

State-of-the-Art: Advances in LCA and LCM

An Update on the Liaison of the Two LCA-Planets¹: 11th SETAC Europe Annual Meeting, 6-10 May 2001 in Madrid, Spain

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The SETAC Europe Annual Meeting was hosted in the friendly Madrid Congress Hall, right by Madrid's most famous and passionate venue, the Santiago Bernabeu soccer stadium of Real Madrid. More than 1350 participants came to the conference, with up to 150 people attending the LCA presentations. The meeting offered stimulating LCA sessions and controversial discussions as well as a taste of Spanish culture and cuisine. A good overview of recent and ongoing activities in LCA and related fields in Europe, and to a lesser extent, in America and Japan was given. For the first time we had LCA key-note speakers:

ROLAND CLIFT, who gave an interesting talk on how to approach the modeling of industrial ecology, and ARI HUHTALA, who introduced the UNEP/SETAC Life Cycle Initiative, which was one of the main LCA topics during the conference. In addition, we enjoyed 118 LCA contributions (56 platform presentations and 62 posters), which we think made this SETAC meeting the biggest LCA event ever. Most of the SETAC LCA working groups met and a LCA short course was offered on Sunday to more than 20 students. To complete the statistics with local data, the growing Spanish LCA community had the annual meeting of the Spanish LCA Society and contributed with 3 platform presentations and 15 posters from 10 different organizations. As a change from past annual meetings there was more emphasis on applications. This resulted in a good combination of research in the purely scientific field (mainly LCIA) and in the area of applied research and development (LCM, etc.). Also, as the number of participants was very high, this event facilitated many bilateral meetings. In fact, some EU LCA research project consortia used the event to meet. In the following report an attempt is made to give an overview of the six sessions dealing with LCA and related issues:

- Goal & scope definition: data quality & uncertainty in LCA (9 platforms and 10 posters)
- Life cycle inventory after 14041: new developments in modeling (9 platforms and 4 posters)
- Advances in life cycle impact assessment: water & other issues (12 platforms and 12 posters)
- LCA & comparative risk assessment (6 platforms and 4 posters)

- Life cycle management (9 platforms and 10 posters)
- LCA & related tools: sustainable and green chemistry, LCC, MFA, SFA, DfE & industrial ecology (9 platforms and 22 posters)

Finally, some observations form the concluding event, the workshop of the UNEP/SETAC Life Cycle Initiative, are given.

Session 1: Goal & scope definition: Data quality & uncertainty in LCA (chaired by Rolf Bretz and Mark Huijbregts)

ANGELINE DE BEAUFORT presented the results of the SETAC working group on data availability and data quality, which focused, mainly, on the issues of data exchange, data quality, and presentation of LCI data. It seems to be that the developed non-conclusive list of recommended inputs and outputs, which could be the basis for a standard, will be very helpful in developing more compatible LCI data sets.

GREGORY NORRIS looked at the question if many negligible LCI process inputs can add up to make a significant impact on the overall result of an LCA. He used an Input-Output LCA approach (I/O-LCA) where he defined breadth as the number of types of inputs included per process and depth as the number of supply tiers included. Norris concluded that limiting the cumulative coverage of impacts to 95 or 90% in his case reduces the total number of inputs from nearly 400 to 30 or 16, respectively. Gregory Norris went on to outline the first ideas of the LCI subgroup of the SETAC/UNEP LC-Initiative. The group wants to focus on compiling and harmonizing existing databases, in strong cooperation with database suppliers. However, the goal is not to compile one giant worldwide database, but to design a filter that can be tailored to the specific needs of the user and that draws upon the different available databases.

The session continued with CLARA MILLEFIORI, who presented the newly established Italian LCA database. This database is based on existing European databases and secondary literature. The available data were chosen and adjusted for the Italian situation (e.g. energy-, transport-, and waste models) and translated into Italian. The main intended uses are environmental product declaration (EPD) and design for environment (DfE). It is available, free of charge, at www.sinanet.anpa.it/ecolprod.

¹ The planet of the method developers and the planet of the LCA practitioners as formulated by Sarah Cowell at the SETAC Case Study Symposium 2000 in Brussels (see Klöpffer and Heinrich 2001)

Efforts to compile a national LCI database were also presented by ROLF FRISCHKNECHT, who gave a report on the status of the Swiss national database project ECOINVENT 2000. It aims at the establishment of a uniform database based on the existing ones in the domain of the Swiss Federal Institute of Technology and associated institutions. It will be web based and include data on a unit-process level. There will also be calculation procedures including allocation factors available to get LCI results for 'building blocks'.

To deal with uncertainty, BO WEIDEMA introduced an uncertainty-based data collection strategy, which makes a distinction between reducible and irreducible uncertainty. The former includes lack of data, data mismatch, and uncertainty from data collection. The latter includes forecasted data, geographical and temporal position of a process (if using averages), and unknown or uncontrollable variations in process data (e.g., due to different climate situations at the process site). Weidema has developed a hierarchy of uncertainty with which one can check which kind of uncertainty is most significant and consequently where the analysis should focus. After these presentations on methodology, the session continued with specific applications.

SHPRESA KOTAJI presented the results of the SETAC working group on LCA in building and construction. She stressed that the use phase is very significant for most kind of buildings (with the exception of purely structural buildings such as bridges, streets, etc.). Activities associated with the service life and with maintenance are often dominating the results of an LCA study in this sector.

MARION TOBLER presented a case study that compares textiles from cotton and from nylon by modeling textile apparel lifecycles in relation to function. A key issue was the functional unit, which was purely based on fashion trends rather than technical function and therefore also considered the life span according to fashion trends.

A life cycle inventory analysis for the assessment of agrochemicals was the topic of GEORG GEISLER, who studied the impacts of the production stage for plant growth regulators. He found that the more complex modern plant regulator needs a much higher number of process steps, resulting in a significant higher impact in production and possibly outweighing the environmental advantages in the use phase.

Session 2: Life cycle inventory after 14041: new developments in modeling (chaired by Bo Weidema and Tomas Ekvall)

The session started with TOMAS EKVAL presenting the findings from SETAC's working group on scenario development in LCA. He outlined the existing scenario concepts and concluded that scenarios should be employed in the development of product system models much more explicitly than commonly practiced today, since the main applications of LCA are about decisions affecting the future.

Economic relationships and life cycle inventory process networks were the topics of ROLF FRISCHKNECHT's talk in this session. He proposed to use economic rather than material and energy flows to identify relevant suppliers in the system model. Physical flows are then utilized to determine the relevant quantities of each supplier. Also, he created the idea of using deci-

sion units (e.g., profit centers) in a company as unit-processes to unify the economic and environmental modeling.

MARC-ANDREE WOLF's presentation dealt with material flow interaction with the environment in renewable resource systems. He stressed the fact that looking at CO₂-neutrality is not sufficient when studying renewable resources. Zinc, for instance, is taken up from the soil and stored in wood. The zinc emissions into air from the incineration of the wood at the end-of-life have to be considered.

PETRA ZAPP continued with a scenario approach to model technical progress in production and recycling of aluminum packaging. Based on the present state, scenarios with the best available technology and the expected technology-mix in 2010 were presented. The market situation, the age of presently used technologies, and technology trends were taken into account.

Indicators for land use were presented by BO WEIDEMA, who considers change in net primary productivity and biodiversity the most important issues in this context. He introduced a biodiversity factor $Q_{\text{biodiv}} = (\text{species richness}) \times (\text{inherent ecosystem's scarcity}) \times (\text{ecosystem's vulnerability})$. A complete report can be found at www.lca.dk/publ/gaps9.pdf.

SANGWON SUH examined strengths and weaknesses of life cycle inventory modeling using (economic) input-output analysis. Suh suggests applying a hybrid approach that uses process LCA whenever possible but tries to close data gaps with I/O models. Using a linoleum floor cover case study with 172 unit processes (in the process LCA, with data gaps) he showed that I/O yielded higher impacts in most categories (but not in all cases) and that the hybrid-LCA yielded slightly higher results than the process-LCA. Therefore, modeling background data gaps seem to be the most appropriate application for I/O-LCA. A software tool and documentation on this methodology can be found at www.leidenuniv.nl/cm/ssp/software/miet.

JESSICA GRANATH presented a model to include municipal wastewater and sludge treatment in LCI/LCA in a modular form. The model consists of modules for mechanical-, biological-, and chemical treatment as well as for digestion. In sludge treatment composting, spreading, incineration, and landfilling (with aerobic and anaerobic treatment of landfill seeping water) were addressed. With this comprehensive model comparisons of the environmental performance of detergents in different areas of the world can be carried out.

New impact categories for the environmental assessment of fisheries were introduced by FRIEDERICKE ZIEGLER. She studied impacts from fishing on fish-stocks (target species, by-catch species, discard species), marine toxicity (release of heavy metals from anti-fouling paint), and impacts on the sea floor. Mass allocation and economic allocation yielded different results when there is a significant amount of by-product (e.g., in the Kattegat sea region, the by-product lobster makes up only 30% by mass, but 70% by economic value). Ziegler suggests to present results with both allocation methods to enhance transparency.

PETER FORSBERG discussed the advantages expected from a mathematician's treatment of LCI. He has developed a matrix representation of an LCI model. There were some dis-

ussions as to the similarity of this approach to a method developed by Heijungs in the past.

Session 3: Advances in life cycle impact assessment: water & other issues
(chaired by Helias Udo de Haes and Michael Hauschild)

ENRICO BENETTO analyzed the model uncertainty in LCIA and its application to the coal by-products based electric power generation. Fuzzy theory and bayesian modeling were applied to provide information on data and model uncertainty to stakeholders and practitioners. The method was illustrated by an LCA of electricity generation using coal by-products.

WOLFRAM KREWITT determined country specific damage factors for air pollutants – as a step towards site dependent impact assessment. His approach enables to measure at endpoint levels the impacts of different air pollution sources on human health (in term of years of life lost), on semi-natural ecosystems (acidification and eutrophication), and on the man-made environment (crop yield and building materials). Using the Ecosense-model, he put into evidence the key parameters that generate important variations in site specific impacts.

PHILIPPE CIFFROY determined characterization factors for ionizing substances in LCIA. Impacts of radioactive isotopes were estimated for releases into air, freshwater, and seawater and expressed in terms of individual and collective doses and number of cancer occurrence.

MARK HUIJBREGTS evaluated ecotoxicological impacts in life cycle assessment, based on the Potentially Affected Fraction of species (PAF). Two ways to implement the PAF concept in LCA were compared on the basis of 33 substances in fresh water aquatic ecosystems, showing differences up to 2.2 orders of magnitude. LLORENÇ MILÀ I CANALS presented the use of soil organic matter models in the implementation of the soil recovery indicator for land use impacts. Soil organic matter is determined and used as an indicator for many land functions, including biotic production and most of the life support functions.

PIA RASMUSSEN reported conclusions of the SETAC-Europe working group on integration of working environment in LCA. She presented and discussed different methods for carrying out working environmental LCA, ranging from scoring and ranking methods, sector assessment based on statistical information, to process methods. Case studies proved the feasibility to include work environment in LCA with a reasonable effort and in a similar form to LCA results carried out for the external environment.

ANDERS SCHMIDT provided additional details on a new sector assessment method for working environmental LCA. Statistics on the number of reported work-linked diseases and damages were related to the amounts being produced in the same sector. This enabled to determine a figure for working environmental impacts per produced unit, which can eventually be combined with impacts to the outside environment.

ISA RENNER presented a preliminary approach to integrating the risks of the agricultural use of transgenic plants into life cycle impact assessment in which a new impact category has been proposed. The indicator chosen includes a scoring of the risk elements identified by the EU and the number of areas of pro-

tection affected. Needs for further methodological developments in this important field were identified during the discussion.

RÜDI MÜLLER-WENK presented an innovative method for life-cycle impacts of road noise. He successively determined the increase in noise level, the number of people living in the noise perimeter, the main health effects due to noise, together with the disability weights for sleep disturbances and communication disturbances. Damages due to noise emitted by transportation are finally expressed in DALY (Disability Adjusted Life Years), enabling a quantitative comparison with damages on human health due to air pollution.

MARY STEWART presented the application of LCA to mining and minerals processing. Based on two case studies on coal mining and on the processing of copper concentrate, she emphasized the present lack of impact categories to describe the mining process, especially to take into account metal species and extraction.

The session on LCIA was continued by STEFANIE HELIWEG, who presented an approach of modeling long-term heavy metals emissions from landfilling to deeper soil layers and the groundwater. Her model for the landfill subsoil considers the temporal distribution of emissions depending on the type of landfill and subsoil. This also involves releases to surface water (when the landfill is still sealed) and ground water in different periods of time. Also the background concentration of heavy metals in the environment – which may vary in the long term – is accounted for.

The assessment of toxic stress on ecosystems in LCA was the topic of JEROME PAYET. Enabling a bootstrap calculation of the confidence interval on the response of species, his approach is based on the median impact on the species in an ecosystem, not on the impact on the most sensitive species. On the one hand it improves the ability to compare the toxicity between chemicals, on the other hand this provoked some discussions, because it could imply a value choice that some species are of less relevance.

In the following HELIAS UDO DE HAES gave an overview on the activities of the SETAC working group on best available practice in LCIA. Clearly, the aim is to include the endpoint level wherever possible, but midpoints are accepted for practical reasons as well (e.g., for global warming). The group also dealt with the question whether impacts on man made environment should be included in LCIA. A comprehensive report is expected to be available until fall 2001.

Session 4: LCA & comparative risk assessment
(chaired by Olivier Jolliet and Jane Bare)

PATRICK HOFSTETTER broadened the LCA view by looking at the most relevant issues influencing human health and life expectancy. The presentation revolved around the question if the *ceteris paribus* assumption in LCA ("all other systems stay the same") is really a valid one. The impacts on human health accounted for in LCA are the most relevant ones for the U.S., but the sum of the work and non-work related accidents cause higher impacts on human health than the environmental impacts. Another observation/thesis is that the number of functional units consumed depends on the disposable income. Hofstetter concluded that the *ceteris pari-*

bus assumption needs justification in meso and macro decision-making and that behavioral and market influences on the income may dominate many LCA results.

DEBORAH BENNETT presented a paper on **understanding and characterizing the source to dose relationship in LCA**. The 'intake fraction' is defined as the fraction of the substance emitted which is eventually taken in by the overall population. It is used as a metric for exposure and a level III fate model is used for calculating the fate of the substances. The method was applied to 200 chemicals, showing that the highest intake fractions are obtained for substances that are easily transferred into food.

DAVID PENNINGTON presented a **multi-region multichemical fate and exposure model for use in LCA in Japan**, taking into account the geographical situation of Japan, as well as the population density in the different regions considered. Significant variations in the intake fraction were observed depending on population densities.

GUIDO SONNEMANN presented in his paper a **methodology of environmental damage estimations for industrial process chains**, which is applicable in detailed studies of production processes for which site-specific data is available.

OLIVIER JOLLIET and MICHAEL HAUSCHILD reported a **review of the assessment of toxic chemicals in LCIA**, performed by the SETAC-Europe working group on LCIA. Fate and exposure (determining increases in concentration or intake fractions) have traditionally been modeled on the basis of multimedia models, whereas the ability to integrate compartment or substance specific models into a common framework should be considered. For effect on human health, toxicological potency indicators such as dose-response slopes are a minimum default. While methods are in their infancy, it is encouraged to take relative severity into account, e.g. using Years of Life Lost or DALY. For ecotoxicological effects, additional research is required to investigate the feasibility of comparing chemicals on the basis of PAF or HC5.

JOANNA JAWORSKA explained a **research plan for fostering the rational integration of human and environmental considerations in public and private decision-making**. This plan was developed for the American Chemistry Council's Long Range Research Initiative (LRFI).

Session 5: Life Cycle Management (chaired by Konrad Saur and Allan Astrup Jensen)

HELIAS UDO DE HAES opened the session with an explanation of the **planned structure of the UNEP/SETAC Life Cycle Initiative** as a whole. It is organized around two to three groups focusing on LCI, LCIA, and possibly LCM. The goal is to develop and identify best available practice in LCA.

STEFAN SEURING continued with a **comparison of life cycle and supply chain management (SCM)**. He explained that SCM has its origin in logistics and mainly focuses on the cooperation of the actors of the supply chain (network dimension). Since it is a management tool the only actors considered are the enterprises whereas LCM also deals with stakeholders outside of the companies involved. Seuring concluded that integrating the network dimension of SCM with the LCM system seems to be a promising direction.

BARBARA STROBL spoke about **waste challenges for LCM**. In her approach, LCA is used to determine the Best Practical Environmental Option (BPEO). The study includes a case study in Norfolk, UK, in which LCM was used to take into account other requirements, as national and EU regulations.

ANDREAS WINDSBERGER went on with a case study on **life cycle management in the paper industry**. Based on EMS data paper mills with different supply chains were compared. He concluded that EMAS statements are a good basis for data on emissions to air and water as well as on waste. Noise impacts and impacts from transport had to be determined by other means, however. Optimization from an environmental point of view can be achieved if most process steps are combined at one site, since synergies (co-generation, etc.) can be used.

An approach to **scenario generation and interpretation analysis for LCM** was introduced by THOMAS GLORIA. This approach is based upon a dynamic I/O-LCA model, with which he investigated the potential impacts of fuel-cell technology automobiles. As a result of his scenario modeling he expects an increase in CO₂ emissions from passenger cars in the US due to increased total mileage in the long term – even with a significant share of fuel cell vehicles. He showed that an improvement in fuel economy of e.g., sports utility vehicles (SUVs) in the range of 20% would help to limit CO₂ emissions as much as a 25% market penetration of fuel cells.

GERD VAN HOF's presentation dealt with the **practical use of LCA in a consumer goods company**. Method and tool development and application, LCA database administration, securing ISO 14040 compliance, and publishing activities are on the agenda. Depending on the specific goal an LCA project usually starts with a feasibility study, goes on to a screening LCA and in some instances to a detailed LCA. Regional influences play an important role in the studies, since different electricity grids, different wastewater treatment and waste management technologies, and different consumer behavior can have significant impacts on the results.

Metallic raw material flows – from analysis towards decision support was the title of GEORG ROMBACH's presentation, which focused on expanding the inventory modeling to include economic and social aspects in decisions concerning large-scale material flows.

REMKE BRAS-KLAPWIJK explained her **ideas for generating and selecting alternatives in LCA**. She stressed that the overall result of an LCA can be highly influenced by the different options considered and therefore special care has to be taken in goal definition and scoping. She also stated that the selection of options might be a highly political process when applying LCA for public policy making.

The session on LCM was concluded by KONRAD SAUR, who gave a **report from the SETAC LCM working group**. Saur explained the goals and findings of the group. The starting point was the perception of many industrial companies that "LCAs cost too much, take too much time, and do not produce usable results". LCM, which itself is clearly not finally developed, aims at facilitating business decisions by incorporating the life cycle approach. Saur also stressed that for LCM to be successful in industry the LCM developers and practitioners have to adapt to the language of business management and not vice versa. Communication seems to be a crucial issue.

Session 6: LCA & related tools: sustainable and green chemistry, LCC, MFA, SFA, DfE & industrial ecology (chaired by Sarah Cowell and Antonio Giacomucci)

SARAH COWELL started the session with an overview of the results of the SETAC working group on LCA and decision-making. The group has developed a three-dimensional description of the problem situation, in which an LCA based or influenced decision has to be seen. These dimensions comprise the process (prescriptive vs. deliberate), the framing (agreed vs. not agreed) and the analytical mode (hard vs. soft). An interaction between the problem situation and the LCA study is essential for a good decision support. Cowell also pointed out that LCA is not only a tool for decision making, but also for learning/awareness raising.

In the following PAOLO FRANKL outlined the DEEP project – ecolabelling improvement, role of LCAP. The EU DEEP project (developing effective and efficient product information schemes) deals with success factors for eco-labels. There is a new EU-ecolabel, which is however not very widely used yet (currently for about 300 products; the German Blue Angel and the Scandinavian White Swan can be found on approximately 4000 products each). Frankl pointed out that the role of retail chains is extremely important in ecolabelling, since demand from this side produces pressure for the suppliers. Information on the project can be found at www.uniroma1.it/deep.

Product development was the focus of GERALD REBITZER's presentation 'LCA – the one and only DfE approach?', which gave an overview of potentials and obstacles for the application of LCA in design for environment (DfE). Though LCA bears enormous opportunities in product development, it is not widely used in industry. This is due to the fact that only very few firms (usually multinationals) do have the know-how and resources for conducting LCAs. As a possible solution he presented the euroMat methodology and software tool for materials selection in product development, which uses an iterative simplified LCA approach. He showed results of a case study from the automotive sector. More information can be found at www.euroMat-online.de.

ARNE EIK discussed the eco-efficiency in recovery systems based on a case study of plastics packaging from households in the municipality of Trondheim, Norway. To evaluate recovery systems, four criteria for indicators were identified as crucial to give the decision makers the most relevant information: the indicators must be integrated into the decision-making process, they must reflect the objectives of the evaluation, they must be science-based, and finally they must be applicable. Based on these criteria and on interviews of local actors, six indicators of eco-efficiency have been developed, among them costs, emissions, recovery rate, and use of energy.

ANDREAS GRANGLER performed a scenario assessment for urban water management as decision support. The environmental effects of the urban water management of Berlin were assessed based on energy and substance flow analysis by a set of so-called sustainability indicators. The implementation of microfiltration would lead to an increase of CO₂ emissions by 12%, compared with the current state.

BART KRUTWAGEN proposed an LCA of eco-services, an adapted LCA approach which includes consumer based rebound effects. As the emerging new economy is turning our product-

based economy into a service-based economy, it becomes necessary to make LCA more applicable for services. The financial impact of services should also be considered, because services can influence the user behavior in a strong way.

Quantifying the effect of dematerialization was the title of MARK GOEDKOOOP's presentation. He pointed to the fact that minimizing material flows per functional unit does not necessarily mean a reduction in overall environmental burdens. If a product is more material efficient, it becomes less expensive and the money saved is spent on other products. He stated that dematerialization could only be successful if the ratio between material flow and added value is changed. As one solution he proposed value creation as a functional unit that allows comparisons of impacts between all product and service flows.

NIELS JUNGBLUTH reported from his study combining LCA and the national greenhouse gas inventory to determine the embodied greenhouse gas emissions caused by international trade. He presented the concept of direct and indirect (or embodied) CO₂ emissions. The latter comprise those emissions that are caused to produce imported goods. For instance, tomatoes imported into Switzerland have embodied CO₂ emissions of about 0.5 kg/kg. Using his methodology, the Swiss per capita CO₂ emissions including imports are about double the amount of direct emissions, which are usually reported in global warming statistics.

ERWIN LINDEIJER reported on Dutch consumer impacts for deciding on product development. This internal TNO study considered seven consumer domains and the burden affected by them for the domestic environment in The Netherlands, using LCA, statistics, and input-output analyses.

The conference was concluded by the one-day workshop of the UNEP/SETAC Life Cycle Initiative, chaired by Rolf Bretz. Helias Udo de Haes, Olivier Jolliet, and Greg Norris presented the planned structure of the initiative as well as the first proposal for a research plan starting with two programs on LCA and LCIA, to be eventually followed by a program on Life Cycle Management. A heated debate developed over such issues as

- Focus on science vs. focus on application: what should be the starting point?
- Form of involvement of industry with the initiative's structure and organization.
- Involvement of second and third world countries and stakeholders.

Many concerns that have to be tackled were identified. Based on expressed proposals and comments, the establishment of a transversal program on the application and communication of Life Cycle Assessment will be considered, involving emerging and developing countries. It will be extremely interesting to follow the development of this important and ambitious initiative.

References

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Proceedings:

Conference proceedings with the presented abstracts from the presentations are available from SETAC Europe (Av. de la Toison d'Or 67, B-1060 Brussels, Belgium; Phone +32 2 772 72 81, Fax +32 2 770 53 86, e-mail: setac@setaceu.org).