Prague Revisited

Progress in Modern Life Cycle Assessment: Practice and Research

14th SETAC Europe Annual Meeting, 19th – 22nd April 2004 in Prague, Czech Republic

Wolfram Scharnhorst[1,2*], Annette Köhler[3], Gerald Rebitzer[1,4], Roland Hischier[3], and Olivier Jolliet[1]

[1] Swiss Federal Institute of Technology, EPFL (ENAC-GECOS), CH-1015 Lausanne, Switzerland
[2] Swiss Federal Laboratories for Materials Testing and Research, EMPA, CH-9014 St. Gallen, Switzerland
[3] Swiss Federal Institute of Technology, ETHZ, CH-8093 Zürich, Switzerland
[4] Alcan Technology & Management, CH-3965 Chippis, Switzerland

* **Corresponding author** (Wolfram.Scharnhorst@empa.ch)

Photo: Gerald Rebitzer

Prague, the charming and pulsating capital of the Czech Republic was the host of this year's Annual Meeting of SETAC Europe. The life cycle assessment (LCA) sessions focused on the subsequent topics:

- Life Cycle Impact Assessment (LCIA)
- LCA and Electricity Markets
- LCA and Input-Output (I/O) Analysis
- LCA and Life Cycle Costing
- LCA and Strategic Policymaking
- LCA – OMNIITOX (special symposium)
- Interactive posters: Uncertainty and Error Calculation in LCA

A total of 38 platform presentations were given and debated both within the sessions and at the various social events, in addition to the interactive poster session, which included nine contributions. Conventional poster sessions, featuring around 60 papers in relation to the platform topics, completed the program. The LCA sessions of the conference were attended by around 150 scientists, practitioners, and students from Europe, America, and Asia. Meetings of the SETAC Working Groups on Life Cycle Costing, Input-Output LCA, and Electricity Markets, in addition to several meetings of the task forces of the UNEP/SETAC Life Cycle Initiative, contributed to a successful Annual Meeting.

Session 1: Life Cycle Impact Assessment (Chairs: Göran Finnveden and José Potting)

The session on life cycle impact assessment was divided into two parts. The first block of presentations focused on the implementation of spatial differentiation in LCA, whereas the second part of the session was devoted to new approaches of weighting, the consideration of social impacts, and the assessment of ionic substances with unknown properties.

Niels Jungbluth started the session with a presentation on the **assignment of impact assessment factors to elementary flows** and elaborated on the **problems and their solutions.** He pointed out that the combination of one inventory with one LCIA method does not necessarily lead to the same results when applied by different users. For the example of the database ecoinvent (see http://www.ecoinvent.ch), the main problems of incompatibility of LCI and LCIA were caused by different names of elementary flows in the database and in LCIA methods as well as by elementary flows not characterized in the impact assessment procedures. Also, the fate modeling in the database and in LCIA methods, e.g. for long-term emissions from landfills, were overlapping or did not match. In order to overcome those difficulties, the factors for elementary flows to river and industrial soil were applied by convention as default factors for 'unspecified' elementary flows to all sub-compartments. Factors of today's emissions were assigned to long-term emissions. Additional principles for implementing LCIA methods into ecoinvent were identified as follows: (i) factors for sum parameters were applied on the basis of individual substances and (ii) the extrapolation of factors to similar substances and to other compartments was excluded.

As some LCA studies and LCA databases provide processes characterized by country codes, Sandra Bellekom investigated the **feasibility of site-dependent impact assessment in LCA.** By analyzing existing LCA studies on linoleum, Bellekom compared site-generic and site-dependent acidification and determined the time needed to obtain the location specific information. The results showed that identifying the source country of acidifying emissions took only low

to medium effort, whereas the collection of disaggregated inventory data was time-consuming and required substantial effort due to the confidentiality of process information and missing data for emissions of unit processes. Bellekom came to the conclusion that the present LCA software tools do not support site-dependency and that there is a lack of site-dependent acidification factors for regions outside Europe.

In his talk on **site-dependent characterization factors in LCIA from a Finnish perspective,** JYRI SEPPÄLÄ demonstrated how different choices of indicators and models selected influence characterization factors for regional impact categories such as tropospheric ozone formation, acidification, and terrestrial eutrophication. In particular, he compared three different models for ozone formation (the FMI photochemical trajectory model, EMEP model and RAINS model), and the indicators used, in order to display that various scientifically sound methods exist for establishing characterization factors. The specific environmental responses and the related weighting factors were identified as the most influential parameters for deriving regional characterization factors.

Expanding the scope of site-dependency considerations, KEISUKE NANSAI elaborated on the **database preparation for a site-dependent LCIA in Japan using an input-output table and the virtual world.** He proposed a new Site-Dependent LCI method (SD-LCI) claiming to save costs for labor and time as well as to improve the quality of a Site-Dependent LCIA (SD-LCIA). This new approach introduces the so-called Equal-impact Areas (E-iA), which are regarded as having homogenous environmental impacts. Using geographical information system software (GIS) and further national statistics in addition to the national input-output table (I/O-table), the E-iAs are determined using characteristics such as population density so that the magnitude of the environmental impacts can be differentiated. Thus, the resulting new SD-LCI table includes both the environmental burdens and the E-iA of a specific unit process. The method allows users to calculate the embodied emission intensity of I/O-sectors and the EXposure Per Emission Coefficients (EXPEC) related to a specific E-iA in order to score the embodied impact intensity of the corresponding E-iA and the I/O-sectors. Showing results from a case study on benzene, Nansai concluded that the impact intensities embodied in sectors obtained from SD-LCIA based on SD-LCI were 10% to 40% larger than those based on a non SD-LCI.

MICHAEL HAUSCHILD devoted his presentation entitled '**Spatial differentiation in characterization modeling – what difference does it make?**' to the question why and in which cases spatial differentiation should be applied. He stated that variations in environmental parameters can be more important than variations in substance properties and that the areas exposed above their critical emission loads varied greatly among European countries giving the example of acidification in Greece and Sweden. Presenting the spatial characterization approach (area of ecosystem exposed above critical load per gram of substance) of the newly developed EDIP 2003 method (guideline and technical report: http://ipt.dtu.dk/~mic/), Hauschild indicated that the uncertainty of interpreting results is significantly diminished when exposure information is included, while additional parameter and model uncertainties for damage modeling were assessed to be acceptable. As spatial characterization can change results considerably, it was recommended to apply spatial differentiation only in the following cases: (i) when spatial differentiation is important at the chosen scale of modeling, (ii) when the uncertainty of the models applied is tolerable and (iii) when damage modeling and monetization is aimed for. Screening LCAs, for example, are not suitable for representing spatial aspects. Another important aspect of the discussion regarding site-dependency was the implementation of spatial differentiation of elementary flows in LCI. In addition, the choice between different indicators for site-dependency and the question how to model spatial differentiation for impact categories like ecotoxicity were intensively discussed.

Following these deliberations, the second block of the LCIA session was opened by ANNETTE KÖHLER, who gave a talk on the **ecotoxicity assessment of industrial organic wastewater contaminants within LCIA.** The presentation displayed that water emissions from industrial wastewater treatment systems are mainly side-products, which are not measured as individual substances, but with composite parameters, e.g. TOC_{ref} (refractory Total Organic Carbon). As these polar and ionic side-products represent very specific and rarely investigated organic compounds, substance property data are missing and QSAR routines are not applicable. Extrapolation of substance data from the products was proposed in order to derive properties for the unknown side-products. Showing a case study on ionic optical brighteners and their structurally related side-products, Köhler applied a regional river model and the global LCIA model USES-LCA for fate modeling. The organic carbon-water distribution coefficient (K_{OC}) was found to be the crucial parameter for the fate modeling of ionic and polar organic wastewater substances released into the aquatic environment. It was shown that the omission of regional environmental parameters might cause either under- or overestimation of the substances' behavior in the environment.

Referring to the aspect of regional differentiation in LCIA, LOUISE DESCHÊNES' presentation dealt with the methodological procedure for the **development of a life cycle impact assessment method specific to the Canadian environmental context.** Existing characterization models with a site-dependent approach for different impact categories were chosen and adapted to Canadian conditions by introduction of different regional scales such as the Provinces and the so-called aquatic and terrestrial ecozones. In order to introduce regional fate modeling of photo-oxidants, acidifying and eutrophying substances, the ASTRAP (Advanced Statistical Trajectory Regional Air Pollution) model was used. Sensibility and vulnerability factors were also developed to assess the effects on a regional level. For human and ecotoxicity the spatial version of IMPACT 2002 (see http://www.epfl.ch/impact) was adapted to the five aquatic and 15 terrestrial Canadian ecozones. Abiotic resource depletion was modeled using Eco-Indicator 99 (see http://www.pre.nl/eco-indicator99), while for land-use the LCAGAPS model (see http://www.lca-net.com/files/gaps9.pdf) was selected. As the LCAGAPS model only takes into account land occupation, it is intended to also include land transformation. Deschênes

emphasized that the integration of area of protection models, normalization and weighting, as well as the uncertainty evaluation will be included in the Canadian LCIA method.

A simplified method to generate disability weights for the application in LCA was the topic of MAURITZ GLAUMANN's talk concerning the evaluation of health problems in buildings. In comparison to the DALY (Disability Adjusted Life Year) concept, Glaumann demonstrated two simplified methods to derive disability weights for a specific disease. The Visual Analogue Scale (VAS) method determines the disability weight between the best possible and worst possible health state, whereas the Person Trade-Off (PTO) method allows users to define the number of persons with the specific disease whose curing is regarded as equal in importance to 1000 healthy persons. In contrast to these approximate disability weights, a simplified approach was suggested for deriving disability weights for experienced endpoint problems. Applying a classification scheme dealing with health aspects and the severity of health impairment, Glaumann obtained disability weights for endpoint problems experienced internally, e.g. noise and thermal comfort in buildings, as well as for external endpoint problems, e.g. unemployment. His conclusion was that the severity of a classified disease stage can be understood by laypersons when using the scheme. Thus, laypersons can easily set disability weights through classification on the basis of experience and description of endpoint problems.

Continuing with the weighting issue, NORIHIRO ITSUBO elaborated on the **weighting across safe-guard subjects in LIME by the application of conjoint analysis.** In order to transform the multi-dimensions of safe-guard subjects such as human health, biodiversity, social assets and primary production into a single weighting index, conjoint analysis was adopted as the weighting method to be used in the Japanese LIME (Life-cycle Impact assessment Method based on Ecopoint modeling) method. Conjoint analysis is a technique used to measure the trade-offs people make in choosing between products and service providers. In LIME, conjoint analysis, based on different surveys performed in Japan, was applied to convert the physical damages to external costs. This procedure allows for estimating a conversion factor depicting the economic value of any damage to the endpoints. The conversion factors obtained from the results of the conjoint analysis were integrated in LIME by multiplying the damage factors (in damage/kg) with the derived conversion factors (in JY/damage) giving a new weighting factor in monetary units (in JY/kg). The debate on this weighting method showed that the aspects which are most preferable for the consumer have to be considered in the survey questionnaire as the most crucial parameters for the conjoint analysis. Concerning a possible conflict between individual and general social preferences, Itsubo emphasized that the preferences of society as a whole have to be obtained from the preferences of a sufficiently large and randomly chosen sample of individuals in a scientifically sound manner. This can be only performed by surveys and statistical evaluation. However, there was also the opinion of politicians and governmental decision makers to be taken into account for deciding on social preferences.

The LCIA session was closed by a contribution by LOUISE DREYER, who gave an overview of relevant issues for **including social impacts in LCIA.** Dreyer presented a company approach for the product system in LCA which considered the company's interactions with society as a whole, the local community, and the employees as the most important stakeholders. Following this company approach, human health in addition to human dignity, and well-being were identified as areas of protection for social assessment. Giving an extended list of issues to be included in a so-called social LCA, topics from different fields were proposed, among them working hours, wages, the social and the economic investment in local society, as well as welfare and social security schemes.

A lively discussion followed on the question as to which indicators could be used for assessing social impacts, particularly, when they are intended to be included in the traditional LCIA framework. Since the assessment of social impacts is still in its infancy, quantifiable indicators are missing. Also, they are extremely difficult to develop due to their different characters as compared to the traditional environmental impact categories. As a first step it was suggested to measure social impacts in terms of the management efforts of companies, or alternatively to include them in the human health category, though in a new dimension.

Session 2: LCA and Electricity Markets
(Chairs: Wolfram Krewitt and Paolo Masoni)

Due to the fact that nearly all production processes and services require energy, datasets on different energy systems, especially electricity, are among the most important and needed for any type of life cycle assessment study. Due to its complexity, however, the topic of electricity production still leaves various research questions unanswered; a commonly accepted position does not exist. Another indication of that is the on-going SETAC LCA Working Group dealing with the topic. The presentations covered various research fields in the area of the electricity market and highlighted some of the most recent scientific insights.

TOMAS EKVALL opened the session presenting on **'Complex marginal electricity in the Nordic countries'.** In the introduction he outlined the two types of marginal electricity mixes. While in a short-term perspective, the marginal electricity mix is based on fixed capacities and thus defined by variable costs, in a long-term perspective the capacity is flexible and thus the marginal electricity mix is defined by its total cost. The complex marginal electricity combines both the short-term and the long-term, allowing users to follow the development over time. For the Nordic electricity mix, Ekvall showed that in a first phase all additional electricity is provided by an increasing number of coal power plants while over time there is a shift to natural gas. Ekvall outlined the dependency of this on a variety of factors. Nevertheless, this dynamic optimization model allows users to make recommendations to Nordic LCA practitioners.

MARTIN PEHNT talked about **dynamic LCAs of renewable energy technologies.** The approach used by Pehnt and coworkers is an iterative approach based on three pillars: (i) inventory data from modern status quo systems, (ii) modeling

of future developments for these systems, i.e. dynamic parameters of scenarios for the various background systems and (iii) dynamic parameters or assumptions for the technology itself. With this dynamic model, Pehnt showed that future developments will reduce the environmental effects of the examined energy systems further.

Subsequently, PAOLO FRANKL, in his speech entitled '**Environmental and ecological life cycle inventories for present and future power systems in Europe (ECLIPSE)**', presented a European project focusing on different electricity supply options. The aim of this EU project was to establish a coherent methodological framework and harmonized datasets of photovoltaic, wind, fuel cell, biomass, gas-fired and bio-fuelled combined heat and power plants. One of the main motivations for this project was the fact that electricity supply systems are characterized by rapid technical development and significant structural changes, in particular due to market liberalization. According to the speaker this development, together with changing environmental policy requirements, is expected to increase the diffusion of distributed generation and renewable energy systems. Within the ECLIPSE project more than 100 different configurations of the above-mentioned five energy systems have been calculated and more than 440 different unit processes have been established. In this presentation, Frankl showed various systems each involving one of the five energy carriers examined – e.g. for the photovoltaic example, a total of 4 different technologies and with this, 47 different complete PV examples have been calculated.

Last but not least, ROBERTO DONES showed the **European energy systems in the LCA data system ecoinvent**. The ecoinvent database from the Swiss Centre for Life Cycle Inventories (see http://www.ecoinvent.ch) is the national LCI database of Switzerland containing datasets characterizing energy systems, materials, metals, transport systems, waste management processes, chemicals and agricultural products. In an energy system the ecoinvent team distinguishes between electricity and heating data. For the first one, oil, gas, lignite, hard coal, nuclear and renewable systems (hydro, wind, solar, wood) for Swiss and European countries' power plants are taken into account. In addition to that, transmission and distribution together with country-specific production and supply mixes were modeled. Dones outlined how these different steps were modeled for the various cases within ecoinvent. First results – based on the Dutch Eco-Indicator'99 method – were shown as the starting point for an animated discussion.

Both theoretical developments and actual state-of-the-art inventory datasets related to electricity issues were presented in this session. Visible trends are to establish future electricity production datasets by using dynamic approaches, while for present datasets static models based on country specific parameters may be the more appropriate way.

Session 3: LCA and I/O Analysis
(Chair: Sangwon Suh)

The core intention of the session on input-output analysis in LCA (I/O-LCA) was to give an overview on the most recent developments and progress in I/O-analysis focusing especially on the analysis of environmental implications due to waste processing using combined I/O-process LCA as well as on regionalization issues.

The session was opened by YUKI KUDOH with the presentation entitled '**Life cycle environmental emissions from public transportation systems: towards environmentally sustainable transport**'. Adopting the OECD's Environmentally Sustainable Transport (EST) Guidelines and using a hybrid LCA approach, environmental profiles were estimated for several different public transport means such as trams and railways on the basis of environmental emissions such as NO_X, CO_2, and particulates. In the approach used the Japanese input-output table (I/O–table) was divided into two categories of inputs: material and non-material inputs. Applying input-output data (I/O-data) for Japan from 1990, Kudoh detected that the manufacturing of railways and subways caused the largest emissions in terms of CO_2, NO_X, and particles. The emissions during the operation phase were dominated by the trolleys due to the fact that they are very old. The focus of the brief discussion that followed was directed towards allocation issues and the fact that data from 1990 might be too old to be of relevance for up to date scientific work. It was not possible to find ultimate answers to either question.

Concentrating on the waste phase of LCA, YASUSHI KONDO **evaluated the cost of 'optimum' waste management** using a **waste input-output linear programming and price model.** The core of the study presented consisted of (i) the application of a hybrid LCA approach combined with a cost model to estimate economic factors and (ii) widening the input-output matrix by disaggregating Japan's waste sector into 80 industries and 40 waste types. The cost model itself consisted of five categories. The objectives of the investigation were minimization of landfill usage due to resource scarcity and optimization of CO_2 emissions. Presuming an elaborate End-of-Life (EOL) treatment consisting of such elements as disassembly, shredding, and incineration of products, and applying the linear extrapolation model, a decrease in CO_2 emissions was estimated at about five percent, as was a decrease of landfill use at 28%. A lively discussion on how to distinguish between industry and public waste as well as the linearity of waste treatment finalized that presentation.

Among the many PhD-candidates participating in the conference, JENNIFER STOKES continued the session by giving her speech on the **life cycle assessment of alternative water supply systems** in California. Applying the so-called WEST-Tool, a hybrid LCA method combining process and I/O-LCA, the object of the study was a comparative analysis of the environmental implications caused by different water supply systems operated to provide California with tap water. Three typical supply systems were analyzed: importing water from distant places (from the Colorado River), desalination of local brackish water, and the recycling of water pre-treated in waste water treatment plants. The analysis of nearly all life cycle stages of the different systems revealed that in terms of global warming the desalination option represents the worst condition whereas the import of water as well as the use of recycled water exhibit nearly equal conditions. The discussion was highlighted by questions referring to the level of quality to which the waste water is treated as well as to whether distant inputs into the supply systems were considered or not.

Stressing the topic of regionalization of LCA, GYORGYI CICAS talked about **regional input-output based life cycle assessment**. The intention of the investigation was to determine the population size exposed to air pollutants originating from regional economic activities. By applying Economic Input-Output (EIO-) LCA, regionalizing the D-matrix (direct-requirement coefficient) of the Leontief equation and using geographic information system (GIS) for visualization purposes Cicas presented exemplary results for Pennsylvania. According to those results most of the toxic release index (TRI) facilities accounting for most of the toxic emissions are situated in the most densely populated counties. In her talk Cicas addressed in detail the problem of data uncertainty, thereby identifying three main sources: data was either (i) scarce, or (ii) aggregated, or (iii) outdated. An attempt was made to solve the latter problem by updating the model applied to the conditions of 1997. It is the intention of the authors to further improve the model, to generate multipliers for the D-matrix for all U.S. industries and States and finally to make the model freely available via the World Wide Web (see http://www.eiolca.net). As in the case with the discussion that followed the preceding presentation, the question was addressed again as to whether distant inputs were included in the model. As before, distant inputs had not yet been considered in I/O-modeling. Similarly, international inputs had not been considered in current I/O-practice either. According to Cicas, the general applicability of the results obtainable from the presented model lies in the possibility of determining the sectors having the largest improvement potential.

It was BO WEIDEMA who finalized this session on I/O-LCA giving a detailed overview on the **prioritization within IPP – results from the Danish project**. The core intention of the project was the sound identification of problems related to traditional I/O-analysis and the update and improvement of the Danish NAMEA (National Accounting Matrix including Environmental Accounts) by prioritizing all product groups. The high level of data aggregation, the lack of use and disposal stages, and the limited number of environmental exchanges were detected as key restrictions to the Danish NAMEA. To overcome these limitations, the authors suggested a disaggregation of diverse industries such as the agricultural sector, which, for example, was divided into 26 farm types. The authors also proposed the distribution of use stage emissions from Danish statistics over applications and activities as well as the inclusion of use phase emissions in the mix of Dutch data. The end-of-life (EOL) phase was addressed by attributing emissions to the products causing those emissions. To adjust for market conditions, consequential LCA was applied thereby separating industries into constrained and unconstrained parts and highlighting limited importance for prioritization. Concluding the study results, the authors emphasized that with the increasing number of products covered by the supply-use table the uncertainty decreased and that the high level of aggregation common in I/O-analysis could be substantially reduced by adopting detailed process LCA-data. The subsequent discussion focused primarily on the use of prioritization within LCA in general.

Continuing last year's session on I/O-LCA key topics, this year's session focused on the application of hybrid approaches combining both process LCA and I/O-LCA to overcome the limitations and to combine the benefits of both. To overcome existing limitations, the disaggregation of diverse sectors of national I/O-tables was favored. Focusing on the practical side of I/O-LCA, the question was addressed as to whether distant inputs into systems should be included in the respective analysis or not. To date this does not seem to be the case. The session revealed that I/O-LCA is quite an active and evolving field. The lively discussions that characterized the session were an indicator that I/O-LCA has been ascertained as an important decision tool for environmental issues indicating at the same time the great potential of I/O-LCA that still need to be elaborated.

Session 4: LCA and Life Cycle Costing (Chairs: David Hunkeler, Kerstin Lichtenvort, and Gerald Rebitzer)

Life cycle costing (LCC) continues to be an emerging field within the methodological developments in sustainability assessment and life cycle management (LCM). For instance, a very active SETAC Working Group (WG) (Rebitzer and Seuring 2003, Rebitzer and Hunkeler 2004) pursues this subject with the goal of creating a code-of-practice similar to the pioneering SETAC documents on LCA. The importance of addressing the economic dimension in addition to the environmental and social dimensions is now broadly accepted, although there are still intensive discussions going on, addressing how the scope, boundaries and modeling choices should be selected, in order to move towards consistent frameworks and methods.

The first speaker of the session, KERSTIN LICHTENVORT, **reflected on basic principles for a general life cycle costing standard**. She gave a concise overview of specific LCC standards for military equipment, buildings, and electronics, etc., some dating back to the 1970s. While these standards are a sound basis, they are application driven and cannot be applied on a general level within the sustainability framework. Lichtenvort summarized discussions of the SETAC WG on LCC, focusing on key issues regarding LCC definitions, scope, functional unit, system boundaries, and perspectives. She concluded that LCC should focus mainly on the internal costs along the life cycle with environmental effects being covered by LCA and social implications by an appropriate third assessment.

Another heavily discussed issue, **discounting future effects in life cycle costing, LCA, and cost-benefit-analysis (CBA)**, was in the centre of GJALT HUPPES' presentation. He addressed differences in accounting for time in environmental and economic analyses and advocated a consistent modeling procedure. Generally, no discounting is applied in LCA; but a positive discount rate is used in economic analysis, although there are reasons for discounting in both methods. Huppes proposed to align both approaches, which finally could lead to identical discount rates in LCA and LCC if social welfare and long term implications are of interest. For such cases he proposed a discount rate in the range of 0.1%, because otherwise long term effects (longer than about 100 years) are minimal and

essentially eliminated. This is in contrast to the discounting rates usually applied in CBA, which are in the range of 3–15%. The discussion that followed confirmed that discounting is a controversial topic. The point was raised that discounting in LCA should differentiate between intrinsic and functional values. It was also questioned whether the same principles could apply to economic and environmental systems, because an economic system grows, while the environment does not.

In the following, BENGT STEEN continued to discuss the interfaces between economic and environmental assessments. He presented **different ways of estimating externalities**, focusing on the questions 'what to include, how to handle trade-offs, and how to address uncertainty'. By going through these issues he elaborated on the implications for paradigms of weak vs. strong sustainability, which can be differentiated by the degree of precaution and the time horizon (all future vs. a few future generations). As an example of an extreme view of strong sustainability, he showed scenario calculations for the future costs of extracting metals with current technologies and knowledge, where the costs increase continuously with time due to lower ore concentrations. In the discussion a challenge was raised as to whether such an extreme view could really add additional insight, since extraction technology as well as recycling technologies develop as a function of the costs for primary extraction, ensuring either cost efficient production of the metal or substitution by something else (similar to the shift from fossil to renewable energy resources when the use of renewables becomes less and the use of fossil resources more costly).

SHINICHIRO NAKAMURA came back to the topic on how to efficiently estimate money flows in the LCM framework with his talk entitled **'Waste input-output life cycle cost analysis of the recycling of end-of-life electrical home appliances'**. He expanded his linear programming model for the environmental I/O-analysis of waste management and recycling options (see also the presentation by Kondo in Session 3) to include life cycle costs. Nakamura showed how his comprehensive model can be used to estimate and compare the costs of different end-of-life (EOL) strategies in parallel to LCA, based on the same boundaries and functional units.

The session on LCA and life cycle costing was finalized by ANDREAS KICHERER, who elaborated on the **combination of LCA and LCC within the BASF eco-efficiency method**. This method, which has been in use at BASF since 1997, is probably the best known eco-efficiency approach and has been applied to several hundred cases to date. For instance, for every investment at BASF exceeding € 2 million, such an analysis is obligatory. Kicherer explained the main steps of the method, which includes a single score LCA and a traditional cost assessment, as well as a normalization to the product, which is 'in-between' in the assessment (average costs and average environmental impacts). More information on this methodology can be found at http://www.oekoeffizienzanalyse.de.

In the following discussion, Kicherer's claim, the method is ISO 14040 compliant, was strongly criticized since weighting is employed for comparative assertions disclosed to the public (single score LCA), which can be seen as one of the most important restrictions set by the standard.

Session 5: LCA and Strategic Policymaking
(Chairs: Tomas Ekvall and Rana Pant)

Due to the increasing reliability and professionalism in both LCA methodology and practice this tool is increasingly becoming a vital component within political decisions on the regional, national, and international levels. The core intention of the session was to illustrate the relation between policy, political issues, and the ability of LCA to serve as an input to successful decision making.

In his speech on **'Life cycle assessment (LCA) approaches in support of EU policies to prevent and manage potential waste'**, DAVID PENNINGTON gave an overview on the structure, tasks and deliverables of the Joint Research Centres (JRC) supporting the European Commission's policymaking. The issues considered by those centers range from energy to health and waste problems. The key issue of the Soil and Waste Unit of the JRC is the development of integrated waste management tools based on life cycle assessment. The cumulative nature of effects, including transboundary effects, was identified as one of the important factors that need to be taken into account. In the subsequent discussion primarily questions concerning an EU directive on transboundary effects, which does not yet exist, and the question as to whether one should carry out LCAs according to the ISO standard or not, which was affirmed by the speaker, were discussed.

Moving the geographical area towards Asia, RATTANAWAN MUNKUNG in her presentation on **using life cycle assessment to inform certification and ecolabelling initiatives for block-frozen shrimp production in Thailand** elaborated on the intensification of shrimp production and the need for an improved information policy. Discussing the Code of Conduct (CoC) certification system currently applied in Thailand, Munkung outlined the study's objectives in detail consisting of the utilization of LCA to evaluate and quantify the environmental implications caused by shrimp farming, the evaluation of the present certification practice using the obtained LCA results, and recommended principles for ecolabelling. The results of the study indicated that impacts from frozen shrimp production occurred over the whole life cycle. Detrimental impacts within the process of farming were primarily caused by electricity production, production and consumption of artificial feed, and the application of limestone. Comparing the CoC with LCA revealed that LCA has a wider environmental view and focuses more on specific topics. The option of weighting environmental impacts was identified as one key advantage. Concluding her talk, Mungkung recommended the utilization of LCA practice for the ecolabelling of agricultural products. Key questions of the subsequent discussion were of a rather pragmatic nature and addressed the question as to whether the destruction of mangrove ecosystems is still a real issue and whether antibiotics are still being applied and what problems they might cause. According to the speaker both questions are no longer of any relevance in Thailand.

Depicting the various flows within steel production as well as illustrating the efforts undertaken to recycle steel and reduce the exploitation of resources, JEAN-PIERRE TAVERNE in his talk **'Towards the development of objective environmen-**

tal legislation on packaging: use of life cycle analysis' discussed both the difficulties steel making companies encounter with the current EU Packaging & Waste Directive as well as fundamental problems inherent in LCA. In this context the so-called P.E.I concept favoring the use of simplified LCAs instead of complete assessments was elucidated and criticized. Continuing nonetheless, Taverne outlined both the strengths and weaknesses of LCA, thereby focusing on, e.g., data weakness and the importance of subjective decisions within LCA. He circumstantiated his findings by presenting the results of a comparative study on beverage cans. One key finding of the study was that even small variations within a sensitivity analysis can result in large overlaps between different options complicating proper decision making. Based on those results, Taverne urgently recommended the utilization of both certified data and profound sensitivity analysis and stipulated the implementation of certification issues in the ISO 14040 series.

Reviewing the more recent history of EU chemicals policy and outlining the reasons for renewed EU chemicals policy, FRANS CHRISTENSEN in his talk entitled **'Current and future life cycle aspects of the new EU chemicals policy (REACH)'** informed participants on and discussed the structure of the new chemical regulation proposal called REACH, standing for: Registration – Evaluation – Authorization – Chemicals. This proposal foresees the registration of manufactured and imported chemicals having a total production of more than one ton per year. Secondly, an evaluation of those registration dossiers is required and the use of substances of very high concern must be authorized. EU member states have the option of restricting the use of chemicals. Continuing his talk, Christensen elaborated on the communication between chemical suppliers and downstream users. In particular he emphasized that clear information exchange between those two parties is of urgent interest. Concluding, he outlined that traditional LCA can support the REACH concept by e.g. identifying substances contained in and released from products; it can also serve as an input to political decision making.

Highlighting the experiences made when applying LCA to company-internal policymaking, PETE SHOWNFIELD presented **the use of LCA in industry to assist strategic policymaking** and gave an overview on the Unilever method of Overall Business Impact Assessment (OBIA). This attempt seeks to combine conventional impact assessment with an economic normalization step. The speaker stressed in particular the importance of the use phase within LCA by illustrating the results of a recent study indicating that water consumption dominates the environmental implications caused during the life cycle of the object under study. In the context of the investigation he identified three sustainable development strategies relevant to water protection: (i) sustainable fishery, (ii) sustainable agriculture and (iii) clean water stewardship. Due to inherent difficulties such as pragmatic assessments, the limited number of issues covered, and value choices, Shownfield underlined that LCA can be used as measurement tool, but should not be used as a decision tool.

HELIAS UDO DE HAES had the honor of finishing this session by talking about **LCA, LCM and the developing countries.** Reviewing the complex theory of LCA and LCM, Udo de Haes determined the top barriers encountered by LCA practitioners in developing countries: lack of know-how, relevant data, and funding. According to the speaker, current LCA is mostly criticized as being too complicated and focused too much on issues concerning developed regions/ countries, and thus is not in line with the interests of developing countries. Discussing the above stated issues, the speaker did not agree with the argument that LCA is too complex, but did accept the argument that most developing countries do not have professional LCA know-how. Continuing, Udo de Haes went into the difficulties with life cycle management (LCM) discussing that LCM, e.g. ecolabelling, is costly in itself. As labeling does not necessarily generate any additional sales, LCM is often practically unaffordable for developing countries. Adding to this, any application of life cycle concepts/ eco-labels could worsen the position of producers from developing countries in those cases where their technologies are outdated.

This session highlighted the increasing importance that life cycle concepts have for present-day political decision making, and addressed LCA related issues important for both developed and developing countries. As political and thus economic decisions can cause serious consequences, it was recognized that LCA has to be used very carefully for political decision making. Across the speakers it was recommended to use LCA as one out of many other inputs for political decisions, but not to rely on LCA as the sole decision tool.

Session 6: Special Symposium: LCA – OMNIITOX (Chairs: Olivier Jolliet, Helias Udo de Haes, and Sverker Molander)

Traditionally, and due to the need for simplification, which is driven by practical constraints, LCA has focused on the environmental impact of the major material flows such as resource uses and major emissions of e.g. greenhouse gases and acidifying or eutrophying substances. In many cases, the toxicity impact categories have been more or less overlooked in LCAs or restricted to some well characterized chemicals. This is partly due to methodological difficulties such as the choice of the characterization model(s) and the lack of input data for a potentially large number of chemicals. To address these problems, the OMNIITOX project (Operational Models and Information tools for Industrial applications of eco/TOXicological impact assessments) was launched as part of the 5th European Research Framework program, aiming at the enhancement of models and information tools necessary for the assessment of potentially hazardous substances within LCA. This special symposium presented the main results of the research project that followed a case study driven approach, where method comparison and development go hand in hand with the application of LCA by practitioners in industry.

The first speaker of the session, RALPH ROSENBAUM, discussed the comparison of **four life cycle toxicity assessment methods**, namely IMPACT 2002, CalTox, USES-LCA and EDIP97 **applied to a test set of 35 organic chemicals**, covering a wide range of properties. Results showed a good agreement between the methods both for total characterization factors and for the intake fraction, with some significant discrepan-

cies on individual substances. Deviations could be explained by several significant issues among which were: (i) the hypothesis of a closed system in certain models, (ii) the importance of considering the intermittent character of rain events for substances partitioning into water, (iii) the estimation of half-lives in plants, (iv) the determination of the dilution volume per unit of area, and (v) of the colloidal organic matter in water.

In the following speech, JEROEN GUINÉE presented a similar **comparison of the same four LCIA methods applied to inorganic chemicals**, looking at the difference between models for inorganics compared to organics and at the source of variation between models. He brought evidence that the fate of metals and inorganic substances in air is quite different from that of organics', an important consideration for the substances. About 50% of the differences in current characterization factors are attributable to differences in the model equations and set-up of the models, the other 50% being due to differences in underlying substance and landscape property databases.

RALPH ROSENBAUM, in his second speech, presented the **OMNIITOX base model, an assessment framework entirely based on a matrix approach**, i.e. using a fate matrix, a human exposure matrix, and effect factor matrices. This has some significant advantages over other mathematical solutions, e.g. in updating or extending the model for new compartments, exposure pathways or effect types by simply adding rows or columns to the respective fate, exposure, and effect matrices. In terms of interpretation, these matrices provide additional insights that facilitate interpretation and improve transparency with clearly defined intermediate results independent from model dimensions such as the intake fraction – describing the fraction of an emission taken in by a population. This framework opens the way for the creation of a flexible and adaptive framework with libraries of processes and matrix factors of substance data and of landscape data. A key objective of the OMNIITOX project is to increase the coverage of substances included in LCIA by proposing simpler models, while maintaining scientific quality as well.

In order to provide LCA impact assessment characterization factors for a range of chemicals as broad as possible, STIG OLSEN proposed a **tiered approach with a hierarchical system of characterization models. A simple base model** (SBM) is derived from the more detailed base model (BM) using different statistical approaches by analytical pre-work, identifying key properties, and by ordinary or partial least square regression. Based on half life, toxicity and possibly Henry's law constant, promising preliminary correlations were obtained between SBM and BM, with correlation coefficients ranging from 0.7 to 0.9 for aquatic ecotoxicity and from 0.6 to 0.75 for human toxicity.

HENRIK LARSEN finished the first part of the special symposium by focusing his analysis on an **effect indicator for ecotoxicity**. He compared the statistical robustness of effect-based average approaches (arithmetic mean, geometric mean, and median) and the non-effect based approach (PNEC). Based on the current and the most likely future data availability as defined by the proposed EU chemicals policy REACH, Larsen suggested using the geometric mean trophic calculated as the geometric mean of three EC50 values: one from each of the three trophic levels, primary producers, primary consumers, and secondary consumers comprising three different taxa, i.e. algae, crustacean and fish. If more than three useable EC50s are available, then the geometric means within each trophic level are used as input data to the final calculation.

The second part of the symposium was opened by SVERKER MOLANDER elaborating on **availability of substance property data for use in the OMNIITOX models** and **data acquisition and data quality foundation in OMNIITOX**. Reviewing data theory in general, the speaker outlined the properties characteristic for the OMNIITOX data sets such as meta data and how those were implemented in the models. Focusing on data quality, three fundamental criteria (i) relevance, (ii) accessibility, and (iii) reliability were identified as being of crucial importance. The speaker stressed the fact that data on substance properties were available only at very different levels. An availability study revealed that for some substance property information was readily and on a high quality level available, whereas for others it was not. In particular measured data were much more easily available for chemo-physical properties than for ecotoxicological data. Based on these insights and to ensure a certain level of data quality, Molander proposed the implementation of a minimum requirement list for data acquisition and compilation. However, at the time of presentation that list was still under development. In the following discussion the option of data exchange with the REACH concept was addressed.

JOHAN TIVANDER gave an overview on **formalization of** the **OMNIITOX characterization model.** In particular he depicted the general content structure of the individual data sets used in OMNIITOX distinguishing between qualitative and quantitative information, and illustrated the way communication between the parties using the model takes place. Going into detail on the difficulties encountered commonly when it comes to data and thus to information exchange, Tivander outlined the theoretical considerations behind the data formalization applied in OMNIITOX. The methodology applied consists of concept modeling, the definition of common data formats and a data documentation format. One of the key tasks of the concept model is to allow for a common understanding of the information exchanged. The data documentation format ensures a standardized data presentation.

Describing the perspective of the industry, RANA PANT, with his presentation entitled **'New OMNIITOX characterization factors for aquatic ecotoxicity: what can we learn for detergent products'**, elaborated on differences in LCIA results when applying OMNIITOX Base Model characterization factors. Presenting a case study on the environmental impacts of different detergents, he stressed in particular the fact that differences in the outcomes were attributable to the different data sources having varying data quality as well as to the differences in the impact assessment methods themselves. As one of the key issues he addressed the question of the proper selection of time horizons when dealing with long term effects.

Finishing this special symposium, THOMAS MCKONE discussed the view of the external reviewers presenting **new developments in LCIA and risk assessment from OMNIITOX: summary of the external review of the base model.** Reflecting on general model theory aspects, he briefly reviewed the goals which were/are associated with the development of OMNIITOX. He then talked about the personal structure of the review team. This team was divided into three groups: fate/ exposure experts, ecotoxicology scientists, and other participants. The key tasks of the reviewers encompassed the assessment of the framework of the base model in general and the identification of improvement potentials. McKone highlighted as some of his key findings the fact that the base model needs to be accepted as a framework rather than a model. Assuming increasing availability of environmental data, he suggested the adoption of a tiered strategy with adaptive modeling. Concentrating on endpoints, the reviewers confirmed the interest of using the concentration at which 50% of the species are affected ($HC50_{EC50}$) instead of no observed effects concentration (NOEC) or most sensitive species.

The special symposium was finished by a thorough discussion dealing in particular with the future work to be done in OMNIITOX. It was recognized that OMNIITOX has reached a first profound basis and a very useful matrix framework, but that the framework has to be completed iteratively. It was agreed that the characterization factors should be tested, evaluated, and up-dated regularly to provide practitioners with sound data. During the discussion it became clear that OMNIITOX thus far is merely a theoretical framework and that its practical relevance and importance have to be communicated to practitioners in more detail. Critics from the practitioners' side also alluded to the fact that OMNIITOX does not seem to be applicable for regional and/ or local issues such as waste water treatment systems.

Interactive Poster Session: Uncertainty and Error Calculation in LCA
(Chairs: Marc-Andree Wolf and Bo Weidema)

Devoted to the issue of data and computation reliability within LCA, this session concentrated on approaches of uncertainty calculation to arrive at a reliable interpretation of modeling results.

THOMAS MCKONE presented a poster entitled '**Linking fate models and monitoring data to characterize the magnitude of uncertainties in emission data: polycyclic aromatic hydrocarbons in Minnesota as a case study'.** For the case of limited emission data on air emissions, he suggested to combine information based on air samples with models for estimating emissions data.

Elaborating on a **system to classify different sorts of uncertainty in different stages in the modeling process of LCA,** JOSÉ POTTING proposed adding an additional aspect of uncertainty, the so-called 'value-ladenness', to the aspects inexactness, unreliability and ignorance, which are usually addressed in uncertainty analysis.

ROLF FRISCHKNECHT explained the Pedigree-Matrix approach applied in the ecoinvent database and demonstrated that the **uncertainty assessment in ecoinvent is based on data quality indicators and basic uncertainty factors.** In order to calculate the uncertainty of the accumulated data sets, Monte-Carlo analysis was used.

MARK HUIJBREGTS dealt with the **human intake fraction of toxic pollutants** and showed **a model comparison between CalTOX and USES-LCA.** The author demonstrated that the uncertainties encountered were partly significant, but only depended on a few model parameters.

Presenting a poster entitled '**Uncertainty analysis in LCA: a case study on pesticides and implications for decision making',** GEORG GEISLER compared the uncertainties in the assessment of two different pesticide products. His results indicated that the uncertainty in the composition of sum parameters was responsible for the large dispersion of the scores of the toxic impact categories. Geisler concluded that those large dispersions apply to any case study. Presenting an additional poster, Geisler gave insights into **generic uncertainty factors for LCI flows.** Based on his case study results, he proposed different dispersion factors k, on the one hand for air emissions and resource demand (k=3), and on the other hand, for water, less accurate air emissions, and less accurate resource demand (k=10).

Applying statistical methods to LCI data of 200 waste solvent distillation processes, CHRISTIAN CAPELLO discussed the **uncertainty quantification in the life cycle inventory of industrial waste solvent distillation.** The central aim of the study was to provide data ranges including probability distributions for all LCI-parameters of each distillation process. Capello concluded that LCI distillation data can be estimated on the basis of his results in cases when no precise information on the process is available.

RALPH ROSENBAUM presented a poster on the **OMNIITOX uncertainty approach,** in which **model uncertainty and parameter uncertainty** are accounted for **separately.** He stated that environmental multimedia models, in general, do not account for model uncertainty. Thus, he suggested the implementation of an additional parameter taking into account the regression's standard error in Monte-Carlo analysis.

Finally, MARC-ANDREE WOLF elaborated on the **sensitivity analysis, the scenario calculation, and Monte-Carlo-Simulation of LCI.** Demonstrating the example of soybean cropping, Wolf stressed that Monte-Carlo analysis seems to be the best solution when dealing with uncertainty issues. This statement was in line with most of the other authors'.

References

Rebitzer G, Hunkeler D (2004): Towards a Code of Practice for Life Cycle Costing – Update on the Progress of the SETAC Life Cycle Costing Working Group. SETAC Globe 5 (2) May/June 2004

Rebitzer G, Seuring S (2003): Methodology and Application of Life Cycle Costing. Int J LCA 8 (2) 110–111

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).