5

A Pragmatic Approach to Lifecycle Analysis

Formal lifecycle analysis is not new; in fact, lifecycle analysis tools and techniques have been around in various forms for decades. What is new is an urgent need to improve the tools and expand the use of lifecycle analysis to a broader spectrum of products and services.

We're going to use a pragmatic approach to lifecycle analysis that keeps the focus on the main goals: understanding the overall impact and making improvements. The truth is that you don't always need to measure everything; you don't always need precise data; you don't always need complete information. You just need to know what to measure, when, and how—and where to place your priorities.

To get started we'll need a model of the product/service lifecycle that we can use to organize our work. So, let's take a closer look at the phases of a typical lifecycle and the key considerations at each phase.

A Basic Lifecycle Model

Every product is different; every lifecycle has unique time frames and characteristics. As a result, many different lifecycle models have been produced over time. For this book, we use a basic three-stage model. We prefer this model because it is straightforward and matches most people's personal experience with the lifecycle stages of common products. The three stages of our model are

- **"Make,"** which covers everything that happens before a product is actually put into operation—including the materials and chemicals that are used to create it, the processes involved in assembling and manufacturing it, the packaging that encases it, and the supply chain that distributes it

- **"Use,"** which includes the power the product consumes as it is operated, the greenhouse gas (GHG) and other emissions it creates, the water it uses, and the noise, light, and heat it generates during operation
- **"Renew,"** which covers everything that happens after the product is used, including the demanufacture or disassembly of the product, reuse of key components, recycling, and take-back

At each stage of the lifecycle we focus on three primary aspects of the environmental impact of a product or service:

- **Energy and emissions,** including the calculation of energy and power, finding the cleanest source of energy for your product, using energy efficiently, calculating GHG emissions and CO_2 conversion, and so on
- **Chemicals, materials, and waste,** including the legal and business considerations of hazardous and toxic substances, packaging and documentation, waste disposal, recycling, take-back, and process-related GHG emissions
- **Water and other natural resources** that are embodied in the product or service, including social and business considerations of using scarce or nonrenewable materials, calculating the water footprint, and so forth

Additional Lifecycle Considerations

Our three-phase model is intentionally simplistic. So, before we discuss each aspect of the lifecycle in more detail, we'd like to offer a few notes about topics that our model doesn't directly address, including supply chains, consumables, hidden impacts, services, and the effects of design and prototypes.

Supply Chains

In this day and age, very few products are manufactured and distributed by one company. Most are produced and marketed through complex ecosystems of geographically dispersed companies. To engineers this means that when you're designing products and services, every participant in the supply chain matters: your company's employees, your company's suppliers, those suppliers' subcontractors—everyone involved in assembling, manufacturing, distributing, and ultimately disposing of your product.

The boundaries of accountability are expanding, and this accountability is so new that most industries and companies haven't yet developed the tools, standards, or certifications needed to fully address it. However, many companies that are committed to global citizenship are beginning to formalize supply chain environmental and social responsibility programs, supplier code-of-conduct contracts, supplier site audits, and more stringent product requirements and specifications.

This presents an opportunity for engineers to set an example, which can directly impact the performance of your suppliers. For instance, engineers at Tesla Motors (the Silicon Valley company that's producing high-performance, 100% electric cars that we talked about in Chapter 2) are conscious of everything environmental—"from the design specs of the automotive systems and software they're working on to the temperature of the building, whether the lights are on, [and] whether you drink water out of bottles or out of the tap," says Craig Carlson, Tesla's director of software engineering. "Eventually, this translates to an ability to migrate suppliers to a more stringent code of conduct that follows our example."

We're also beginning to see more collaboration within various vertical industries centered on lifecycle supply chain issues. For example, the electronics industry has banded together to help improve socially and environmentally responsible performance across manufacturing and supply chains. Two major working groups in that field are collaborating: the Global e-Sustainability Initiative (GeSI) and the Electronic Industry Code of Conduct (EICC).[1] These types of collaborations are important in larger industries where suppliers often sell to more than one of the major manufacturers. Without alignment, such suppliers may be faced with trying to meet a set of different—and potentially contradictory—environmental goals and reporting standards.

Finally, from a practical point of view, how do you get sustainability information about suppliers? The place to start is with the group that manages suppliers within your company. They may have data and mechanisms already in place. Also, it is always important to make sure they are aware of discussions you are having directly with suppliers, as the supply management team owns the contractual obligations between your company and the supplier.

Beyond that, there are two ways to get data, and you will often find yourself resorting to a mix of the two. First, you can simply request the data from your suppliers. The second approach is to use externally generated models, which may not provide information about a specific supplier, but can characterize a general process or industry. For example, you may use the Economic Input/Output (EIO) models that we discuss later in this chapter. Another example of this approach is paper; well-established models exist for calculating the impact of paper lifecycles without consulting specific manufacturers.[2]

Gathering data one supplier at a time can be a complex and time-consuming task, but if you do it correctly (and if suppliers are cooperative), you can get very accurate results. External models are often much simpler and quicker, but may miss important, supplier-specific details.

"Mini Lifecycles" of Consumables

Many products don't fit the simple lifecycle model outlined in the preceding section because they contain elements or subsystems that have their own separate lifecycles, and it's important to factor these in when performing a lifecycle environmental impact analysis. Examples include

- Batteries, toner cartridges, ink refills, filters, and other consumables.
- Transport packaging, bulk shipping packaging, retail display packaging, consumer packaging, packaging that holds other packages together, and so on.
- Manuals, technical guides, troubleshooting references, warranty cards, and so forth.

The approach for dealing with these is pretty straightforward: Do a lifecycle analysis for each one and add them up. In the case of the printer, you can

1. Work through the impact of the printer unit itself.
2. Add in the lifecycle of an ink cartridge multiplied by the typical number of cartridges used in the lifetime of the printer.
3. Add in the impact of the packaging and documentation.

4. Do the same thing for the paper usage (try the Environmental Defense Fund's paper calculator at www.papercalculator.org).

From a pragmatic point of view, it is worth coming up with a rough estimate of each component before spending too much time on the specific measurement of any given piece. If you find that the energy use of one component is a thousand times greater than any other, from an energy perspective it's probably a good idea to focus on the part with the greatest energy usage and ignore the others until they become more significant.

Hidden Impacts

Some products or services have environmental impacts above and beyond the readily observable direct impacts. Here are just a couple of examples.

- If your product runs on electricity or is often used in an air-conditioned environment (such as a PC in an office) it will usually generate some heat as a result of inefficiencies in the electrical components. Therefore, you need to account for the environmental impact of the air conditioning required to compensate for its operation.
- Many products require a professional installer or regular visits from a service technician. The environmental impact of the technician's travel to and from the site should be accounted for, as well as spare parts that are needed.
- Some products have special disposal requirements. The mercury in compact fluorescent light bulbs requires that they be recycled at specially equipped facilities that can deal with the mercury.

Generally, these situations aren't hard to calculate; you just need to spend some time and make sure you think of these "hidden" impacts for your specific situation. And again, from a pragmatic view, you may be able to determine that some of these impacts are small enough to be ignored. If a product travels 10,000 miles from China after it's made, and then has to make one last trip of an average of 2 miles to be recycled, you can probably safely ignore the impact of the recycling trip for now.

Services

The lifecycle model applies to services as well as products. In fact, sometimes services can have a major impact when they are done on a large scale (remember what happens when we multiply anything by 1 billion). Here are a few types of services, and tips on how to approach them.

Traditional services, such as consulting engagements or technical support services, often involve sending trained specialists or replacement parts to customers. As a result, these services are often dominated by the travel and shipping involved. Services can also involve call centers, where the impact is from the office space, commuting, and equipment required to support the call center operation. In any of these cases, the impacts are fairly straightforward to calculate based on travel or shipment calculators, or from energy bills.

Web-based and online services, such as search engines, online shopping sites, or massively multiplayer online role-playing games (MMORPGs) such as World of Warcraft or Lineage 2, often involve massive compute power from very large data centers. In one notable example, the avatars or virtual characters in the online 3D world called Second Life were actually determined to have a carbon footprint almost as big as that of a typical real person in Brazil!*

Some products have both a product and a service element. One example is a Webkinz stuffed toy, which comes with a special code on its label that allows access to the "Webkinz World," a Web site where kids can interact with a virtual version of their stuffed pet (see Figure 5–1). The maker, Ganz, has sold more than 2 million units to retailers and claims more than 1 million registered users of the Webkinz Web site. To assess the full lifecycle impact, you have to add together the impact from the manufacture and delivery of the physical good along with a pro rata share of the online infrastructure.

Another example is TiVo, a digital TV recording system that includes a physical box that attaches to your TV, as well as a back-end online service that is responsible for feeding the box TV schedules and software updates.

The key point is to understand the environmental impact over the entire lifecycle—both the product and the service components must be accounted for.

Design and Prototypes

As engineers, we know the true lifecycle of a product begins well before the manufacturing stage. Prior to that, we're writing specs, doing design, building prototypes, testing, fixing bugs, and testing again. In a rigorous lifecycle

* Source: Author Nicholas Carr. Carr calculated that, on average, there are about 12,500 active avatars on Second Life at any given time of the day, and that 4,000 servers and cooling systems are used to support the world, combined with the 12,500 PCs that are used to control the avatars. That amounts to 1,752 kWh of electricity used by each avatar over the course of one year, and the average citizen of Brazil consumes 1,884 kWh, writes Carr (read Carr's blog at www.roughtype.com/).

FIGURE 5–1 The Webkinz Web Site

analysis, you'd need to fully account for all of these activities. However, for most real-world products, the premanufacturing impact is very small compared to the impact of full production and usage.

Of course, in some situations this may not be the case, and you will need to include design and prototyping in your model and accounting. For example, only a few copies of the space shuttle have been built, so the effort to build prototypes of the pieces may be nontrivial compared to the production runs. Similarly, the number of cars smashed in crash tests may be worth counting for cars with smaller sales volumes.

How do you decide whether you need to count the design and prototype impacts? As in earlier cases, do a quick analysis and see whether you can gauge the relative sizes of that impact versus the production and usage impact. If it's less than 1%, you can ignore it unless you're doing a very detailed model. If it's more than 1% of your overall impact, it is worth at least tracking and paying attention to possible ways to reduce it.

Embodied Energy and Embodied Carbon

As you do more work in lifecycle analysis you will come across the concept of **embodied energy**, and related concepts such as **embodied carbon** (which really is inaccurate shorthand for embodied carbon dioxide equivalents [CO_2e], which we will discuss in a later chapter).

Embodied energy is a measurement (or, in reality, a modeled estimate) that represents the total energy required to manufacture a product and get it to the customer. This concept provides a useful way to understand the impact of the parts of the product lifecycle that are usually not visible to the consumer. If someone tells you the embodied energy of a product, you can get a sense of the scale of energy impact of making that product without having to know the details of how it was made and shipped.

The concept of embodied carbon is similar to that of embodied energy—it's an aggregate of the direct and indirect carbon emitted for the entire production process. The methodologies for calculating embodied carbon are also similar to those used for embodied energy, though there tend to be more areas of ambiguity in how things are accounted.

However, standards are emerging for measuring embodied carbon within individual companies and across the supply chain. For example, the World Resources Institute's GHG Protocol Corporate Standard[3] provides standards and guidance for companies and other organizations preparing a GHG emissions inventory. It covers the accounting and reporting of the six GHGs covered by the Kyoto Protocol, and was designed to help companies prepare a GHG inventory that represents a true and fair account of their emissions while simplifying and reducing the costs of compiling a GHG inventory. We make use of this standard in our free, online GHG tool, OpenEco.org, which we will discuss in detail in Chapter 11.

In addition, the **Carbon Trust**, created by the U.K. government, is developing a draft Publicly Available Specification (PAS) standard by which the carbon content of all products and services can be measured. The final PAS standard will be a useful tool for engineers to identify and analyze GHG emissions associated with the products and services their companies provide. It draws on lifecycle assessment (LCA) techniques and can help identify and quantify the environmental loads involved, the energy and raw materials used, and the emissions and wastes consequently released.

Lifecycle Assessment Tools

Since lifecycle analysis has recently become such a hot topic, it's not surprising that there are tools you can work with today—or that significant work is underway to create new tools. While you won't be able to rely on any single tool to do all of your analysis work, the important thing is that learning to use the tools can be very helpful and illuminating, even if they don't always give you complete, consistent, and precise results. Our general advice is to start using the tools that are available, come up with some consistent methods for measurement, and present your findings openly and transparently, no matter what they are. Remember to keep track of which tools you used for which estimates. As tools and accounting methods improve, this information will help you understand how accurate your results are.

On one end of the spectrum are tools based on the **Economic Input-Output Life Cycle Assessment (EIO-LCA)** method. This method is based on macroeconomic data, so it's great for getting a very quick overview of the impact of a class of products. It is also unique in that it includes a broad range of impacts, including natural resources, energy, and GHG emissions. In that regard, EIO-LCA can help you understand the relative sizes of various impacts and a top-level estimate for each. It's also a great way to get an estimate when no other method is viable.

On the other hand, the EIO-LCA method is primarily based on macroeconomic data, which makes it very difficult or impossible to examine individual product traits or tradeoffs. For example, if you make a change to your product, the resulting change in impact won't show up in an EIO-LCA model for years (if ever).

The mathematics of EIO-LCA analysis is straightforward, but the model requires that someone has done a detailed analysis of the industry and product classes in question. This renders the tool impractical in some instances, because specific industry data may not exist or may be incomplete or inaccurate. However, when the right data exists, an EIO-LCA model can provide very complete results. Want to understand the impact of the trucks that delivered parts to your suppliers? An EIO-LCA model won't tell you how many trucks were involved, but it can give a good estimate of the impact.

For an excellent tutorial on the economic input-output analysis method, we suggest you visit the Eiolca.net Web site sponsored by Carnegie Mellon's Green Design Institute at www.eiolca.net/tutorial-j/tut_1.html. This tutorial provides step-by-step instructions on how to enter data into the EIO-LCA model and the process behind choosing the data to enter. The tutorial also describes how to read and interpret results. We also recommend the technical white paper by Chris T. Hendrickson, Lester B. Lave, and H. Scott Matthews, "Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach."[4]

The main alternative to EIO-LCA for measuring environmental impacts is the **process-sum** approach. It's based on process and facility-level data that quantifies material inputs (consumables), material outputs (products), and emissions over the three lifecycle phases. In other words, you calculate the energy expenditure for each discrete activity involved in making, using, and renewing the product, and you add them all up. For a given product there may be hundreds or thousands of separate calculations, but the process-sum analysis can provide a fairly accurate assessment of embodied energy for the processes or products being analyzed.

The EIO-LCA and process-sum methods actually complement each other quite well. EIO-LCA is good at getting an estimate of the total impact, but is weak on the details. Process-sum is strong on the details, but it requires a big effort to build a complete picture. As a result, we highly recommend using a mix of both methods, with the specific tool being chosen depending on what question you're trying to answer.

Because these methods are so complementary, a new method that formally combines the two has emerged. The **separative hybrid** approach supplements process data with I/O analysis and uses estimates where hard data is not available. This approach is fairly new, but it has shown promise in more accurately gauging the embodied energy for consumer products such as desktop computers or refrigerators.[†]

In many cases, you can make simplifying assumptions about certain elements of the model to get a meaningful result with less effort. For example, when you're considering the energy expended during shipping you could just use the whole weight of the product shipped *n* number of times, as opposed to summing all of the individual components at various times during the process and trying to track exact values at multiple times. Or you may be able to extrapolate good data from previous studies. Lifecycle studies of PCs, for example, may contain data that's helpful in understanding the eco impact of everything from cell phones to servers to DVRs to the electronics in cars. Leveraging other people's work as a starting point can help you take a huge step forward in analyzing your specific project.

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† For details about the economic I/O and separative hybrid techniques, and a case study using the methods to calculate embodied energy for a desktop computer, see the white paper "Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input-Output Methods," by Eric Williams, published in *Environmental Science & Technology* 38(22): 2004.

Finally, lifecycle modeling often involves straightforward calculations that can be done simply if you just have the right constants to calculate with. For example, burning gasoline in a standard internal combustion engine creates 19.9 pounds of GHG emissions (measured in CO_2 equivalents) per gallon of gas used. This convenient fact makes it easy to know the GHG emissions of operating any gas-powered vehicle; you don't need to know the weight, the engine size, the miles per gallon—just knowing the fuel involved is enough!

Most other tools provide insight into particular products or product elements, and are sometimes limited to a smaller number of impacts (e.g., GHG emissions only). The paper calculator that we discussed earlier is a prime example, and other similar calculators are becoming available.

One interesting example, created by the Flemish Waste Agency, is a set of cards that makes it easy to compare the lifecycle environmental impacts of commonly used materials and processes.[5] The "Ecolizer Designwijzer" cards contain several hundred eco-indicators quantifying the environmental impact of the three lifecycle phases of materials and processes, including ferrous metals, nonferrous metals, polymers, wood, paper and packaging, building materials, chemicals, energy, transportation, as well as buildings, land use, lighting, and services (see Figure 5–2).

FIGURE 5–2 The Ecolizer Designwijzer Tool

The method used to create the indices looks at the damage caused in terms of resource depletion, land use, climate change, ionizing radiation, acidification/eutrophication, and toxicity. This tool is mainly intended for quickly estimating relative comparisons of products and components. The guide is written in Dutch and currently is distributed only through workshops, but it offers an example of how governments everywhere could make getting ecodesign know-how into people's hands in forms they can use.

Other examples of recently developed lifecycle analysis tools include the following.

- **TEAM:** This is an LCA tool from Ecobilan (a.k.a. Ecobalance), which allows the user to build and use a large database and to model any system representing the operations associated with products, processes, and activities. TEAM can be used to calculate the associated lifecycle inventories and potential environmental impacts according to the ISO 14040 series of standards (for more information see www.ecobilan.com/uk_team.php).
- **LCA calculator:** This tool, from Industrial Design Consultancy, helps users assess the environmental impact of a product by calculating its energy input and carbon output (for more information see http://lcacalculator.com/).
- **GaBi 4:** Available from PE International, this provides sustainability data administration and evaluation at the organization, facility, process, or product lifecycle level.[6] Technically GaBi 4 is not a tool, but a set of tables of useful numbers (for more information see www.gabi-software.com/english/gabi/gabi-4/).

Starting a Top-Level Assessment

Some engineers like to immerse themselves in understanding the formal process before engaging in a problem. Others (especially certain software developers) like to dive right in and learn by doing, adding process as they get further along. Those who use the latter approach may even start from the beginning more than once, using what they learned on the last try to tune their approach.

This section is for engineers who like to jump right in. We're going to walk through the process of starting a lifecycle assessment based on what's in your head, and we suspect you'll realize that you know more about the sustainability of your product than you might have thought.

The first thing to do is to open a text file (or just pull out a pencil and paper if that's more natural for you) and write down the three major lifecycle phases: make, use, and renew. For each phase, simply write down where potential impacts may lie for each major category of impact: energy usage, chemicals, emissions and waste, and water and natural resources. At this stage, this should just be a brainstorming exercise—don't go crazy with numbers, just try to identify any area that may have a significant impact.

Next, review the special cases we covered in this section: Are mini lifecycles involved? Are there any services? Are there any indirect or hidden impacts?

Now identify the scale involved. At this point, you probably don't know the size of the impacts, but you should be able to describe the size of the process that is causing the impacts. Here are some examples of what you might write down.

- "Water and natural resources to create 100,000 copies of the documentation"
- "Energy and resulting emissions to ship 500 units from our factory in Mexico to customers in Europe"
- "Electricity to run 50,000 units for one year"
- "Fraction of the product that is easily recyclable aluminum or plastic"
- "Impact of making and disposing of 1.2 million batteries"

This level of information provides you with a basic model for diving in and understanding where your impacts are and what to do about them. Each of these can be worked through and converted to more specific numbers (e.g., actually calculating the water involved to make the paper in the first bullet). We'll discuss how to do these calculations in more detail in later chapters.

Next, for each item you listed, write down some additional notes where applicable. For example:

- **Estimate the cost of the activity.** For instance, estimate the shipping cost, electricity cost, cost of materials, and so on. This will provide a basis for finding the potential cost savings associated with eco improvements.
- **Look for product benefits.** Are any of the items you listed valuable to your customers? Do they view them negatively? This will highlight potential areas for feature improvement.
- **Consider legal implications.** Obviously, you need to do a detailed analysis of applicable laws, but even at this point it's worth noting the areas where you suspect or already know there are important laws or standards.

Before we go too much further, it's useful at this point to check your work against some other models. In some cases, you can find published analyses of products that are similar enough that you can do a sanity check, and some quick work with the EIO-LCA models might also give you a sense of whether you've missed anything big. While there may not be a perfect EIO-LCA category for your product, you can look at a similar product, or apply the EIO-LCA model to subcomponents of your product or service that you identified earlier.

Deciding When to Stop Assessing

This is one of the tough questions of lifecycle assessment. You need to be clear what your goals are, and then think through how good the data needs to be to meet your goals. At a minimum, you need to

- Be able to communicate where your biggest impacts lie and how big they are
- Have sufficient data to meet any legal claims you'll be required to make
- Be able to use your model to understand the size of the impacts as a result of design changes in your product or service

For some situations getting within a factor of two for the overall impact in the key areas may be good enough. For other projects you may find that you need to be accurate to within one or two percentage points. And in some areas, such as the level of potentially dangerous chemicals, you may need to be even more precise. Note that the answer doesn't have to be the same for each part of your project. The precision and accuracy needed to meet a legal requirement will not be necessary in other areas.

Finally, it's important that you keep track of how good your data and model are in each area. For example, you may have decided that a factor of two was sufficiently close for one purpose, but then find that your marketing department wants to make some strong public claims based on your numbers. It's critical that you keep yourself honest on what the numbers really mean, and make sure they aren't being misused.

At this point, you've created an assessment model and you can iterate on your model until you're comfortable that you've captured the major impacts to a level of detail required for your project. So, now we'll shift gears from the model itself to determining where to focus first.