LCIA: State-of-Art

Life Cycle Impact Assessment Sophistication

International Workshop

Jane C. Bare[1], David W. Pennington[2], Helias A. Udo de Haes[3]

[1] U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, Ohio 45268, USA
[2] ORISE Research Fellow, U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, Ohio 45268, USA
[3] Centre of Environmental Science (CML), Leiden University, P.O. Box 9518, NL-2300 RA Leiden, the Netherlands

Corresponding author: Jane C. Bare; e-mail: bare.jane@epa.gov

Abstract

On November 29 - 30, 1998 in Brussels, an international workshop was held to discuss Life Cycle Impact Assessment (LCIA) Sophistication. Approximately 50 LCA experts attended the workshop from North America, Europe, and Asia. Prominent practitioners and researchers were invited to present a critical review of the associated factors, including the current limitations of available impact assessment methodologies and a comparison of the alternatives in the context of uncertainty. Each set of presentations, organised into three sessions, was followed by a discussion session to encourage international discourse with a view to improving the understanding of these crucial issues. The discussions were focused around small working groups of LCA practitioners and researchers, selected to include a balance of representatives from industry, government and academia.

This workshop provided the first opportunity for International experts to address the issues related to LCIA Sophistication in an open format. Among the topics addressed were: 1) the inclusion or exclusion of backgrounds and thresholds in LCIA, 2) the necessity and practicality regarding the sophistication of the uncertainty analysis, 3) the implications of allowing impact categories to be assessed at "midpoint" vs. at "endpoint" level, 4) the difficulty of assessing and capturing the comprehensiveness of the environmental health impact category, 5) the implications of cultural/philosophical views, 6) the meaning of terms like science-based and environmental relevance in the coming ISO LCIA standard, 7) the dichotomy of striving for consistency while allowing the incorporation of state-of-the-art research, 8) the role of various types of uncertainty analysis, and 9) the role of supporting environmental analyses (e.g., risk assessments). Many of these topics addressed the need for increased sophistication in LCIA, but recognised the conflict this might have in terms of the comprehensiveness and holistic character of LCA, and LCIA in particular. The participants concluded that the exchange of ideas in this format was extremely valuable and would like to plan successive International workshops on related themes.

Keywords: Decision making; LCA; LCIA; Life Cycle Assessment; Life Cycle Impact Assessment; sustainable development; uncertainty analysis; valuation; value choices; weighting

1 Introduction

The international workshop on LCIA Sophistication, held on November 29-30, 1998 was a complement to an earlier UNEP Workshop titled "Towards Global Use of LCA" held on June 12 - 13, 1998 in San Francisco. The purpose of the San Francisco workshop was to develop recommendations and an action plan that would lead towards a greater use of LCA in the context of sustainable development. At the end of the San Francisco workshop, each of the participants was asked what actions could lead to greater development and use of LCA in sustainable development decision making. One of the many ideas suggested was to provide a forum for an International discussion of the appropriate practice of LCIA. LCIA Sophistication was taken up as subject of the workshop held in Brussels, which was attended by approximately fifty LCA practitioners and experts from various countries.

Practitioners of LCA are faced with the task of trying to determine the appropriate level of sophistication in order to provide a sufficiently comprehensive and detailed approach to assist in environmental decision making. Sophistication has many dimensions and dependent upon the impact category, may simulate the fate and exposure, effect and temporal and spatial dimensions of the impact (Udo De Haes, 1999a; Owens et al., 1997; Udo de Haes, 1996; Fava et al., 1993). In the context of the Brussels workshop, sophistication was considered to be the ability of the model to accurately reflect the potential impact of the stressors, or in language more consistent with recent ISO publications, the ability to reflect the environmental mechanism with scientific validity (ISO, 1999).

The impact assessment phase of LCA, termed LCIA, helps decision-makers interpret inventory data in the context of a number of impact categories and to bring them into a more surveyable format. Ideally, an LCIA would be based on high quality data. All impact categories and processes in the environmental mechanism of each of these categories would be considered using state-of-the-art techniques, which would fully account for spatial and temporal variation. In such an Ideal World, decisions would be made based on these assessments with a high level of confidence and certainty. However, real world practitioners have to deal with limita-

tions (e.g., budget, and poor quality data) and simplifications are made. Some modifications may include: 1) reduction in spatial and temporal discrimination (or ignoring these dimensions altogether), 2) ignoring fate, 3) assuming linear dose-response curves and/or 4) eliminating an impact category because appropriate data or assessment methodologies do not exist.

While ideally an impact assessment should be sophisticated in all dimensions, this high level of sophistication requires exhaustive time, data, and resources and generally cannot be reached due to limitations in methodology and data available. Hence, the scope of the assessment needs to be defined, possibly iteratively, to provide the appropriate level of sophistication, including the required level of detail and accuracy, together with an uncertainty analysis practical for individual studies, and the specification of value choices within the framework of the LCA. Appropriate definition of this scope, including sophistication, uncertainty analysis, and comprehensiveness is the key to effective environmental decision making.

Many practitioners in the past have attempted to evaluate impacts to support broad LCA-based decisions, but have oversimplified the impact assessment step. Unfortunately, limitations in simulation sophistication lead to a reduced ability of the study to answer the questions at hand with a high degree of certainty. In the absence of accompanying uncertainty analysis, and validation (which addresses model uncertainty) many LCAs are conducted at such a low level of simulation sophistication that they are ineffectual in differentiating the very options they are trying to evaluate (COULON, 1997; POTTING, 1997, UDO DE HAES, 1996). Workshop participants also discussed the dichotomy of sophistication and comprehensiveness. As an example, very simplistic methods such as relying solely on toxicity data may allow a larger chemical database set than a more sophisticated approach which would require additional chemical and physical properties to determine the relative human health potentials.

More recently, researchers are recognising the many types of uncertainty involved in environmental decision making. Two types of uncertainty discussed at this workshop were model uncertainty and data uncertainty. Data uncertainty may be estimated by the propagation of uncertainty and variability of the input parameters. Model uncertainty can only be characterised by comparison of the model prediction with the actual response of the system being addressed. As data uncertainty is relatively easy to characterise, whereas model uncertainty is difficult, especially in a field like LCIA, the presentation of data uncertainty alone may not appropriately be used to compare two methodologies. For example, a simplistic approach utilising only persistency, bioaccumulation, and toxicity data may appear to be more certain when compared in terms of data uncertainty to a more complex multimedia/human exposure approach, but the unaddressed model uncertainty may significantly overshadow the data uncertainty.

The specification of value choices, has a bearing on the level of sophistication and has been the subject of many recent papers (OWENS, 1998; FINNVEDEN, 1997; VOLKWEIN, 1996a; VOLKWEIN, 1996b; POWELL, 1996, and GRAHL, 1996). Some practitioners are uncomfortable with the subjectivity of the Valuation Process, but fail to recognise the role of subjectivity in other phases of the LCA framework. All LCAs are conducted under the influence of subjective decisions. In fact, subjective decisions, value choices, or scientific or engineering judgements are made throughout the LCA process. Thus, the selection, aggregation, or disaggregation of impact categories and the determination of the methodologies to quantify the potential impacts are all influenced by value choices. The Brussels workshop was chosen to explicitly address the incorporation of value choices within the LCA process.

Unfortunately, the important issues of deciding the appropriate level of sophistication often remain unaddressed in LCIA. The determination of the level of sophistication is often not based on sound and explicit considerations, but on practical reasons (e.g. the level of funding, level of in-house knowledge). The workshop was therefore formulated to allow a more explicit discussion of the many factors outlined above that can influence the choice of the level of sophistication of a study, including:

- The project objective
- The perceived value placed on the specific impact categories
- The availability of inventory data and accompanying parameters
- The depth of knowledge and comprehension in each impact category
- The quality and availability of modelling data
- The uncertainty and sensitivity analyses
- The level of validations
- The available supporting software
- The level of funding

This paper provides a summary of the results of this workshop, including discussion on many of the above topics. An attempt is made to provide short reviews of the presentations and discussions. However, in documenting the workshop it was not possible to capture the full detail of the many points raised. For a more detailed coverage including overheads and summary papers, the reader is encouraged to e-mail the corresponding author.

2 Workshop Logistics

On the 29th and 30th of November, 1998 in Brussels, Belgium an international workshop was held to discuss Life Cycle Impact Assessment (LCIA) Sophistication. Approximately 50 LCA experts attended the workshop, coming from Europe, Asia and the USA. Several prominent practitioners and researchers were invited to present a critical review of the associated factors, including the current limitations of available impact methodologies and a comparison of the alternatives in the context of uncertainty. Each set of presentations, organised into three sessions, was followed by a discussion session to encourage international discourse with the aim to improve the understanding of these crucial issues. The discussions were focused around small working groups of LCA practitioners and researchers, deliberately selected to include a balance of representatives from industry, government and academia. Each group was given the charge to address the questions that most interested them, as opposed to assigning specific groups with specific questions.

3 Introductory Session

Jane Bare of the U.S. Environmental Protection Agency (EPA) opened the workshop noting that many of the participants had been involved in previous meetings as LCIA experts, sometimes even discussing related issues in the development of ISO 14000 series and SETAC Working Groups on LCA and LCIA. Requirements are being developed under ISO 14042 to specify a high level of sophistication for Comparative Assertions, including language concerning the scientific validity, environmental relevance, and the role of value choices. Within SETAC-Europe efforts are on going to develop a document related to the selection of the "state-of-the-art" impact assessment methodologies. Bare asked that participants consider the present workshop as a more open format than either of these settings to allow a completely uninhibited technical exchange. She stressed that Life Cycle Impact Assessment can be effective in supporting environmental decision making, but only if the data and methods are sufficiently scientifically defensible. Scientifically defensible was defined as being dependent upon the level of sophistication, the level of certainty (including both data and model certainty), the level of comprehensiveness, and data availability. The participants were challenged to address several additional questions throughout the two days of discussions including: What is "scientifically defensible"? In the sphere of determining whether impact assessment is based on sound science, where does one draw the line between sound science and modelling assumptions?

Garrette Clark from the United Nations Environment Programme (UNEP) then provided a short history of UNEP's involvement in the area of LCA, which includes providing technical assistance to developing countries and the development of an associated guidance document for LCA (UNEP, 1996). She stated that LCA is considered by UNEP to be an important tool for achieving cleaner production and consumption. She also summarised findings from the recent LCA workshop in San Francisco in June 1998 (UNEP, 1998).

David Pennington discussed two extremes of LCIA sophistication. One extreme he called the "Contribution or Burden" approach, which is comparable to what has been historically used in LCIA (reflecting the Precautionary Principle and the combinatory potential to cause impacts). The other extreme, the "Consecutive Risk Assessment" approach, he noted as being particularly recommendable for use in areas with high stakes, such as comparative assertions, but as often limited to the assessment of chemicals in isolation. He introduced the question concerning the need for spatial differentiation and asked when site-specific differentiation was appropriate. He also pointed out that the category indicators are chosen at different points in the environmental mechanism (or cause-effect chain), and stated that the U.S. EPA has been using the term of "midpoint" to address indicators that stop short of expected effects on the final "endpoint" of the environmental mechanism. He presented acidification as an example of a category with the indicator at "midpoint" level and human health as a possible example of a category with the indicator at "endpoint" level. He concluded by asking about the different levels of sophistication. What is possible? What is required? When to use the various levels of sophistication?

4 Session One: Overview

Willie Owens of Procter and Gamble spoke about comparative assertions (i.e., public comparisons between product systems) and the requirements for LCIA under ISO 14042. He stated that ISO 14042 requires a sufficiently comprehensive set of category indicators, a comparison conducted indicator by indicator (i.e. no weighting) and that LCIAs should not be the sole basis for comparative assertions. Current language in ISO 14042 states that subjective scores, such as weighting across categories, shall not be used for comparative assertions; that category indicators be scientifically defensible and environmentally relevant and that sensitivity and uncertainty analyses shall be conducted.

Mark Goedkoop of Pré Consultants discussed LCIA for ecodesign. He pointed out that the point of conducting an LCA is typically to determine whether A is better than B. He then presented three problems with LCA and ecodesign: 1) LCA studies are too time consuming, 2) LCA studies are hard to interpret, and 3) Designers never become experts, but remain dependent upon experts. His proposed solution for these problems was to calculate pre-defined single scores for the most commonly used materials and processes, and to incorporate uncertainty into the modelling. He also discussed the sometimes hidden role of societal values in characterisation modelling, even for internationally agreed models. As an example, he presented the three classes of carcinogens (proven, probable and possible) and pointed out that the practitioner must make a decision about whether to include one, two, or all three classes. He proposed that a single truth does not exist and that modelling is dependent upon the chosen perspective. He then introduced three different views of the world based on values: egalitarian, hierarchical and individualist. (A topic discussed later in more detail by Patrick Hofstetter.) He pointed out that if A is not better than B in all three cases then the result is dependent upon the perspective.

Henrik Wenzel of the Technical University of Denmark discussed the application dependency of LCIA. He mentioned several applications including life cycle management, strategic planning, product development, process design, green procurement and public purchasing, and marketing. In addition, he discussed three main variables governing application dependency: the environmental consequence of the decision (including spatial and temporal scale), the socio-economic consequence and the decision context. He discussed the application dependency of uncertainty, transparency, documentation and the inclusion of temporal and spatial resolution. He stated that the need for sophistication of LCIA is largest in decisions with the highest requirements for certainty. He also stated that the decision-maker may impact the choice of normalisation and weighting (WENZEL, 1998).

Helias Udo de Haes wrapped up this first session by providing a summary of some of the key points covered and challenging the participants to address the questions provided

during the small group discussions. Workshop participants were asked to address the following questions and to provide additional questions to aid discussion.

Determination of Sophistication and Uncertainty Analysis

1. What are the most common methods by which the level of sophistication is determined?
2. Which methods are considered more acceptable? Why?
3. What are the barriers to using the acceptable methods? What can be done to overcome these barriers?
4. To which extent should LCIA be application dependent?
5. What are the expectations regarding the level of sophistication for the various LCA applications (e.g., by government, by industry, for public communication, and for internal use)?
6. When should LCIAs be as detailed as possible, aiming at the maximum level of accuracy? And when is it better to limit the scope of LCA to addressing questions on a macroscopic scale, leaving spatial and threshold considerations to other analytical tools?
7. How do practitioners deal with the trade-offs necessary when sophistication and comprehensiveness are "at odds" (e.g., choosing a detailed modelling approach that may limit the comprehensiveness vs. a scoring approach that may limit the sophistication)?
8. What case studies are available using uncertainty analyses within LCIA? And what are the major findings to date (levels of uncertainty discovered)? When is the uncertainty determined to be unacceptable?

Questions Added at Workshop

9. What is scientifically and technically valid, as included in the requirements of ISO 14042?
10. If LCIA is an iterative process, what drives the decision on the level of sophistication (e.g., uncertainty analysis, relevance, and existence of trade-offs)?
11. Define uncertainty in the context of LCIA. What parameters must be analysed?
12. How do we incorporate background levels into LCIA? Should we define working points (as in Mark Goedkoop's presentation)? Should this be done for individual chemicals or combined?
13. What is the best currently available method to represent the combined effect of chemicals without double counting, or inappropriately allocating?
14. How do we incorporate (or should we incorporate) the differing philosophical views in characterisation?

First Session Discussion Summary

An aggregation of the resultant views is presented below:

Determination of Sophistication – Many different groups commented on the appropriate level of impact assessment sophistication. One group commented that some sound decisions may be/have been made on the basis of LCA studies, which did not have very sophisticated LCIAs, but these tended to be more obvious cases. They recommended using the most sophisticated impact assessment models that provide information closest to the endpoint. Another group commented that sophistication is dependent upon a number of things including: inventory data availability, the availability of characterisation models and data to support these models, objective, the application dependency, the decision maker's sphere of influence and the impact category. A third group stated that the choice of sophistication depends upon an iterative process, where the iterations may be dependent upon uncertainty, the environmental relevance of the results and the minimum level of certainty required to support a decision. Several participants commented that sophistication is often limited by budget, inventory data availability, ease of use of impact assessment methods and in-house knowledge. These participants stressed the practical side of LCA and recognised the difficulty in data collection and the structuring of public data bases to support more sophisticated analyses.

Application Dependency – There was a general belief that LCIA sophistication is application dependent, according to the type of application and not the individual user. For example, screening level LCA studies may not require the rigorous use of sophisticated impact assessment techniques but final comparative assertions may require much more rigor, particularly if the benefits are not apparent. LCIA studies should be performed based on the type of question or decision at hand and the purposes that the LCIA may be serving.

Validating the Results of LCIAs – There was agreement that one cannot validate the results of a single LCIA study, because of the lack of temporal and spatial specification associated with the inventory data, and an inability to accurately model complex interactions in the environment, including the combinatory effects of chemical mixtures. However, input data can be quality checked, and elements in the models can be compared with models developed in the context of other applications such as environmental risk assessment. It was also noted that validation may not be as important in the context of LCIA since models simply reflect a relative comparison as opposed to an absolute assessment.

Backgrounds and Thresholds – Practitioners have tried to incorporate background levels in LCA studies in the past but there was a lot of discussion that this practice may or may not be appropriate. One of the questions at hand is whether impacts do occur in above or below "threshold" situations. Another issue concerned the fear that defining backgrounds and thresholds will lead to treating many environments as infinite sinks (e.g., for acidic chemicals) when in reality nature's ability to absorb the impact may be exceeded at some future time. The distinction was also made that thresholds may be less strict, because of the presence of very sensitive species or human individuals. Thresholds may also not be protective enough in many environments in which the combined effects of chemicals may cause effects at a level much lower than the threshold effect. Finally, practitioners were cautioned not to use LCIA to the exclusion of recognising the problem of hot spots surrounding facilities. (See the following point for more information on mixtures). On the other hand, some participants believed that thresholds may be valuable indicators of relative potency for many chemicals and that thresholds had been derived with statistically sound methods. Further clarification of the decision making context may be necessary to determine the value of thresholds and backgrounds in particular applications of LCIA.

Mixtures – One of the basic limitations of the current state-of-the-science of LCIA of human and ecotoxicity is the inability to effectively deal with potential combinatory effects of chemical mixtures. Toxicologists operate under the assumption that chemicals acting on the same organ can be considered to have an additive effect, but often LCIA impact categories are much broader than a focus on target organs. Therefore, the same assumptions used in risk assessment are not applicable to LCIA. This is especially an issue when practitioners try to incorporate threshold levels for individual chemicals into LCIA. Because mixtures are not well characterised in LCIA, effects may be occurring at much lower levels than the accepted threshold levels of the individual chemicals. Practitioners often try to compensate for these and other model deficiencies by adopting the Precautionary Principle.

Data Gaps – There was a concern that data gaps can be significant. Particularly in human and ecotoxicity, availability and quality of both inventory and chemical data to support the modelling of a large number of chemicals can be frustrating. These impact categories are a good example of where less sophisticated screening techniques may, with an appropriate degree of caution prove useful.

Uncertainty Analysis – LCIA still faces great challenges before fully addressing uncertainty analysis. Some of these challenges include the lack of awareness, lack of associated methodology, and the perceived difficulty of presenting the results to decision-makers. Specifically, practitioners need better knowledge of uncertainties in existing methods within the different impact categories and of the potential for improvement, if any, by using methods with greater sophistication. Many participants acknowledged a need for a better understanding of the uncertainty involved in each of the impact assessment methodologies for each of the impact categories, noting that uncertainty is associated with the models as well as the input data. The potential trade-off in available models between increased sophistication (i.e., detail) and reduced comprehensiveness (e.g., number of stressors simulated) was again noted.

Unnecessary Rigor? – There was a belief that the ISO standard on LCIA, specifically for the comparative assertions to be disclosed to the public, is too demanding in the areas of scientific validity and certainty. Examples were given of some other modelling arenas that face the same challenges (e.g., economic modelling, risk assessment studies). In these fields large uncertainties are accepted, expected and (sometimes) clearly documented. There was also a concern that the rigor expected of the impact categories without a working international acceptance (e.g., human toxicity) exceeds the rigor and certainty requirements compared with the impact categories that benefit from having international consensus (e.g., global warming potentials).

Model uncertainty vs. data uncertainty – Some participants commented that the current disparity in levels of uncertainty analysis may have lead to the false impression that the more sophisticated models have increased uncertainty when compared to less sophisticated techniques. Typically this is not the case. Usually, with a more sophisticated model the model uncertainty has decreased and the ability to model data certainty quantitatively has increased. Deceptively (since model uncertainty is not typically characterised) the increased characterisation of data certainty may have seemed to increase total uncertainty. (Additional details on uncertainty analysis may be found in Edgar Hertwich's presentations.)

Standardisation – While it was recognised that the level of sophistication may depend upon the type of application and the availability of data, there was a belief that consistency of approach or methodology may be an important priority to allow comparability between studies. Some participants pointed out that certain studies may only require Life Cycle Thinking and therefore, should not be subject to the standardised methodologies. Others addressed the idea of approach hierarchies that differentiate between screening and more intensive techniques but noted that the approaches could be consistent within these tiers. It was similarly noted that there could be a trade-off between sophistication and comprehensiveness, while one approach provides a more complete picture but with low level of detail, another may provide a higher level of detail but at the expense of comprehensiveness. It was further noted that there is continual development of methods and standardisation should not discourage further research efforts.

More Focused Research – More energy needs to be expended to ensure that LCA research is focused on areas that will have the greatest impact. Research needs to be conducted in deriving better methodologies for more relevant indicators. Specifically, land use, habitat alteration, and environmental toxicity were mentioned as examples of impact categories requiring much more research.

5 Session Two: Human Health and Ecotoxicity

Edgar Hertwich of the University of California, Berkeley opened the session on Human and Ecotoxicity with his presentation: "A Framework for the Uncertainty Analysis of the Human Toxicity Potential". He presented the purpose of uncertainty analysis: "to develop confidence in an analytical result, as an input to formal decision analysis techniques and as a tool to refine impact assessment methods." He noted that uncertainty analysis includes: parameter uncertainty, model uncertainty, decision rule uncertainty and variability. He then presented various examples of each of these as they might pertain to modelling for human toxicity impact assessment in LCIA. Finally, he pointed out that simply conducting a sensitivity analysis can often provide valuable insights about the significance of the multiple uncertainties involved in the decision and can help refine impact assessment techniques (HERTWICH et al., 1993; HERTWICH, 1999).

Patrick Hofstetter of the Swiss Federal Institute of Technology in Zurich addressed the question of "What is science?" in the presentation: "The Different Levels of Uncertainty Assessment in LCIA: The Case of Carcinogenic Effects." He stated that the development of models is dependent on the perspective of the modeller. Three perspectives were described: hierarchist, individualist and egalitarian. An individualist optimises the spending of resources based upon the known or certain types of harm that can be modelled (e.g., only choosing to include IARC Group 1 Carcinogenics in an analysis). A hierarchist could be closest to the operating positions typically held by government and international organisations and would include Group 1 and Group 2. Egalitarians tend to take a more risk aversive and preventive standpoint and thus would include Groups 1, 2, and 3 in a carcinogenic analysis. Similarly, these different perspectives would derive different discount rates for use within an assessment in terms of the Disability Adjusted Life Years (DALY). An illustration showed the combination of the assumptions of all three cultural perspectives in an eco-index probability graph. Finally, he concluded that LCIA could be made simple to use and yet robust by incorporating the values associated with various perspectives and allowing an analysis of the related technical, methodological and epistemological uncertainties (HOFSTETTER, 1998).

Olivier Jolliet of the Swiss Federal Institute of Technology in Lausanne discussed "Human Toxicity and Ecotoxicity Modelling vs. Scoring." He opened by saying "Tell me your results and I will tell you who paid you!" Then he called for the identification of best available practice regarding impact assessment methods to reduce the ability to provide LCAs that support such malpractice. He also proposed that this process should try to meet the ISO 14042 requirements to be "scientifically and technically valid" and "environmentally relevant." After comparing different human toxicity modelling efforts, he pointed out parameters and model characteristics that are important in human and ecotoxicity modelling, including exposure and fate uncertainties, that can be responsible for significant uncertainty and which open options for reduction of modelling uncertainty by proper empirical or experimental validation. He concluded by say-

ing that modelling comparisons should be made based on model characteristics and consistent data.

Mark Huijbregts of the University of Amersterdam presented a paper on "Priority Assessment of Toxic Substances in LCA: A Probabilistic Approach." Citing previous publications (e.g., GUINÉE et al., 1996 and HERTWICH et al., 1998), he suggested that the following specific improvements are needed: a review of default values with the possibility of using more realistic values, an inclusion of all relevant environmental compartments and inclusion of a Monte Carlo type of uncertainty analysis . He presented a probabilistic simulation of weighted human, aquatic and terrestrial RCRs for 1,4-dichlorobenzene and 2,3,7,8-TCDD and demonstrated that only a few substance-specific parameters are responsible for the uncertainty in results. Finally, Huijbregts concluded that variability is not of significance if it is identical for all options being compared and asked that researchers continue to explore the issue of when data uncertainty/variability cancel in relative comparison applications.

Second Session Discussion Summary

Workshop participants were asked to address the following questions and to provide additional questions to aid discussion.

1. In human toxicity and ecotoxicity, when is spatial and/or temporal differentiation necessary? If necessary, what spatial and/or temporal details are recommended (e.g. indoor/outdoor, height of emission point)?
2. With respect to ecotoxicity what is the best approach to addressing multiple species? If suggested, what are recommended representative species?
3. With respect to human toxicity and ecotoxicity, what are the greatest barriers to conducting uncertainty analysis?
4. What are recommendations for research and development in these impact categories?

An aggregation of the groups' views is presented below:

Standardisation – Again the question of standardisation was discussed. Specifically, if the practitioner or study commissioner can have such a strong influence on the final results of the study, then perhaps some standardisation would be useful to provide comparability between studies. However, what perspective or aggregation of perspectives should be represented in a standardised approach? Should central tendency assumptions or worst-case assumptions be used? Some participants stated that additional time was needed to ferment an opinion in this area. Others contended that "allowing" for too many methods and approaches could undermine the credibility of LCIA. However, many believed that now is the time to capture the state-of-the art in a document, while still allowing room for advances in the future. Several participants expressed interest in being involved in the current SETAC-Europe Working Group on Life Cycle Impact Assessment (UDO DE HAES et al., 1999a and UDO DE HAES et al., 1999b).

Midpoint vs. Endpoint Level – In further discussion of the concepts of midpoints vs. endpoints, many participants discussed the advantages of making all impact assessment models as close as possible to the final endpoints of the environmental mechanism of the impact categories (e.g., quantifying fish kills and trees lost as opposed to the acidification potential of the substances). One benefit of this approach would be to allow more common endpoints for the valuation process, perhaps even opening the door to allowing more economic valuation of endpoints. Others pointed out that this may be unnecessary in a relative comparison context. They stated that extending the models to the endpoints will narrow down the comprehensiveness of the impacts considered, and will include many more assumptions and value judgements into the assessment. This may subsequently increase the uncertainty of the results and reduce credibility by further mixing "science and value judgements."

Ecotoxicity – There was a strong call for research in this area. There was a recognised need to extrapolate ecotoxicity in a manner similar to human toxicity with representative species but also a realisation that representative species may vary within different areas. However, there was also some discussion that LCA is a very macroscopic tool and, can not be expected to accurately model local issues. Perhaps, ecotoxicity is so specific to the locality affected that an attempt should not even be made to include it as an impact category. The most widely held view on this topic seemed to be that ecotoxicity should continue to be included, for the sake of providing a more holistic picture, and that the potential for more site-specific approaches should be considered further.

Potentially Affected Fraction of Species (PAFs) – Mark Goedkoop gave an impromptu presentation on PAFs. He stated that PAFs are different from PNECs in that they take the background level of the substances into account and thus enable non-linear modelling of impact on the species composition. Many in principle liked the idea of PAFs and combined PAFs that represent the combined effect of chemicals. However, there were concerns related to the possibility of identifying PAFs, due to the limited availability of dose response curves and of background concentration data for so many chemicals. A discussion of Eco-Indicator 98's relationship to PAFs was held (GOEDKOOP, 1998).

Borrowing from Risk Assessment – Concern was voiced that LCIA for human toxicity is often based on typical risk assessment practice (e.g., the use of toxicological benchmarks). Caution was particularly high in the context of deterministic safety factors used in the toxicity component of the characterisation factors, many of which compensate for low test species numbers. As this reduces the equity and comparability of chemicals, participants suggested that LCIA must be careful when adopting deterministic risk assessment perspectives.

Research into Increasing Sophistication and the Role of Other Assessment Techniques – One group asked for increasing temporal modelling, real ground concentration measurement, incorporation of population density into simulations and better representation of food webs. In this group, there was a concern that the current direction of research in multimedia modelling would not address these areas. However this must be viewed in the context of the aims which are to be met by LCA as opposed to the types of analytical tools. Thus, another group stressed that perhaps practitioners are too concerned with detail. Perhaps the focus should remain on macro differentiation of substances in terms of their persistent bioaccumulative and toxic (PBT) properties. This could be subsequently complimented (if required) by local scale analysis using other tools, and would help to include a larger set of chemicals at a sufficient level of differentiation.

6 Session Three: Acidification, Eutrophication and Inventory

Greg Norris of Sylvatica, North Berwick, Maine, USA, presented a "Value-of-Information Approach." He pointed out that uncertainty analysis allows some additional information (e.g., confidence intervals associated with data uncertainty) within the decision-making framework. Norris stated that the level of sophistication should be partially dependent upon the inventory data and its uncertainty, upon the appropriate models and upon decisions about weighting. He

suggested using Input/Output-based upstream LCI databases to answer many of the common questions that practitioners face, such as "How many sites, with how much geographic dispersion, contribute significantly to inventory totals?" And "What are the expected shapes of these distributions?" He also cautioned participants against trying to draw conclusions about the preferability of more detailed LCIA, based on a Probability Density Function (PDF) or Cumulative Density Function (CDF) diagram, pointing out that further simulations may be required. Finally, he discussed the difference between analysing uncertainty in weighting and in characterisation modelling and the need to treat these issues jointly in the determination of the level of sophistication and decision support.

José Potting of the Technical University of Denmark presented "Levels of Sophistication in Life Cycle Impact Assessment of Acidification." Potting presented a case study comparing alternative locations for copper production and demonstrated the potential need for site-specific simulations, including: emission dispersion and deposition patterns, background depositions on receiving ecosystems and the sensitivity of receiving ecosystems. She used the Regional Air pollution INformation System (RAINS) model (from IIASA) with calculations based on Critical Loads provided by the National Institute of Public Health and the Environment (RIVM) in the Netherlands and transfer-matrices from EMEP MSC-W at the Norwegian Meteorological Institute. She announced that easy-to-use acidification factors had been established for 44 European regions and suggested that utilising this site dependent approach for acidification resulted in a significant reduction in uncertainty.

Göran Finnveden of Stockholm University presented two topics: "Eutrophication – Aquatic and Terrestrial – State of the Art", and "Thresholds/No Effect Levels/Critical Loads". Finnveden discussed the site dependency of eutrophication in three models, developed since 1993. He presented additional topics for discussion and research related to eutrophication. In his second presentation, Finnveden proposed that thresholds may, at the macrolevel, have no scientific basis and in fact may just be "acceptable" levels of risk and thus constitute value choices. Acidification and human toxicity were used as examples of impact categories that should not ignore "below threshold values." In line with this, he proposed that threshold values should not exist in LCIA for any impact category.

7 Conclusions

In meetings and journals world wide, practitioners have debated the utility of conducting Life Cycle Assessment studies. The debate has often hinged on the appropriate level of sophistication. While some have advocated abandoning LCA altogether, since it is not achievable in its most sophisticated form, others have supported the concept of conducting LCA stuides at a more holistic level, while making the limitations and uncertainties transparent. This workshop discussed many of the issues of dealing with the appropriate level of sophistication in the Life Cycle Impact Assessment phase of an LCA study.

A number of prominent practitioners and researchers presented a critical review of the associated factors, including the current limitations of available impact methodologies and a comparison of alternatives in the context of model and data uncertainty. On the one hand the workshop addressed the various factors which are connected with an increase of sophistication in LCIA. Examples include the need for better fate and effect models and the role of spatial and temporal differentiation therein, the identification of background levels and thresholds, but also the need to specify value-laden aspects such as connected with different cultural perspectives. On the other hand, the holistic and comparative character of LCA was stressed. In this context, many questioned whether LCA should aim to conduct sophisticated site specific risk assessments, particularly when this high level of detail may give a false impression of great confidence, especially when it is not presented with a stringent uncertainty analysis. Moreover, it was recognised that thresholds reflect value choices about what is regarded acceptable, rather than science based parameters. And finally, increasing level of detail can increase model certainty, but, in some cases, may reduce the comprehensiveness.

Workshop speakers and participants discussed the way that philosophical views may affect not only the valuation process, but also the impact assessment phase by including assumptions that include values based on the differing perspectives. This further complicates the question of what is "science-based" and what are "reasonable" modelling assumptions. Arguments were raised both for and against striving for consistency at this time in the effort to standardise some of the methods and assumptions to allow comparability between studies.

There was much discussion about the decision-making framework and the role of other environmental analyses, such as risk assessment. From the sophisticated uncertainty analyses presented it was obvious that great advances are being made, but there are many very basic principles that still lack consensus (e.g., the use of threshold values and background concentrations). As in risk assessment, there is great attention to being true to the science, but in the interest of practicality, a great need for simplifying assumptions.

There was consensus that the workshop was very valuable and that this exchange should be continued through e-mail discussions and periodic workshops (next target workshop in Brighton, U.K. in May 2000). Several topics were mentioned for future workshops, including: LCIA at strategic levels of decision making (including sustainable development decision support), community planning using LCIA-type indicators, the role of value choices in characterisation modelling, and the state-of-the-science for characterising ecotoxicity in LCIA.

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Editor in Chief:
Prof. Walter Klöpffer, PhD
C.A.U. GmbH
WG Assessment of Chemicals, Products and Systems
D-63303 Dreieich, Germany
Phone: +49-6103-983-28; Fax: -983-10
e-mail: C.A.U.@t-online.de

Publishing House:
ecomed publishers AG & Co. KG
Managing director: Harald Heim
Rudolf-Diesel-Straße 3
D-86899 Landsberg, Germany

Managing Editor:
Almut Beate Heinrich
Phone: +49-8191-125-469
Fax: +49-8191-125-492
e-mail: a.heinrich@ecomed.de
http://www.scientificjournals.com

Assistant Editor:
Susanne Rapp
Phone: +49-8191-125-500
Fax: +49-8191-125-492
e-mail: s.rapp@ecomed.de

Editorial Consultant:
Edward Beese, M.D., B.S.
Taschnerstr. 14, D-80638 München, Germany
Phone: +49-89-1784226
Fax: +49-89-171928
e-mail: ebeese@primus-online.de

Marketing and Advertising:
Barbara Ohnesorg
Phone: +49-8191-125-544
Fax: +49-8191-125-492
e-mail: b.ohnesorg@ecomed.de

Subscription Service:
Nicole Kandra
Phone: +49-8191-125-318
Fax: +49-8191-125-305
e-mail: n.kandra@mi-verlag.de

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