutrophication**
- Impact to the climate: **Carbon Footprint**

SolidWorks Sustainability has been developed to enable sustainable design in the context of product design, helping developers make informed choices about environmental impacts early enough in their life cycles to lock in benefits from the start. With tools of this type, environmental impact becomes a design decision and not a post mortem examination.
Life Cycle Assessment

Several of the other methods described so far have addressed each of the components of a product’s life cycle. There is however a specific process called Life Cycle Assessment (LCA) with a standardized set of steps and output in the form of environmental impact measures. In fact, life cycle assessment is part of the ISO 14000 (environmental management) standards, and is specifically addressed by ISO 14040:2006 and 14044:2006.

LCA is defined as “an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements.”

Performing a full LCA requires significant expertise and effort. There are many resources available that go into much more detail about the process than this guide covers. However, it is useful to at least be familiar with the four major steps of the standardized LCA process:

1. Goal and Scope Definition – *What are we trying to learn?*
2. Life Cycle Inventory (LCI) – *What’s embedded in the product?*
3. Life Cycle Impact Assessment (LCIA) – *What effects does it have?*
4. Data Interpretation – *What does it all mean?*

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8 Society of Environmental Toxicology and Chemistry (SETAC), 1990

Goal & Scope Definition

As with other assessments, the first step involves clarifying the purpose and extent of the LCA. This entails formally determining the functional unit, impacts of interest, and system boundary—elements from our "First Choice".

While LCA “light” approaches have been described above, a “full” LCA includes actual primary environmental impact data gathered once the product’s full lifecycle has been determined. Such detailed LCAs take, on average, three months\textsuperscript{10} and cost $10,000-$60,000\textsuperscript{11}, and are only possible to complete once the product is in use and has gone through all stages of its life cycle. This increased accuracy is worth it for benchmarking or external reporting (such as green marketing) purposes.

Inventory Analysis

The next phase entails creating a list of all of the components of the products life cycle that fall within the defined system boundary. It has three major steps:

1. Construct a process flowchart that shows the following:
   - Raw materials
   - Mfg processes
   - Transports

\textsuperscript{10} A full (internal) LCA study takes 8-16 weeks to complete. http://www.industrial-ecology.com/services/lifecycleassessment.html

Uses
- Waste management

2. Collect data for:
- Material inputs
- Products and byproducts
- Solid waste, air and water emissions

3. Calculate the amounts of each in relation to the functional unit

Essentially, this is the process flow diagram—with detailed mass and energy values attached—that Tom and Priscilla sketched out. The resulting Life Cycle Inventory (LCI) provides a breakdown of all of the energy and materials involved in a product's system at a level of detail that provides a basis for evaluation.

Impact Assessment

Once a detailed LCI is created, environmental impacts can be ascribed to its parts, and if desired to the whole system. There are four steps to the Life Cycle Impact Assessment (LCIA) process, the first two of which are considered mandatory, while the last two are optional.\(^\text{12}\)

1. Classification
Classification involves assigning specific environmental impacts to each component of the LCI. It is here where decisions made during the scope and goal phase about what environmental impact categories are of interest come into play.

2. Characterization
Once the impact categories have been identified, conversion factors—generally known as characterization or equivalency factors—use formulas to convert the LCI results into directly comparable impact indicators as described in the Measurements section above.

3. Normalization (optional)
Some practitioners choose to normalize the impact assessment by scaling the data by a reference factor, such as the region's per capita environmental burden. This helps to clarify the relative impact of a substance in a given context. For instance, if global warming contributions are already high in the context in which the product is being assessed, a reference factor would normalize whatever the product's global warming contributions are in order to clarify its relative impacts.

4. Weighting (optional)
The pros and cons of weighting were described in the Measurements section above.

Interpretation

Although listed fourth, life cycle interpretation actually occurs throughout the whole LCA. It involves the ongoing process of clarifying, quantifying, checking, and evaluating the information

\(^{12}\) As dictated by the ISO 14044 standard
used by, and resulting from, the life cycle inventory (LCI) and impact assessment (LCIA) phases. The standard that covers the LCA process, ISO 14044, gives two main objectives:

1. Analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and to report the results of the life cycle interpretation in a transparent manner.
2. Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study.

To achieve these objectives, the ISO standard states that interpretation should cover at least three major elements.

1. Identification of the significant issues based on the LCI and LCIA. Which life cycle stages or components stand out as major contributors to overall impact? What are the anomalies?
2. Evaluation which considers completeness, sensitivity, and consistency checks. Is all the information needed for interpretation present in the LCI and LCIA? How reliable is the information related to any identified significant issues? How much do changes in such factors influence the overall results? Are all of the assumptions, data, characterization factors, etc. that were used in the assessment consistent internally and with the overall goal and scope of the LCA?
3. Conclusions, recommendations, and reporting. As discussed in later sections of this guide, a great deal of an LCA’s value depends on how its results are communicated to people involved in making relevant decisions, whether other designers, engineers, management, marketers, or other parts of the supply chain.

Although LCA is the most comprehensive impact assessment, even full, ISO 14044-compliant LCAs are never the definitive answer. They require interpretation, which is turn requires transparency and judgment. The data sources, assumptions, and all other relevant information must be transparent to decision makers so that they can understand the full context of the results of the life cycle inventory assessment. Deciding among design options is not as easy as just comparing LCIA numbers, whether single- or multi-factor, weighted or not. LCIA results can be a source of insights, but do not stand alone in guiding product development choices. Engineers will need to take them in the context of the other attributes they are trying to optimize, including cost, manufacturability, performance, and so on. In addition, there are myriad other factors guiding product development decisions not covered by LCAs, including social impacts and acceptance, pricing, political agendas, and regulations.

**Mapping Life Cycle Assessment to the Three Choices**

1. Impacts – Any
2. Scope – All lifecycle stages (or the ones we’ve chosen to focus on)
3. Metrics – Measurements from actual product life cycle, supported by data tables
“Whew, I never knew environmental assessment was such a complex world!” breathed Tom.

“Well, we’ve already decided that we wanted to use measurements for our Third Choice, the one on metrics. If only there were a handy table to show us what Tools were available to us now, given our three choices.”

### A Handy Table of Tools for the Three Choices

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<thead>
<tr>
<th>Intuition</th>
<th>Choice 1: Impacts</th>
<th>Choice 2: Scope</th>
<th>Choice 3: Metrics</th>
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<td>Visible stages</td>
<td>Comments, checkmarks, scores</td>
</tr>
<tr>
<td>Product Scorecards</td>
<td>Any</td>
<td>Set boundary, usually product mfg and assembly</td>
<td>Checkmarks, scores</td>
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<td>Conceptual Life Cycle Thinking</td>
<td>Any (but usually not specific)</td>
<td>All (or selected) lifecycle stages</td>
<td>Scores</td>
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<td>Life Cycle Assessment (LCA)</td>
<td>Any</td>
<td>All (or selected) lifecycle stages</td>
<td>Measurements (primary data)</td>
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“It looks like what I need is a Life Cycle-Based Design Assessment,” said Priscilla. “Since I already have my model in SolidWorks, it makes sense for me to use Sustainability.”

“I do too,” said Tom. “So I’ll start out in SolidWorks Sustainability too. But if I want to use my results in marketing, I’ll eventually need to do an LCA to verify the results.”
So what? (Using the results of your assessment tool)

The previous sections have laid out the context of sustainability and described how to know it when you see it. However, all of that information is irrelevant if it doesn’t enable action—the point of assessing and reporting environmental impacts is to give you information on how design choices affect the relative sustainability of one product compared with other options. This section and the ones that follow show how to put all of that information into action.

The first step is to determine what the results of the environmental impact assessments mean. No matter which tools or techniques you used, you should have some impact information about your product. As was noted earlier, sustainable design is a relative concept, so you should also have impact information against which to compare it. Common comparisons include:

- **Standards**: These may be certain thresholds or impact profiles that have been accepted as industry, or maybe even just company, standards.
- **Previous Designs**: The goal may be to make each generation of a product more sustainable than the previous one.
- **Competitive Products**: Whether for market positioning or internal purposes, it is sometimes helpful to compare to other companies’ solutions.
- **Alternative Designs**: One of the most common is to compare variations on a given design to each other to narrow down development to the best, most sustainable design options.

The comparison set should have been identified early in the process so that relevant impact information about the alternative designs could be gathered as a part of the overall process.

As you conduct the comparisons, it’s important to know what differences are meaningful. The significance of any differences identified will depend on the products and the measurement approach used. For even the more data-driven techniques used, not all incremental improvements are worth investigating. As a simple rule of thumb:

- A +/- 10% difference on one or several environmental indicators gives an indication that the changes between the options can be considered “directionally” correct. Chances are, you’re moving on the right path.
- For a relatively simple product—like Priscilla’s cup—a difference of +/- 30% on the indicator(s) is generally a meaningfully greener product.
- For a more complex product, the decrease in impact that you should look to see to identify a greener product are higher, perhaps +/- 40-50%, because the chances of overlooking process steps or incorrectly modeling some assumptions increase with the complexity of the product.

These may seem like large percentages, but they can serve as a helpful reminder not to get caught up in trying to tweak less relevant aspects of a product and instead to focus on the major contributors to its impacts. This is particularly true given the need for the designer to simultaneously balance the environmental impacts of a product with its cost, durability, and other design criteria, along with how it fits in with the overall product strategy.
Once you have a sense for which impact areas are worth looking at, whether because of the significance of their differences from alternatives or other reasons (e.g., a corporate focus on carbon footprint), it is time to look for ways to reduce those impacts as effectively as possible. In many cases, there are certain elements of the design or product life cycle that generate most of the impact. It's often a classic example of the 80/20 rule, with 20% of the design contributing 80% of the impact. For instance, in decreasing the impact of an electric coffeemaker the temptation might be to remold the plastic housing, since plastic is generally considered a less-than-sustainable material. However, simply shortening the electric cord decreases its overall impact many times what is saved by replacing the handle; and decreasing its energy usage may even dwarf that impact.

“Alright, enough preparation, Tom! I think we know enough now to responsibly dig into our products. Can I go first?”