Estimating the Value of Life Cycle Assessments[1]

Gregory A. Norris
2.-0 LCA consultants Sylvatica – Harvard School of Public Health
USA

Abstract

What is a life cycle assessment worth? How much should one spend on an LCA, and what are the expected returns from undertaking one? The value of an LCA ought to be readily estimable by anyone proposing to fund an LCA, or by anyone seeking funds for undertaking an LCA. Assessing the value of a potential LCA as a function of its uncertainty and scope and the characteristics of the decision should be part of goal and scope definition. The present paper proposes and illustrates a framework for estimating the value of LCAs as a function of these and other parameters. We begin by describing two different perspectives for characterizing an LCA's value: private and public. Next, we suggest which characteristics of the decision context and the LCA results are most influential in determining the value of the LCA. We then construct a basic model of the value of an LCA, which incorporates these characteristics as floating parameters, and use this model to draw some general and qualitative conclusions about how the value of an LCA depends on these characteristics. Finally we demonstrate application of the method and model to a case study.

Two Perspectives on LCA Value

There are two distinct perspectives from which the value of an LCA can – and should – be assessed. The first perspective is that of a private sector company which might undertake an LCA either in-house or as a client, for whom the value is governed by potential impacts of the LCA upon costs and revenues. We'll label this the "client perspective." The second perspective is a public or societal point of view. From the public perspective, the value of the LCA is governed by potential impacts of the LCA upon society-wide costs and benefits. We briefly consider the potential value of an LCA from each perspective.

Client Perspective

There are a series of potential impacts for a company from undertaking an LCA, some of which are interconnected. We summarize the relationships in Figure 1. LCA can be used directly in marketing claims, either offensively (promoting a product's environmental superiority) or defensively (deflecting claims of competitors). The LCA can support marketing claims for existing products, or can lead to product redesign, which better positions the product with respect to offensive or defensive marketing claims. All such changes impact the company's bottom line by impacting sales by first impacting product image. Changes in product image can in turn impact the overall corporate image as well. Corporate image changes can feed back onto product image, and may also have an influence on employee morale (thus productivity, retention, recruiting), regulator relationships, and investor attitudes. Simply conducting LCAs for the ostensible purpose of environmentally improving products can be used directly in promoting the corporate image. Finally, LCAs may uncover opportunities for efficiency improvements or cost reductions.

Next we note that each of these client impacts can occur either *directly* from the LCA, or *potentially* in the event that other future occurrences also take place. Examples of these latter potential benefit scenarios include the ability to deflect future criticism if it comes, or the discovery and avoidance of exposure to risk of future regulatory costs. The direct benefits of an LCA could be termed tactical benefits, while potential future benefits are strategic in nature.

[1] Presentation for the 1st International conference on life cycle management, Copenhagen, 2000.08.26-29. Pages 157-162 in Proceedings.

Societal Perspective

The total potential costs and benefits of an LCA from a social perspective are broad in nature. They will vary in both the type and the receiver of the costs and benefits, as summarized in Table 1. Costs and benefits due to an LCA will be either market or non-market in type. Market costs and benefits are automatically valued in monetary units such as dollars, and are reflected in market transactions. Non-market costs and benefits are those for which market transactions do not take place, but which can be estimated by studies attempting to assess what people do pay or would pay or forgo in order to avoid the costs or receive the benefits.

The distinction of market versus non-market impacts is different from the distinction between internal costs (both private sector and public sector) versus external costs. External costs are those borne by parties not involved in the transactions or decisions, which cause them. Thus, the cost of hospital visits due to ambient air pollution are external, market costs, while the estimated monetary valuation of the pain and suffering due to asthma attacks brought on by air pollution are external non-market costs.

Table 1: Matrix of Types and Recipients of Costs and Benefits from LCAs

Type	Internal Recipient (private &public sectors)	External Recipient
Monetary	For example, the costs and benefits to the LCA client and competing firms, and firms in their supply chains	For example, health care costs/benefits from changes to air pollution;
Non-monetary	Not generally relevant	For example, changes in mortality and morbidity resulting from changes in pollution;

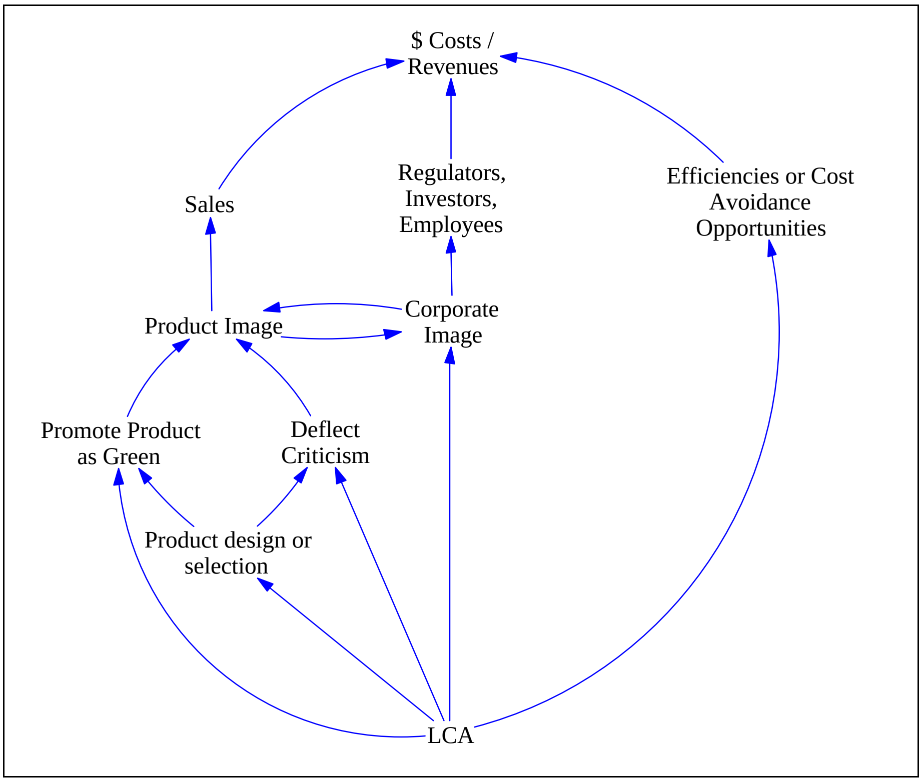

Figure 1: Potential Client Impacts of an LCA

LCAs themselves focus on the system-wide pollution and resource consumption consequences of product decisions over their life cycles. But which portions of the total matrix of social costs and benefits of LCAs should be the focus in assessing the social value of an LCA? One option would be to address all sectors of the matrix in Table 1. A narrower focus consists of the *external* cost and benefit impacts of an LCA, both market and non-market. This latter choice can be motivated by noting that internal cost and benefit impacts are presumably already being taken into account by the decision makers whom they effect. For this reason, we suggest and here apply a societal perspective evaluation of the *external* costs and benefits of the LCA, which assesses the impacts of the LCA upon those parties who are not in a position to otherwise directly alter those impacts. In the remainder of this paper a model of LCA value from the societal perspective with a focus on external costs is developed, explored, and applied.

A Model of LCA Value from the Societal Perspective

From a societal perspective, the impact and thus the value of an LCA stems from the shift in market shares, which it brings about. This may be a shift in market shares among competing products already being sold, or it may be a shift from existing to new products, or it may be the selection (and subsequent market penetration) of a single new product from among competing new alternatives.

The environmental damage which would result if the entire market were supplied by alternative ***i*** is labeled D_i**.** The value of the LCA is the environmental damage avoided by the LCA: the damage without the LCA minus the damage with the LCA. In a world where purchasing decisions were governed *only* by LCA results, all market share would shift to the environmentally best alternative. In a world with perfectly accurate LCAs, the alternative identified by the LCA results as being environmentally best would always correspond to the true best alternative. In the real world, LCAs are neither perfect nor all-powerful. The question of interest to us is: What is the value of LCAs in this real world?

First, we suggest a simple one-parameter model of LCA influence upon market shares, using an *"influence coefficient" α*, with $0 \le \alpha_i \le 1$, such that the LCA causes a fraction □ of each alternative's pre-LCA market share to shift to alternative ***l***. More complex models of LCA influence could be proposed, such as ones where the market shift depends on the degree of difference between D_i and D_l. In this basic model the value of an LCA is proportional to its influence, and depends as well on the magnitude of the differences between the D_i and D_l, weighted by their prior market shares. Note that the value of the LCA can be negative if D_l adequately exceeds one or more D_i's which have large enough prior market shares.

This basic model reminds us that the value of an LCA depends in part upon the degree of difference in environmental performance among the available alternatives. Recall as well that the true differences in environmental performance among the alternatives are never known with certainty. To capture this relationship in our model we introduce a random variable ***k*** where $k \ge 1$. For simplicity we allow ***k*** to be triangularly distributed and symmetric, with minimum value of 1, mode **k,** and maximum value (2**k**-1), where ***k*** *is the deterministic "difference coefficient.*

We model the differences in environmental performance among the alternatives by letting the true damage values for all non-best alternatives to be given by kD_b. Thus, the environmental damage from all non-best alternatives will be symmetrically distributed about the deterministic value $\mathbf{k}D_b$, with a minimum possible value of D_b and a maximum possible value of $(2\mathbf{k}-1)D_b$. Given this model we can calculate the value of an LCA as a function of its influence α and the expected difference between the best and the other alternatives, **k**.

Finally, what is the value of a real-world, imperfect LCA, and how does it depend upon the degree of uncertainty in the LCA results? To investigate this question we introduce a simple single-parameter model of the LCA uncertainty. We assume that each LCA result $\hat{D}_i$ equals the true value D_i times by random variable ***u***. How is ***u*** distributed? Specifically, what are its expected value and variance, and how do they depend upon the data sources, methods, modeling decisions, and level of effort underlying the LCA? These are the key (and as yet uninvestigated) questions of LCA uncertainty analysis. The present paper endeavors to show how answers to these questions can be used to assess the value of LCAs, to design them for maximum value, and to help only ones with positive value be undertaken. In order to achieve these goals we make simple but plausible assumptions concerning the properties of ***u*** and subject them to sensitivity analysis.

An expected value of ***u*** equal to 1 would mean that LCAs are unbiased in general. Is this to be expected? On the one hand, LCAs are by definition incomplete, which leads to an expected bias of underestimation, or $\bar{u} < 1$. On the other hand, data underlying LCAs generally pertain to the past rather than the present or future, and with emissions coefficients and factor productivities generally increasing with time this fact will tend to make LCAs biased upwards.

For the present analysis we assume that LCAs have an equal probability of overestimating or underestimating the true value. In other words, the *median* value of ***u*** is 1. We variance of the LCA uncertainty is expressed using an *"uncertainty coefficient"* ***m***, to which we test the sensitivity of our conclusions. We use a model of LCA uncertainty which coincides to the statement that "LCA estimates vary from the true values by a factor of **m**." Being off by a factor of 2 means that the LCA estimate $\hat{D}_i$ could range from $\boldsymbol{D_i}$/2 to 2*$\boldsymbol{D_i}$. Thus, we allow ***u*** to range from 1/**m** to **m**. If we believe that LCAs approximate the true values "to within plus or minus 10%" for example (a *very* confident assumption), we would reflect this by setting **m** equal to 1.2. Perfect LCAs are modeled using **m** = 1.

Finally, how should ***u*** be distributed around 1, between the limits 1/**m** and **m**? We have specified that 50 percent of the probability density function for ***u*** will be below ***u*** = 1, but what degree of central tendency should the distribution reflect? Are all values between 1 and **m** equally likely, which calls for a uniform distribution? Or is there greater likelihood closer to 1 (a perfectly accurate LCA result), which calls for a peaked distribution? Again, it is the unsolved task of LCA uncertainty analysis to deliver empirical hints at the answer, and to show how the answer depends upon decisions made in the design of the LCA. However, numerical case study comparisons have shown that the influence of the distribution shape is minor compared with the influence of variations of **k** and **m** over the tested ranges, and thus the choice of distribution shape does not affect the qualitative nature of our conclusions.

Case Study Illustration

Finally we demonstrate the application of the principals, methods, and model developed in this paper on an example. We attempt to develop a first-order estimate of the potential value to society of an LCA comparison of alternative sandwich packaging, or "clamshells", in support of a product selection decision by a major worldwide fast food restaurant chain. In order to assess the value of an LCA, we first must define the "life cycle of the decision." In this example the question is how many clamshells will this decision impact for how many years? Let's imagine that the restaurant chain will revisit the packaging question again after 4 years, and let's estimate that they package 1 billion burgers in clamshells worldwide each year. Finally, let's consider the three major material alternatives of polystyrene, fluted paperboard, and a new biodegradable option based on cornstarch, which indeed are the materials that have been compared in a series of peer-reviewed LCAs of clamshell alternatives over the past decade.

The challenge in prior estimation of the value of an LCA is that it requires input information that can only be estimated (unless we already have a perfect LCA of the situation). In particular, we require the following in order to estimate the value of an LCA:

- an estimate of the cost to society per functional unit of the best performing alternative;
- an estimate of the degree of difference in environmental cost among the alternatives;
- the number of alternatives, and estimates of the prior market shares for each;
- estimates of the shifts in market shares to result from the LCA-based decision.

With this information we can then estimate how the value of the LCA would depend upon the uncertainty in its results.

According to the Earthshell Corporation's website,[2] prior peer-reviewed life cycle assessments of its cornstarch-based clamshell along with competing polystyrene and fluted paperboard designs have identified that the non-minimum clamshells' lifecycles require 1.4 and 1.6 times the energy of the best performing product. We will use these ratios to estimate an expected value of 1.5 for the ratio of the total life cycle damage for the non-optimal alternatives versus the best alternative: **k** = 1.5.

Next, we develop a conservative estimate of the external cost to society per clamshell, by first estimating the societal costs of releases of the US EPA criteria air pollutants and CO2 from one gram of expanded polystyrene. Note that the conservative bias comes from the fact that published external cost factors ($ per kg) are only available for a subset of the flows reported in life cycle inventories. Table 2 presents the inventory of air emissions, the cost factors, and the calculated total external cost per g of expanded polystyrene. We have hypothesized a total market size of 1 billion clamshells per year over 4 years, or 4 billion clamshells. A polystyrene clamshell weights 5.8 grams.[3] Using a weight of 5 grams, a conservative estimate for the external environmental damage from a market monopolized by the best alternative is on the order of $20M.

Table 2: US EPA criteria air pollutant emissions and CO2 for 1 g expanded polystyrene

Substance released to air	Unit	Release	Estimated cost (1998 $) / kg	Estimated external cost
CO	mg	2.4		0
CO2	g	2.7	0.03	0.00008
Dust (we assume PM-10)	mg	5.1	15	0.00008
non methane VOC	mg	17.1	1	0.00002
NOx (as NO2)	mg	43	5	0.0002
Pb	ng	73	2	0.0000002
SOx (as SO2)	mg	140	5	0.0007
			Total cost (1998 $):	0.001

Sources: LCI data: Buwal 250 database, 1997, as reported in SimaPro 4, PRe Consultants, NL;
Costs: rough mid ranges from values extracted from US literature by Tellus, 2000.

Finally, what are likely to be the market share consequences of the LCA? Currently, fluted paperboard is the dominant packaging material. We don't know which of the alternatives will come out best from the LCA, nor (of course) which one is environmentally best in reality. For simplicity here let's assume that all 3 have an equal probability of being environmentally best, and that the LCA is not systematically biased against any material, so that each has an equal probability of being found best by the imperfect LCA. Let's also assume that the company is committed to a 100% shift to the LCA-identified alternative ($\alpha = 1$). Then there is a 1/3 chance of no market change, and a 2/3 chance of a 100% shift in market share. This is equivalent in expected impact with a 100% shift to the LCA-chosen material from a starting point of equal market shares – both ways, the expected shift is 2/3 of the total market from a non-optimal choice to the best choice. With this information, equation (8) provides an estimate of the societal value of a perfect LCA in this decision context: $6.67M. What is the expected value of a real LCA as a function of its uncertainty?

Figure 2 shows the expected societal value of an LCA for this decision as a function of the uncertainty factor, m. Note that for values of **m** above 16, the expected value remains stable at roughly $1M. This indicates that for this problem and model, moving from equal market shares (or from a randomly selected single alternative) provides a positive expected benefit of approximately $1M, even if the LCA is highly uncertain (as long as it is not expected to be systematically biased

[2] www.earthshell.com
[3] Franklin Associates 2000

against the best alternative). The results also indicate that improvements in the accuracy of the LCA add to the LCA's value *if* the uncertainty is below the range of m = 16.

In fact, we rarely start with zero information. Instead, our prior position may be one of an LCA of some estimated uncertainy (due to its age and a degree of mis-match between the subject of the original LCA and the specifics of the decision problem at hand). We can estimate the incremental value of a new LCA as a function of the new LCA's uncertainty by subtracting the value of the old LCA from it, given our best estimate of the uncertainty in the old LCA.

Finally we examine the level of uncertainty in estimates of the value of the hypothetical "clamshell LCA." These results are shown in Figure 2. First, note that the 95th percentile for the societal value of the LCA exceeds the expected value of the perfect LCA! This is not a mistake, but rather a consequence of the fact that **k** = 1.5 is the mode (and mean or expected value) of the differences among the actual LCAs, but not the upper bound on those differences. Recall from page 5 that the difference multiplier ***k*** is a random variable, triangularly distributed and symmetric, with minimum value of 1, mode **k,** and maximum value (2**k**-1). Thus, while the *expected value* of the LCA is bounded from above by the expected value of the perfect LCA, the *actual value* of the LCA may well exceed the expected value of a perfect LCA.

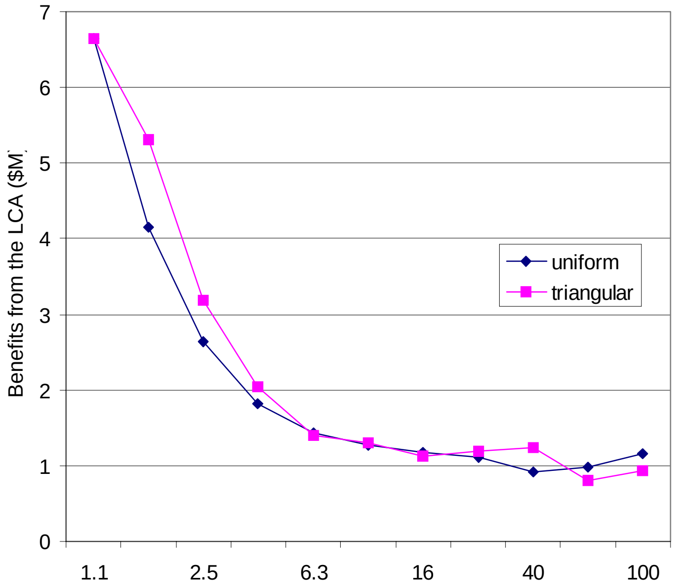

Figure 2: Expected societal benefits from a sandwich "clamshell" LCA

Next, we see that for LCA uncertainties of **m** > 2 there is a 25% chance that our LCA will lead to wrong choices that yield negative societal value from the prior modeled situation of equal market shares among the 3 materials.

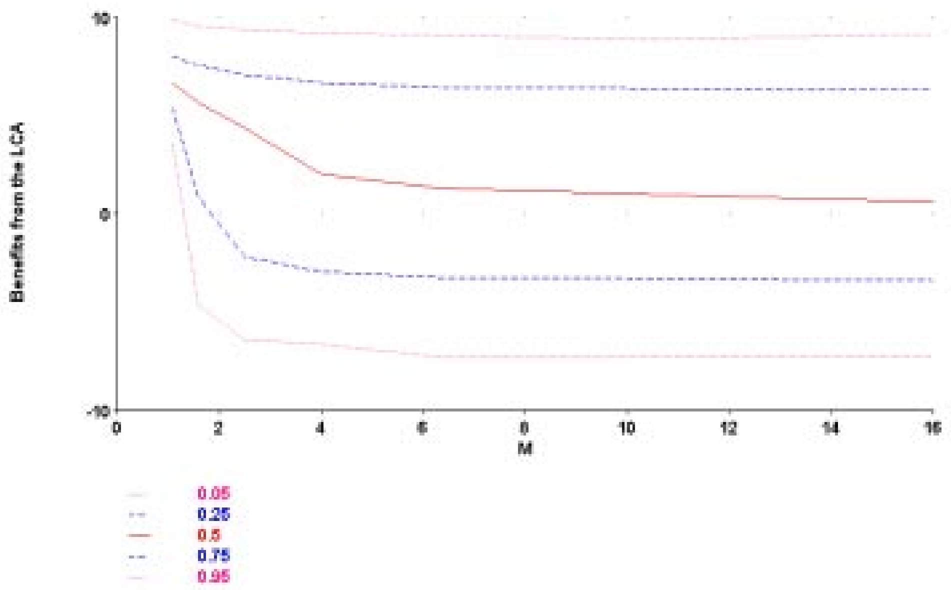

Figure 3: Confidence intervals for the societal value ($M) of a sandwich "clamshell" LCA

Now, LCAs are not free. So a final question might be: given an estimated relationship between LCA cost and LCA uncertainty (expressed using m), what is the optimal level of LCA sophistication and investment from a societal point of view? This is the sort of important question for which we will be readily able to estimate answers using the framework developed in this paper, once we have developed empirical knowledge about how uncertain LCAs really are, and how this uncertainty depends upon their design and thus (in part) upon the resources devoted to them. Developing this empirical knowledge should be a major agenda of LCA researchers, LCA clients, and LCA funders.