Special Issue Honouring Helias A. Udo de Haes: Broadening the Scope of LCA

Social Impacts in Product Life Cycles

Towards Life Cycle Attribute Assessment

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Abstract

Background, Aims and Scope. Social impacts in supply chains and product life cycles are of increasing interest to policy makers and stakeholders. Work is underway to develop social impact indicators for LCA, and to identify the social inventory data that will drive impact assessment for this category. Standard LCA practice collects and aggregates inventory data of the form "units of input or output (elementary flow) per unit of process output." Measurement of social impacts within workplaces as well as host communities and societies poses new challenges not heretofore faced by LCA database developers. Participatory measurement and auditing of social impacts and of workplace health issues has been shown to provide important benefits relative to external auditor-based methods, including greater likelihood of detecting rights abuses, and stronger support of subsequent action for improvement. However, nonstandardized auditing and metrics poses challenges for the supply chain-wide aggregation and comparison functions of LCA. An analogous challenge arises in the case of resource extractive processes, for which the certification of best management practices provides an important and practical environmental metric. In both the social and resource extraction examples, it may be that *attributes* of the process are more valuable metrics to measure and incentivize than measured quantities per unit of process output. But how to measure, how to aggregate across life cycles, how to compare product life cycles, and how to incentivize progress as with product policy?

Methods. A methodology is presented and demonstrated which estimates the health impacts of economic development stemming from product life cycles. This methodology does not introduce new social indicators; rather, it works with the already common LCA endpoint of human health, and introduces and applies a simplified empirical relationship to characterize the complex pathways from product life cycles' economic activity to health in the aggregate.

Results. A simple case study indicates that the health *benefits* of economic development impacts in product life cycles have the potential to be very significant, possibly even orders of magnitude greater than the health *damages* from the increased pollution. While the simple macro model points up the dramatic importance of socio-economic pathways to health in product life cycles, it lacks any sensitivity to the vitally important, context-specific attributes of the economic development associated with each process. This result begs the question of how to measure, aggregate, compare, and stimulate society-wide improvement of context-dependent attributes within and across product life cycles in LCA.

Discussion. Before attempting an answer to the question noted above, a brief reconsideration is offered concerning life cycle assessment. Namely, where does it come from, and what does it bring?

Recommendations and Outlook. Finally, the paper concludes by sketching a life cycle approach to promoting localized assessments, to summarizing their results over supply chains and life cycles, and to comparing product life cycles in terms of their results. Often, localized assessments will yield information on the *attributes* of a process, rather than (or in addition to) the traditional form of life cycle inventory information, which is "units of something per unit of process output." The methodology can enable product policy users to promote reporting of basic attributes of processes within supply chains, together with local measurement and reporting of context-relevant impacts. For attributes linked to progress on impacts of local and global concern, promotion of these attributes within supply chain processes will bring strong benefits. In addition, over time it may be possible for researchers to develop and refine models that estimate, based on cross-sectional and time series analysis of attributes and impacts, relationships between attributes and impacts. In any case, while local impacts across supply chains may not be precisely knowable – let alone controllable – by a micro-decision maker at the time of their product-related decision, life cycle attribute analysis may give such decision makers an opportunity to empower progress throughout life cycles and supply chains, which is after all a motivating goal of LCA.

Keywords: Attribute assessment; health impacts; life cycle assessment (LCA); poverty; social impacts

1 Background, Aims and Scope

The worlds of product policy and sustainable production and consumption to which the methods and results of life cycle assessment (LCA) contribute have changed. With increasing globalization of supply chains, and especially since the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, it is less acceptable to NGOs, policy makers, and concerned consumers to consider product-related environmental impacts without also attending to their social impacts. Also, without even extending the scope of *impacts* addressed within LCA beyond its well-established endpoints of human health, biotic environment, and non-biotic environment (e.g., Jolliet et al. 2004), there is still ample reason to consider socio-economic *pathways* to the human health endpoint. For example, in 2002, the European office of the World Heath Organization named poverty as "the most important single determinant of ill-health" in Europe (WHO Europe 2002). The governments and companies who use LCA-based methods and tools increasingly call for attention to social impacts and to socio-economic influences on health.

The developers of LCA-based methods and tools are responding. Two recent articles proposed frameworks for social impact assessment in LCA, including determination of damage categories, impact categories and suggestions for category indicators or inventory data (Dreyer et al. 2005, Weidema 2006). The UNEP/SETAC Life Cycle Initiative has formed a working group on social impacts (UNEP 2005), and two of the recent SETAC meetings included sessions addressing social and occupational impacts in LCA (SETAC 2005, SETAC 2004) LCA software tool developers continue to add features that enable users to track such economic and occupational variables as worker-minutes in various occupational categories per unit of process output.

The contributions cited earlier from Dreyer et al. and Weidema, as well as progress within the UNEP/SETAC working group on social impacts follow a standard LCA approach to developing impact methods and inventory data for new impacts. The traditional steps to method development and application might be summarized as follows:

1) Determine a set of endpoint indicators, or safeguard subjects (e.g., health (life expectancy and morbidity), autonomy, participation and influence, etc.). Optionally (as in Weidema 2006), propose a method for aggregating results across the different endpoint indicators into a single indicator (e.g., quality-adjusted life-years).
2) Determine measurable 'social inventory data', measurable and reportable in units per unit of process output, at the process level. For example, total wages paid; wages paid by wage level and by country; occupational injuries; child-labor-minutes, etc., all reported per unit of process output.
3) Develop empirically-based quantitative models of the impact pathways that relate inventory data to endpoint indicators, and express these using characterization factors. For example, as presented in section 2 of this paper, changes in mean national life expectancy related to changes in mean per capita income.
4) Gather or estimate inventory data per process, and use these data to develop social inventories and social impact assessments for product life cycles, using the same computational framework of today's (environmental) LCA.

The above traditional approach is where my thinking stood until quite recently as well.

The remarkable career of Helias Udo de Haes has included, among a long list of achievements, leadership of projects that developed and refined integrative frameworks for LCA and especially impact assessment. Through activities related in part to the UNEP/SETAC Life Cycle Initiative, which exists as the result of tireless effort by Udo de Haes more than any other person, LCA is now being enriched by the involvement and outlooks of whole continents and regions, including Africa, Latin America, and Southeast Asia, which have in earlier and recent debates been marked by a defensive posture towards LCA and product policy.

Recently, Helias has been thinking a lot about local indicators, connected primarily with his interest in accounting for the impacts of land use associated with resource extraction processes such as mining and the logging of forests. He further notes that the impacts of these activities are very site-specific, being highly dependent upon management practices at the site, as well as the sensitivity of local ecosystems. This interest has lead Helias to consider especially the available systems for *certification* of resource extraction activities, including those related to sustainable forestry and sustainable mining.

The method of 'Life Cycle Attribute Assessment' (LCAA) presented later in this paper offers a way to summarize attributes of processes across a product life cycle or company supply chain. Examples of process attributes are whether or not they are certified as following best management practices, free of child-labor, etc. In May, 2005, Helias responded to a conference presentation of the LCAA concept with the following points:

1) We know that some attributes of processes, such as being certified via one method or another, are not expressible in the standard life cycle inventory data system of units per unit of process output.
2) It appears that site-based certification systems may be an excellent way to evaluate certain kinds of site-specific impacts, such as the 'environmental sustainability' of the land use associated with resource extraction operations, for a variety of reasons.
3) The proposed method of LCAA offers a way to aggregate information from site-specific reporting, including categorical results of certification, as part of a life cycle-wide assessment.
4) However, just because we *can* bring certification results and other process attributes into a life cycle-wide assessment, that doesn't mean that doing so is worthwhile. What does it really contribute, what does it add to the value already brought by certification systems alone?

The concluding section of the present paper attempts to address the question raised by Helias in point 4 above.

The remainder of this paper contains four sections. In Methods we present a rather simple approach to quantify the possible magnitude and relative importance of life cycle socio-economic pathways to health, vis-à-vis life cycle environmental impacts on health. Rather than introduce one or more social indicators, this approach considers socio-economic pathways to the existing LCA impact endpoint of human health. In Results, we note that this simple approach indicates that socio-economic pathways can have dramatic influences on health, motivating a serious critique of the limitations in the simple, aggregated approach. One of the major limitations is its lack of attention to context-dependent characteristics of economic activity and development. Another is the multi-dimensionality and context-dependence of poverty, and the crudeness of a national, average, economic indicator for estimating the influence of product life cycles on this phenomenon. In partial response to these serious limitations of the preliminary method, the Discussion section introduces localized or site-specific methods of measurement, auditing, and evaluation. Localized assessments including audits and certifications pose an obvious challenge to a system-wide, quantitative and comparative method such as LCA. This challenge, in turn, motivates the concept and method of Life Cycle Attribute Assessment outlined in the Recommendations and Outlook section.

2 Method

In a project supported by the Japanese government agency AIST and the Society for Non-Traditional Technology (SNTT), research was undertaken that accomplished the following:

1. Extending the existing LCA model with estimation of income changes in different countries brought by consumption changes;
2. Extending existing LCIA methods to include health consequences via socio-economic pathways;
3. Demonstrating the extended approach to sustainable consumption analysis in a case study.

The intent of the extension was to enable LCA to capture, in a first-order and preliminary (or 'beta') way, the influence of product life cycles on health through pathways summarized in the recent world health literature and shown in **Fig. 1**. The solid arrows in Fig. 1 indicate the pathways from process activity levels to human health that are traditionally modeled in LCA. The dashed arrows in Fig. 1 indicate the new pathways being addressed in a simple way in this beta model. The intent was to address the health consequences associated with long-term changes in levels of economic activity throughout the supply chain. There is evidence that much of the correlation across countries between average health indicators and average income can be explained by differences in the incidence of income poverty and in public spending (Bidani and Ravallion 1996).

As summarized in the 2002 report of WHO Europe: "While GDP per head does have a significantly positive correlation with life expectancy, this relationship works mainly through the impact of GDP on (a) the incomes of the poor and (b) public expenditure". The report continued: "Growth-mediated processes work through faster economic growth with a strong employment component, the enhanced economic prosperity being used to expand relevant social services such as education, social security and health care… Unemployment as a cause of poverty and ill health is a major issue in all European countries" (WHO Europe 2002). Health status and socioeconomic status influence each other in a viscous/virtuous cycle, as increases in health promote economic development over time. Other research shows that countries with weakest conditions of health and education find it much more difficult to achieve sustained growth than do those with better conditions of health and education (CMH 2001).

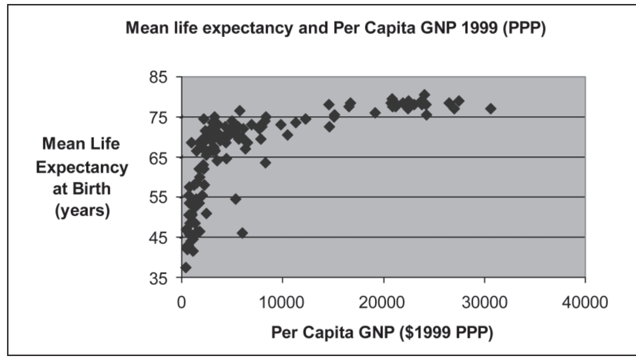

Fig. 2: Mean life expectancy at birth in relation to per capita gross national product (Data source: World Bank, 2002, World Development 2000–2001, Chapter 12, Tables 1 & 2)

As **Fig. 2** makes clear, the long-term benefits of an incremental increase in GDP vary significantly by country. In general, we see that among the countries below $5000 per capita GNP there is a very steep influence of economic growth on life expectancy, while above $5000 per capita the influence becomes much more slight.

A nonlinear relationship was estimated between mean life expectancy at birth and per capita GNP, based on 2002 data from the World Bank for 126 countries (World Bank 2002). The data sample contained life expectancy data for 132 countries, but 6 of them lacked data on GNP. Data were provided separately on female and male life expectancy at birth, so independent relationships were estimated for each of these.

Models of the following form were estimated:

$$LE = a - b * GNPPC^{-c} \quad (1)$$

where LE is life expectancy in years, GNPPC is per capita gross national product in 1999 dollars after adjusting for purchasing power parity, and ***a***, ***b***, and ***c*** are parameters estimated for the model. Model parameters, and model R^2 (percent of variance explained by model) are summarized in **Table 1**.

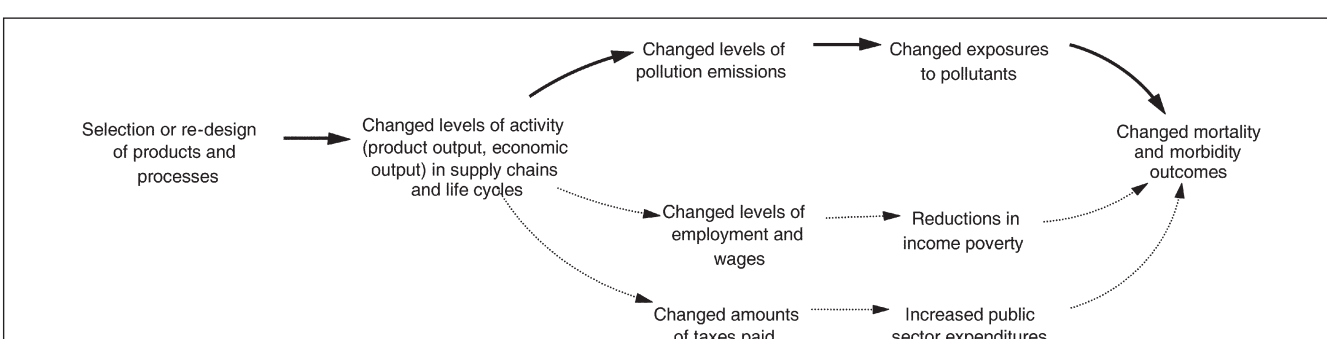

Fig. 1: Pathways from product decisions to human health outcomes

Table 1: Model parameters to estimate life expectancy from GNP per capita

	Male life expectancy	Female life expectancy
a	82	87
b	639	1176
c	0.44	0.52
R^2	0.78	0.81

The composite model for a country is then the weighted mean of the male and female models, with the weights equal to the gender population shares. Now, the change in person-years of life lived due to a change in economic output (Δ GNP) is given by the population multiplied by the difference in the life expectancies before and after the change.

$$\Delta YL = Pop * \left[LE(GNPPC_1) - LE(GNPPC_0)\right] \quad (2)$$

This expression can be successively simplified to arrive at an expression for the change in life expectancy in terms of the model parameters from Table 1, the initial GNP, the population, and the change in economic output.

$$\Delta YL = Pop * \left[(a - b * GNPPC_1^{-c}) - (a - b * GNPPC_0^{-c})\right] \quad (3)$$

$$\Delta YL = Pop * b * \left[\left(\frac{GNP_0}{Pop}\right)^{-c} - \left(\frac{GNP_1}{Pop}\right)^{-c}\right] \quad (4)$$

$$\Delta YL = Pop * b * \left[\left(\frac{GNP_0}{Pop}\right)^{-c} - \left(\frac{GNP_0 + \Delta GNP}{Pop}\right)^{-c}\right] \quad (5)$$

$$\Delta YL = b * Pop^{c+1}\left[GNP_0^{-c} - \left(GNP_0 + \Delta GNP\right)^{-c}\right] \quad (6)$$

Next, the data from the World Bank data set were used in Eq. (6) to calculate the estimated change in life years resulting from a $1M increase in GNP for each of the 126 different countries in the data set. The resulting constant coefficients, one for each of the countries, are expressed in units of life years saved per additional million dollars of output ($1999 adjusted for purchasing power parity). These constant coefficients represent simplified, country-specific life cycle impact assessment (LCIA) characterization factors for the socio-economic pathway from process output to health, where process output is measured in terms of economic value.

3 Results

A simple application of the method was performed. Specifically, the application estimated the health consequences of pollution in the total (global) supply chain of Dutch electricity, and compare these impacts with the health consequences of increased economic activity in the (global) supply chain of Dutch electricity. The goal was to compare the relative magnitudes of these two types of impact.

The life cycle inventory data and model came from a multiregional input/output LCI database provided by PRe Consultants, Amersfoort, NL. This database contained IO-LCA models for four interconnected regions. The Netherlands was addressed by a 153-sector model; three other regions were addressed by 33-sector models: Other European OECD countries, non-European OECD countries, and non-OECD countries.

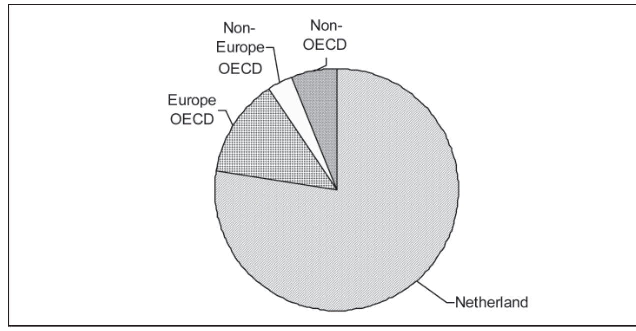

Fig. 3: Supply regional shares of economic output for Dutch electricity

In order to evaluate health impacts in terms of life years lost, the EcoIndicator 99 methodology (Goedkoop et al. 1999) was used. The health impacts, measured in disability-adjusted life-years (DALYs) were found to be dominated by the impacts of primary and secondary particulate emissions ('respiratory inorganic') and the potential health consequences of global warming.

Of course, it must be stressed that LCA provides information about impacts on at least three separate endpoints or areas of concern: human health, ecosystem health, and resources. The focus on the human health endpoint was strictly a reflection of the fact that we were adding a new impact pathway to this endpoint, and were *not* meant to imply that human health is the only important endpoint in LCA.

Fig. 3 shows the regional distribution of the economic activity in the supply chain of Dutch electricity. We can see that approximately three quarters of the total economic activity stimulated by the entire supply chain of the Dutch electricity occurs within the Netherlands; another roughly 15 percent occurs in other OECD countries, and less than 10% reaches non-OECD countries. Although the fraction of supply chain *economic* activity reaching developing countries is small in this example, we find that the fraction of supply chain *development impacts upon health* is expected to be very large indeed, as shown in **Fig. 4**.

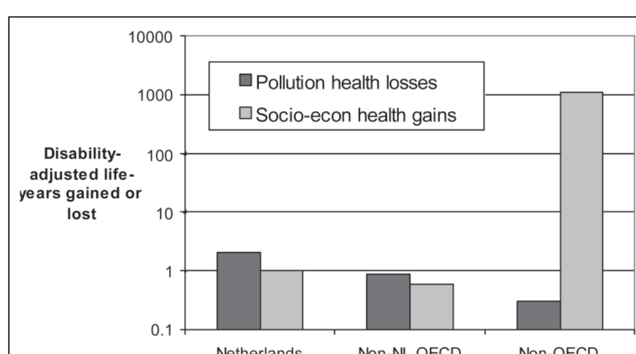

Fig. 4: Geographic distribution of pollution health losses and development-base health gains in the supply chain of $1M of Dutch electricity

In Fig. 4, the blue bars represent damages, while the red bars represent benefits; both are plotted as positive impacts numerically because we are using a logarithmic scale; this in turn is due to the fact that *the health benefits in the non-OECD region of the world dwarf the health benefit and cost impacts in the remaining regions*. Recall from Fig. 3 that three quarters of the economic activity in the total supply chain of Dutch electricity occurs in the Netherlands, while less than 10% of the supply chain economic activity finds its way to the non-OECD countries. However, recall as well from Fig. 2 that economic growth is much more powerful at achieving health benefits when it occurs in the lower-income countries. This is why the results as a whole are dominated by the health benefits of socio-economic development in the non-OECD countries.

3.1 Caveats and considerations

Although these results are powerfully indicative that product life cycles may offer strong potential for consumers to make choices that promote human health and well-being through development, a number of cautions must be raised in relation to the very simple method described above. For example, international time series studies of the influence of economic growth on poverty reduction and health improvement increasingly find that while economic growth appears to bring improvements in average health indicators, this response is highly variable among countries (World Bank 2002). Positive impacts on income poverty and public investment do not *necessarily* follow at all from increased economic output. Poverty alleviation requires that the wage and employment benefits reach people who are otherwise in poor socioeconomic status. Likewise, increased tax receipts by the government can improve health if the increased receipts cause an increase in health-promoting public investments.

In addressing environmental impact categories, we LCA practitioners feel justified in using indicators of average and/or sum total impact – e.g., total CO_2 released per unit of product, or expected acidic deposition to terrestrial ecosystems per unit of product. Even if there are large uncertainties in the expected intervention (e.g., pollutant quantity released) per unit of output from one actual unit process to the next, and even if there are also large uncertainties in the expected consequences or impacts per unit of intervention from one location to the next, research indicates that total impacts are well-estimated when using average factors for emissions and impacts, as long as there is not systematic bias in the estimate (e.g., Norris 2002, Spadaro and Rabl 1999).

The questions of relevance here, however, perhaps especially for social and socio-economic impacts, are:

a) Whether there is reason to expect systematic bias or error in our estimates; and
b) Whether it is in fact *average* impacts that matter.

There is ample evidence that the largest share of income gains associated with economic growth in a host of countries has gone to the already well-off in those countries. As a single example among many, in the USA nearly 2/3 of the earnings gains of males during a recent decade went to the top 1 percent, in a country where less than 20 percent of the population controls more than 85% of the wealth (Feenberg and Poterba 1992, cited in Minkler 2002).

In addition, there is the valid question of whether changes in aggregate measures such as total income or average life expectancy are proper indicators at all. While average CO_2 concentrations are a good measure of the atmosphere's increased tendency to trap infrared radiation, there are plenty of ethical reasons, some reflected in standard public policy, to focus on *distributional* descriptions of income gains, rather than averages. The simplest example is probably the existence and use of poverty statistics.

Now, measures of poverty are far from straightforward. First, there is the blunt nature of data on numbers of people above and below a rather arbitrary income threshold. Poverty statistics capture incidence but miss severity. Next there is the fact that income poverty is just one dimension of poverty; other dimensions include health, political, and cultural. Next there are the many problems with the selection of a national (or international) poverty threshold. In the US, for example, it is well-documented that the poverty threshold is dramatically out-of-date (woefully low) (Segal 2002, Segal et al. 2002), and that there is significant regional variation in the income required to meet a standard and measurable set of basic materials needs (Bernstein et al. 2000). Of course, this need-required income also varies among households depending on demographics (including the number of adults and of children present). Next there is the problem that local increases in economic output and employment also tend to introduce new income *needs*; simple but important examples are direct work-related expenses including transportation, clothing, and possibly food expenses. Clearly the wages used for these expenses must be deducted from any estimate of actual increases in disposable income. Other, socially-mediated impacts of employment on income needs arise when the economic development leads to transitions of land use rights, water use rights, and access to other resources from public/common goods to private property regimes (see, for example, Tammilehto 2003).

Take a very simple example of small-scale 'eco-tourism' being introduced in a rural village. The same increase in economic output can lead to *dramatically different* social and health and outcomes. Imagine one case where the local tourism businesses is locally co-managed by the villagers themselves; there is local re-investment of some of the profits in schools, clean water, sanitation, and medical care. There are opportunities for other local businesses to offer goods and services to visiting tourists. At the other extreme, envision a development that is 'eco' strictly in the sense that water and energy are used efficiently, and the development is constructed using 'green' materials. However, in this case, access to the land and water resources for development, part of which were previously used as common-pool resources by all villagers, is achieved for the developer by paying local elites. Profits all go to a company located elsewhere. Most employment opportunities pay extremely low wages for very long work-weeks in laborious tasks lacking skills development or growth potential. Local inequalities are aggravated, local poverty is increased for most people who now experience reduced resource access along with increased costs; there is probably increased crime and poor health as a result of this increased poverty – all in the context of what looks from afar like 'sustainable economic development'.

As will become clearer below, a major part of the solution for sorting out, and *transforming*, the good development from the bad includes systems for local control, local management, and local evaluation using metrics of local importance. Without such systems, the preceding discussion provides two major lessons: (a) social pathways to health in product life cycles appear to offer the potential to be significantly beneficial *on average*; and (b) the actual impacts can deviate drastically from average impacts that are estimated using idealized, macro-modeling based on aggregated data and cross-sectional correlations. The grave inaccuracies are likely to persist even with attempts to gather and report data on wage-based changes in national poverty rates, by process, by country. Poverty is a highly local, context-specific, culturally and socially-dependent attribute.

How can buyers or policy-makers somewhere on earth, whose decisions have strong impacts on these local situations elsewhere across earth, take into account their desire that these impacts be positive rather than negative? For buyers seeking such assurance for a single production site or on a single issue within supply chains, the proliferating set of *certification systems* address this need. For example, 'Fair Trade' programs certify that producers in developing countries of agricultural and handcrafted products are paid fair wages, work under safe and just conditions, and in some cases also follow procedures for environmental protection. The Fair Trade Labeling Organization (FLO), an international umbrella organization for Fair Trade labeling, indicates that manufactured products "are becoming an important future candidate for Fair Trade certification". Their website lists national fair trade labeling and certification programs for 20 different countries (FLO 2006). There are many other certification systems that address social and/or environmental practices in resource extraction sectors such as mining and forestry; the Forest Certification Resource Center lists and compares five separate certification systems addressing the North American market alone (Metafore 2006).

Is a productive and beneficial synergy possible between this burgeoning community of certification systems on the one hand, and life cycle methods or the life cycle perspective on the other? Before suggesting an answer to this question, let us consider what is the fundamental nature of the contribution of life cycle methods and the life cycle perspective.

4 Discussion: Reconsidering Life Cycle Assessment

It strikes this author that two scope-related insights inspire the life cycle approach, and that a third fundamental characteristic of the method results from the two founding insights.

The first insight inspiring the life cycle approach is that "Everything is connected". Processes in the 'technosphere' are connected by material and energy input requirements, so that changes to one process have consequences 'upstream' in supply chains. Product design changes that impact use phase requirements, durability, functional performance, and/or end-of-life fates all have consequences 'downstream' in supply chains and life cycles. There are also connections in the environment, so that pollutant releases trigger cause-effect chains through pathways in environmental media and food webs leading to endpoints in the environment and to human exposures. And as discussed in the first section of the paper, there are also connections in society, so that changes in economic activity can influence poverty as well as public spending, bringing impacts on public health. Product-related decisions can have very wide-ranging causal influences.

The second insight inspiring the life cycle approach is that "multiple impacts matter". Once we start to contemplate the connections in the economy, in society, and in the environment, this compels a sensitivity that extends beyond single-issue advocacy. Acid rain, persistent pollutants, eutrophication, habitat loss, climate change, inhalation of particulates ... how can we focus on only one in a way that ignores the impacts of our decisions on the other endpoints that we, or at least other people, also care deeply about?

Now, the essence of LCA is driven by these two scope-related insights. But they in turn lead to a third characteristic of LCA: a quantitative approach to modeling the process inter-connections and the impacts, that allows aggregation and comparison across life cycles. Why is this so? Consider for a moment the non-quantitative guidance not to buy product X because its life cycle is "linked to tropical deforestation" or because its life cycle is "linked to the release of POPs/PBTs." After we have had our thinking influenced by the first founding insight that "everything is connected" we realize that *every* product's life cycle is linked to the release of at least trace quantities of PBTs and POPs, somewhere far back in the supply chain. So the questions become *how much¸ of which POPs/PBTs, and how can actors throughout society most powerfully reduce these releases and their impacts throughout society and the environment?* And after we have been influenced by the insight that multiple pathways and multiple impacts matter, we can no longer ignore climate change, habitat destruction, and other impacts that were "not our focus" before.

At this point some readers might be tempted to argue in mounting frustration that a smoke screen of trade-offs is being erected needlessly – at least we can be unequivocal about the fact that "less is always better", right? Less pollution per unit of process output, certainly. But what about less inputs per unit of output, higher process efficiency, less consumption? When we include socio-economic impacts in supply chains (your livelihood, my livelihood, taxes paid to fund teacher salaries and malaria clinics...) even the axiom that "less is always better" on the input side becomes subject to a second look. This is because not all impacts of product life cycles are bad. And thus we return to the life cycle modeling approach, which attempts to characterize *how much of which impacts* are tied to a product life cycle, and how to achieve more of the desired outcomes with less of the bad outcomes in an overall sense.

5 Recommendations and Outlook

This final section begins by introducing a rather simple quantitative methodology that is termed Life Cycle Attribute Assessment. It then describes a web-based system that makes practical the reporting and aggregation of attribute data over supply chains life cycles. Finally, it takes up the question posed by Helias, namely "what is the benefit of bringing certification systems (or more generally, attribute reporting) and life cycle methods together?"

Life Cycle Attribute Assessment (LCAA) uses existing life cycle models to assist in the aggregation of data about process attributes across product systems. The method is illustrated with a simple example. Consider a university that wants to promote chlorine-free paper production. 'Chlorine-free' is an *attribute* of paper production processes. Other attributes of interest to the university might include child-labor-free, or Fair Trade certification on agricultural production processes in the life cycles of products purchased by the university, and/or sustainable forestry certification on forest harvesting processes in the life cycles of products purchased, and so-on.

With basic existing certification systems, the university may have the ability to purchase from paper product suppliers who certify that the production of the paper products is chlorine-free. A quick analysis using the US Input/Output database developed by Sangwon Suh, contained in the SimaPro software, shows that for the sector titled 'Colleges, universities, and technical schools,' direct purchases of products from paper and paperboard mills (including all purchases by the university via wholesalers and retailers) accounts for just 25% of the total output from this sector in the average university's supply chain. In other words, another 75% of the total paper production induced by the university's purchases is done to provide intermediate inputs from the paper and paperboard mills to other processes in the university's supply chain. For example, university purchases from the Book publishing sector stimulates another 9% of the total supply chain paper and board production; university purchases of commercial printing accounts for another 8%; Advertising 6%, Periodicals, Repair and maintenance construction 4%, Business forms 4%, and so-on. If the university could readily purchase products in these next six categories from suppliers whose paper in turn was certified as chlorine-free, it could go from addressing just 25% of the paper output in its supply chain, to over 60% of that output. LCAA is designed to make this doable.

An LCAA is a calculation of the amount of total output from all processes of the relevant type in a supply chain that comes from processes that:

a) Have the attribute of interest;
b) Lack the attribute of interest; or
c) Lack data reporting on what the process's attribute status is.

Output quantities may be measured in physical units (kg, kWh, etc.) and/or economic value.

Thus, the university could use this information to:

a) Compare all of its purchasing categories in terms of the total supply chain output from the relevant type of process: in the example, how much paper production (in kg, or $) is there embodied in each of the university's annual categories of purchasing;
b) Compare suppliers of a given commodity in terms of the amount of total embodied output which has (or lacks) the attribute of interest; in the example, which supplier of business forms, or any other purchased commodity, has a higher amount or share of its total supply chain paper output coming from processes certified as chlorine-free.

Before we turn to a summary of the potential benefits of making LCAA feasible, it is probably important to explain *how* it can be made feasible! Clearly, LCAA requires several new kinds of information not now provided in LC databases or models:

1) Data on attributes of processes
2) Data from specific companies about the characteristics of specific companies in their supply chain.

Data on attributes of a single process is simple enough to obtain, for example as a result of certification audits for that process or plant or production site. But how can site-specific data be practically aggregated across whole supply chains and life cycles? Not only is the data gathering challenge monstrous, but this is compounded by the reality that many companies will divulge the identities of neither their suppliers nor their customers, for competitive reasons.

The solution lies in making use of free publishing in the semantic web, which is simply the web marked-up with metadata, or machine-readable information about the information in the web pages. The central principle of the Semantic Web (Berners-Lee et al. 2001, Berners-Lee and Miller 2002) is simple: with metadata, the web is transformed, from being essentially a large hypertext document searchable strictly based on text strings (free of any context); with metadata, it becomes 'machine-searchable', queryable and analyzable by algorithms that take advantage of the structuring and labeling of information.

First, companies voluntarily use the system to publish data on the commodities that they produce for sale; this is attractive, especially to marginalized producers, for the simple reason of free advertising in a globally accessible database. Next, companies voluntarily report any attributes that they wish and that they believe may help them sell more of their product to some customer groups, such as the results of local certifications and audits. Third, the companies can optionally download software that they use together with their own confidential data on purchases and on the identities of their suppliers, to estimate the share of each purchased input that comes from a supplier with any attributes of interest. Fourth, the companies can optionally publish, in the semantic web, data about the *attributes* of their immediate suppliers of one or more commodities, without divulging the identities of these suppliers or the amounts/value purchased of any inputs. Finally, since my suppliers can use steps one through four to report on their first-tier suppliers, then I can use steps one through four to report on my first- and second-tier suppliers, and my customers can report on their tiers one through three … and all actors can eventually report on entire supply chains.

The intent of the system is to promote the increasing use and positive impact of attribute reporting by companies. Attributes will include the achievement of one or more certifications in an un-limited variety of certification systems on an un-limited variety of issues. The system is designed solely to make it easy and transparent for anyone to find out:

- The voluntarily self-reported attributes of companies
- The presence of verification from relevant 3rd parties concerning those attributes
- The share of a company's supply chain and a product's life cycle which possesses those attributes

With such transparent and flexible reporting of attributes, for individual companies and their supply chains, the following outcomes should arise:

- Increased ability of any buyer or stakeholder to know about the certification status and attributes of companies that they might buy from, work for, etc.
- Increased incentive for companies to achieve certifications that consumers, major buyers, and the government choose to value; this in turn should lead to increased participation in those certification programs;
- Existence of a 'marketplace' or 'ecosystem' of certification systems, allowing interested persons to consider more than one certification system, more than one attribute at a time;
- Ability of any third parties to develop and report independent 3rd-party summaries based on the (always transparently-available) 'raw data' on attributes. For example, investor scorecards can take attributes of companies and/or their supply chains into account, as they see fit.
- Ability of companies to use the semantic web for one-time reporting that satisfies a variety of different evaluation systems.
- Ability of purchasers to use the semantic web to report the attributes that they are using to evaluate products and suppliers, and to optionally indicate the volume of purchasing which is predicated on the presence or absence of different attributes. From this information, separate web-crawlers can develop up-to-date tabulations of the market importance of different attributes, and this information can be freely available for producers to read. In this way, purchasers are able to send signals to global supply chains concerning the attributes – and attribute aggregation schemes – of interest to them.

Finally, it is time to close the discussion with one last look at the question posed by Helias: "What is the benefit of bringing certification systems (or more generally, attribute reporting) and life cycle methods together?" In the author's view, the integration of LCA's quantitative modeling and multi-impact scope with data on attributes including the results of certification audits has the potential to provide the following benefits:

- Increased communication of attributes to the market, going beyond simply one-link reporting (from seller to buyer) to availability of the information along entire supply chains; this in turn brings increased market incentive to, and rewards from, attribute reporting;
- Ability of purchasers to communicate to global supply chains about the attributes of highest concern to them.
- Ability to view the results of a host of different attributes and certification systems side-by-side, and potentially trade them off or aggregate them. This helps attribute reporting move from single-issue scope to the multi-issue scope of life cycle methods; indeed, LCAA and LCA results can be considered side-by-side, or in combination.
- A bottom-up reporting system which was motivated by the desire to make attribute reporting practical, but which also brings immediate potential to make site- and company-specific publishing of life cycle inventory data also possible.
- A bottom-up reporting system about product availability, that was motivated by the desire to make environmental and social data available, but which also brings immediate potential for small and disadvantaged businesses, as long as they can connect to entities (such as producer co-ops, government agencies, NGOs, etc.) with internet access, to increase their access to markets and to achieve no-cost use of LCA and LCAA reporting – to get into the global Life Cycle game.

The last set of benefits, among all of them, may be the one most in harmony with the legacy of Helias Udo de Haes.

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