

Conference Reports

Input-Output Life Cycle Assessment: From Theory to Applications

16th Discussion Forum on Life Cycle Assessment

Lausanne, April 10, 2002

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Input-output life cycle assessment (IO-LCA) was the central theme of the 16th LCA Discussion Forum, which featured four plenaries and four short presentations, as well as numerous lively discussions on this emerging approach. The goal of the conference was to elaborate the underlying principles and the background of input-output methodologies, as well as to explore the opportunities for applications either as a stand-alone approach or in combination with process LCA (P-LCA) according to ISO 14040 (1997). This successful event was complemented by a short course on IO-LCA on the following day, which allowed for practical exercises and hands-on application of the specific methodological procedures.

In the introduction, OLIVIER JOLLIET viewed the shortage of process data in life cycle inventory analysis (LCI) and the increased interests in assessing services, which are usually not accounted for in process LCA, as the main drivers for integrating input-output approaches into the LCA framework. IO-LCA allows for the usage of economic data, enabling one to define the system in a more complete way. However, compatibility in regards to geographical differences, as well as in regards to data on environmental interventions, has to be carefully addressed.

Plenary Sessions

In her presentation on **From Input-Output Tables to Modeling Environmental Issues**, GABRIELLE ANTILLE GAILLARD (University of Geneva, Switzerland) first explained the origins and framework of economic input-output analysis, the basis for IO-LCA, and then went on to present first approaches to use this approach for environmental considerations. The origins of economic input-output analysis go back to the 1920s, where Wassily Leontief, the later Nobel prize laureate, elaborated on the level of economic flows in regard to the demand of final consumption (Leontief 1936). It was Leontief himself, who, in the 1970s attempted to open this purely economic approach to environmental applications (Leontief 1970). This was done by the inclusion of pollution as a by-product of economic activity through a pollutant matrix representing the output of pollutants per unit of good produced by an industrial sector. Later, energy consumption was also included in these analyses that aimed at calculating

the external costs of the economy. Refined approaches were developed, including the SEEA (System of Integrated Environmental and Economic Accounting) developed by UNEP, as well as equilibrium models, which move from static to dynamic systems.

ANTILLE GAILLARD concluded that there are several powerful methodological approaches in the area of environmental assessment based on IO-tables, but that in many cases the availability and format of available data poses problems in practice. Also, issues such as consumer behavior, influence of governmental activities, and import and export of waste have not been addressed comprehensively to date.

GREGORY NORRIS (Harvard University and Sylvatica, USA) continued on the methodological background by discussing **strengths and weaknesses of IO-LCA and comparing it with process LCA**. He started with a review of the inventory phase of P-LCA and explained the difficulties in including all processes up to the initial resource extraction (cradle), caused, for example, by recursive processes. Another issue concerns the definition of the boundaries of a unit process, which can include one single technical process step, a complete manufacturing plant, or fully aggregated data (building blocks). Norris explained how the representation of a process based inventory in the form of a matrix solves the problem of recursions and loops within the system. Such a matrix structure is very similar to matrices of economic IO-tables, with the reference flow being equivalent to the final demand. IO-LCA, on the other hand, is based on national accounts representing supply and use of goods and services by the industry sector. Several classifications of sectors exist; therefore, IO-tables differ widely in scope and detail depending on the country. Issues of allocation and changes in demand (as in an effect oriented process LCA approach) can be addressed as well, although with a lesser level of specificity. If suitable pollution coefficient matrices are available (in some countries such as the US, The Netherlands, or Germany matrices on energy related emissions, greenhouse gases, or toxic emissions, etc. exist) calculation of IO-LCA results can be carried out with minimal effort. When comparing the approaches, Norris noted that IO-LCA and P-LCA are mathematically equivalent. P-LCA has its strengths in its specificity, allowing for detailed trade-off comparisons, e.g. in as-

sessing alternatives in design for environment (DfE). IO-LCA, on the other hand, has fewer limitations in regard to system boundaries and data availability. Therefore, P-LCA has to be used when specific options within one sector have to be assessed or compared, but IO-LCA offers opportunities for strategic policy decisions (comparing sectors) as well as in providing complementary data on sectors not easily covered by P-LCA.

TORSTEN MARHEINEKE (MMP Consultants, Germany) focused on **input-output tables as background inventory data for LCA**. Similar to NORRIS (see above) he explained the difficulties in establishing a product system whose boundaries are only crossed by elementary flows, as aimed for by ISO 14041 (1998). He discussed a procedure to solve this problem with a hybrid approach, meaning a combination of process and IO-LCA. He recommended the following steps: 1) establishment of the P-LCI system, 2) identifying processes and flows that are missing due to cut-off criteria or due to their nature (service flows, etc.), and 3) adding missing flows with input-output life cycle assessment. MARHEINEKE explained the German IO-tables and the corresponding, existing environmental tables on greenhouse gases, standard air pollutants, and energy use. In order to deal with different aggregation levels in the unit processes, he introduced the coefficient of net value, which should ensure a proper allocation of the economic sectors of the IO-tables. In a hybrid case study of a freight transport with a 40-ton truck (15 tons transported for 160 km), the share of emissions accounted for by the IO-part ranged between 8% for CO₂ and 40% for N₂O. The conclusion of this presentation was that – if IO-tables and the corresponding environmental data are available – the additional effort of a hybrid LCA compared to a pure process LCA can be minimal. However, the monetary value of the output of every process and the proper assignment of that output to the IO-table has to be available or determined.

Synergies between process and IO-LCA was also the topic of SANGWON SUH's (Leiden University, The Netherlands, see also pp. 134–140 in this edition) presentation on the **hybrid LCA approach**. He noted that there is a significant trade-off between process specificity, as can be reached by process LCA and completeness of the system, which is more easily achievable by IO-LCA. For instance, totally different inorganic chemicals would be treated identically by a sector producing 'inorganic chemicals' in the IO-approach. Therefore, the impacts of using different inorganic chemicals for one application would not be identifiable. He proposed to use process LCA as far as possible and only to add parts of the IO-LCA system that cannot otherwise be covered with a reasonable effort. He explained a systematic combination of IO-tables and P-LCA matrices, which allows not only for including flows going from the IO-system to the process system, but also vice versa. For such a combination, allocation methods of economic IO-analysis are applied which are methodologically equivalent to systems expansion or economic based allocation, thereby ensuring compatibility. Price adjustments (consumer vs. producer prices) also have to be

carried out. SUH illustrated his approach with a case study on linoleum flooring. For this case, the hybrid results were between 5% and 73% (average 18%) higher than those of P-LCA, depending on the impact category indicator. This study showed the value of the hybrid method, which allows for covering a more complete system without losing the required specificity. In addition, the mathematical representation in the form of a combined matrix seems to be very helpful in systemizing and further developing the hybrid LCI approach. To facilitate the application of hybrid LCAs, Leiden University has developed the Missing Inventory Estimation Tool (MIET), which is publicly available at www.leidenuniv.nl/cml/ssp/software/miet.

Short Presentations

In the first short presentation DAVID SHIPWORTH (University of Reading, UK) proposed a **new method for the stochastic modeling of embodied greenhouse gas emissions of materials**. This method integrates process LCI data progressively into probability distributions of embodied greenhouse gas emissions of industrial sectors and calculates the influence of these data on the distributions. The goal is to determine which carbon dioxide reductions can be achieved through preferential selection of low impact materials in the building sector. The probability distributions give an indication, where improvements tend to be either easier (wide distribution) or more difficult (narrow distribution) to achieve. Through environmental accounts in the UK, the potential overall impacts of replacing one material with another can be assessed. For the analysis Bayesian statistical techniques and Markov Chain Monte Carlo methods are employed. SHIPWORTH pointed out that this model, which is still under development, is aimed primarily at public policy in comparing effective mitigation strategies for greenhouse gases.

YVES LOERINCIK (Swiss Federal Institute of Technology Lausanne, Switzerland) **compared IO and process LCA methodologies with a case study on the computer network of the Swiss Federal Institute of Technology Lausanne**. This case was chosen to examine how input-output LCA could enable one to assess the impacts of very diffuse network infrastructures of telecommunication and of Internet applications such as e-commerce. Overall, the production and use phase of the personal computers and the computer monitors have the highest impacts in the system. For this case, the IO-LCA based on US data gives higher results than the P-LCA with European data, mainly in production of the hardware. Explanations for the differences are: variation in energy efficiencies in the US and Europe, price fluctuations, and importance of service sectors that are only accounted for in the IO-LCA. A first analysis based on total cost of ownership (TCO), where impacts have been derived based on cost/spending and related emission data, shows that computer maintenance/repair and network management represent a significant share of the environmental impacts. For the most relevant parts of the system, a hybrid LCA (see above) will be carried out in the near future.

A case study on photovoltaic (PV) power production using the hybrid LCA approach was presented by MORITZ NILL (Institute for Energy and Environment, Germany). For this study, the German IO-Table with 58 sectors and existing emission data, which were extrapolated to the year 2000, were employed. The PV system examined had a lifetime of 30 years, a power output of 5 kW, and 15% cell efficiency. Results of other hybrid studies leading to higher results compared to P-LCA were confirmed; here, calculated impacts were 25% to 85% greater. NILL analyzed the differences and found that the main sources are services and capital investments (machines, buildings). A sensitivity analysis revealed that the results of the hybrid LCA are very sensitive to the assumed price of the PV modules, but less sensitive to the assumed value-added in manufacturing.

TOURANE CORBIÈRE-NICOLLIÈRE (Swiss Federal Institute of Technology Lausanne, Switzerland) discussed the evaluation of sustainability at a communal level. The goal of her research activities is to develop a methodology that allows for assessing communal projects such as investments in certain industries in the context of Agenda 21 in a coherent manner. She explained an approach based on IO-tables with satellite accounts, which models economic exchanges between a region and the national economy. This was tested for the community of Vevey in Switzerland. CORBIÈRE-NICOLLIÈRE showed that such an analysis can give fast and efficient decision support for assessing the environmental and economic implications of a community project at a local and a global level, as well for estimating impacts on social factors such as employment influences.

Summary

This extremely inspiring Discussion Forum showed potentials and limitations of using data and methodologies from economic input-output analysis in environmental assessments. It has to be noted that components from IO-analysis

can offer advancements in LCA, mainly in capturing a more complete system. The specific benefit strongly depends on the application and goal of a study. Pure IO-LCA does not have the potential to replace process LCA, because only the later is capable of studying specific components or design options within a given industrial sector. Overall, the hybrid LCA approach seems to be very promising, though extensive, further research and case studies are necessary to improve and validate its application. On the one hand, significant progress in IO-data availability has to be made in the coming years, especially in Europe and emerging countries. On the other hand, IO-LCA tools are already available and should be applied systematically in conjunction with process LCA, at least to check that the most significant processes and sectors have been included in the system description and definition.

More material from this conference, including presentation files, is available in the new scientific Internet-Journal Gate to Environmental and Health Science (EHS) at <http://www.scientificjournals.com/ehs/globalvillage/welcome.htm>. The next conference (in German) in the Discussion Forum series will take place at the Swiss Federal Institute of Technology Zürich on 4 September 2002. It will focus on issues of studying the future in LCAs. More information can be obtained by contacting LCAforum@epfl.ch.

References

- ISO 14040 (1997): International Standard Organization: Life cycle assessment – Principles and framework, ISO 14040
- ISO 14041 (1998): International Standard Organization: Life cycle assessment – Goal and scope definition and life cycle inventory analysis, ISO 14041
- Leontief W (1936): Quantitative Input and Output Relations in the Economic System of the United States. *Review of Economic Statistics* 38 (3) 105–125
- Leontief W (1970): Environmental Repercussions and the Economic Structure – An Input-Output Approach. *The Review of Economics and Statistics* 52 (3) 261–271

Ph.D. Vacancy Announcement

Doctoral Assistant in Impact Assessment Modelling: The Life Cycle Systems Group (www.epfl.ch/lcsystems; headed by Prof. Olivier Jolliet) has the pleasure to announce an opening for a Ph.D. student focusing on chemical impact modelling in life cycle assessment (LCA). As part of a growing team and a cross-European collaboration, the successful applicant will help develop models to assess toxicological impacts to human health and ecosystems. The initial stages of this project, prior to developing a specific novel aspect, will include the comparison of

existing tools for modelling a chemical's fate in the environment, human exposure pathways, and potential toxicological effects. The emissions from five life cycle assessment case studies, from government and industrial partners, spanning a range of chemical types, will be taken into account. Please send a letter of motivation and a detailed resume to Dr. David Pennington, Building GR, GECOS, ENAC, EPFL, Lausanne CH1015, Switzerland. (tel. 021 693 3729, david.pennington@epfl.ch).