Chapter 3
LCA History

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Abstract The idea of LCA was conceived in the 1960s when environmental degradation and in particular the limited access to resources started becoming a concern. This chapter gives a brief summary of the history of LCA since then with a focus on the fields of methodological development, application, international harmonisation and standardisation, and dissemination. LCA had its early roots in packaging studies and focused mainly on energy use and a few emissions, spurring a largely un-coordinated method development in the US and Northern Europe. Studies were primarily done for companies, who used them internally and made little communication to stakeholders. After a silent period in the 1970s, the 1980s and 1990s saw an increase in methodological development and international collaboration and coordination in the scientific community and method development increasingly took place in universities. With the consolidation of the methodological basis, application of LCA widened to encompass a rapidly increasing range of products and systems with studies commissioned or performed by both industry and governments, and results were increasingly communicated through academic papers and industry and government reports. To this day, methodological development has continued, and increasing attention has been given to international scientific consensus building on central parts of the LCA methodology, and standardisation of LCA and related approaches.

Learning Objectives
After studying this chapter, the reader should be able to:

- Explain how LCA emerged and what characterised the early years of development.

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- Outline the history of LCA from the 1970s to the present in terms of methodological development, application, international harmonisation and standardisation and dissemination.

3.1 Introduction

Concerns over environmental pollution and energy and material scarcity have motivated the development of life-cycle-oriented approaches for environmental profiling of products. Life Cycle Assessment (LCA) has experienced a strong development both in methodology and applications since the first life-cycle-oriented methods were proposed in the 1960s. Today LCA is defined as "a tool to assess the potential environmental impacts and resources used throughout a product's life cycle, i.e. from raw material acquisition, via production and use stages, to waste management" (ISO 2006b). In this chapter, we present a brief account of the history of LCA in terms of methodological development, standardisation and regulation, application, and education and dissemination. Important elements of the history are summarised chronologically in Table 3.1.

3.2 Methodological Development

Life-cycle-oriented methods that were precursors of today's LCA were developed in the 1960s in collaboration between universities and industry. They were known as Resource and Environmental Profile Analysis (REPA) (Hunt et al. 1992) or Ecobalances until the term LCA became the norm in the 1990s. The method development initiated in the US and mainly took place there and in Northern Europe. Early methods could be characterised as material and energy accounting and were inspired by material flow accounting, as they were focused on inventorying energy and resource use (crude oil, steel, etc.), emissions and generation of solid waste, from each industrial process in the life cycle of product systems.

As inventories got more complex, the initial focus on accounting the physical flows in a product life cycle was gradually extended with a translation of the inventory results into environmental impact potentials. In other words, from a list of resource uses and emissions a set of indicator scores for an assessed product was calculated, representing contributions to a number of impacts categories, such as climate change, eutrophication and resource scarcity.

In the early years of the LCA history, environmental concerns addressed by the methods tended to shift with public concerns, and there was no consistency or harmonisation of the applied methods. In some years, the focus was on the generation of solid waste, which was considered problematic, especially in the US, where landfilling was the dominant waste management practice. In other years,

Table 3.1 Selected events in LCA history

Event	Year	Note
The (perhaps) first LCA-oriented study was presented on energy requirements for the production of chemical intermediates and products	1963	World Energy Conference, Harold Smith
Coca Cola commissions its first study comparing beverage containers	1969	Not public
The methodological foundation for environmentally extended input/output analysis is made	1970	Leontief (1970)
Publication of the first public and peer-reviewed LCA study "Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives", commissioned by the US EPA	1974	EPA (1974)
First impact assessment method based on critical volumes introduced	1984	BUS (1984)
The first widely used commercial LCA software, GaBi, was released in its first version	1989	Thinkstep (2016)
SimaPro, another widely used commercial LCA software, was released in its first version	1990	PRé (2016)
The term "life cycle assessment" was coined	1990	SETAC (1991)
Emergence of a number of LCI databases managed by different institutions	Early 1990s	
First environmental theme-oriented impact assessment methodology, CML92	1992	Heijungs et al. (1992)
SETAC Code of Practice published in effort to harmonise LCA framework, terminology and methodology	1993	SETAC (1993b)
The academic journal fully dedicated to LCA, The International Journal of Life Cycle Assessment, was born	1996	
ISO 14040 standard on LCA principles and framework released	1997	ISO 14040
ISO 14041 standard on goal and scope definition released	1998	ISO 14041
Damage-oriented methodology Eco-indicator 99 emerges	1999	Goedkoop and Spriensma (2000)
ISO 14042 standard on life cycle impact assessment released	2000	ISO 14042
ISO 14043 standard on life cycle interpretation released	2000	ISO 14043
UNEP/SETAC Life Cycle Initiative launched	2002	
The LCI database ecoinvent version 1.01 is released	2003	Ecoinvent (2016)
Establishing of a general methodological framework and guideless for LCA through ISO 14040 and ISO 14044	2006	
A framework for Life Cycle Sustainability Analysis was proposed	2008	Klöpffer (2008)
ILCD handbook published	2010	EC (2010)
PEF and OEF guidelines published	2012 and later	

when the price on oil was fluctuating or high, energy use was the focus of early studies. Public concerns also shifted with respect to emissions, which in some periods were deemed to be sufficiently controlled by regulation and voluntary measures by industry, but at other times considered very problematic. Early impact assessment methods tended to represent impacts from emissions in the form of dilution volumes of air or water needed to dilute the emissions to safe levels, or below regulatory thresholds [e.g. the Swiss Ecopoint method from the 1980s (Ahbe et al. 1990)].

During the 1990s many impact assessment methods evolved, and the ambition has since then been to quantify all relevant environmental impacts, independent of shifting public concerns, with the goal of avoiding burden shifting. The first impact assessment methodology to cover a comprehensive set of midpoint impact categories, as we know them today, was CML92 (Heijungs et al. 1992). It was released in 1992 by the Institute of Environmental Sciences at Leiden University in the Netherlands. The Swedish EPS method (Steen 1999a, b) looking at the damages caused took a different approach focusing on the damages to ecosystems and human health, rather than midpoint impacts, an approach that was followed by the Dutch Eco-indicator 99 methodology released in 1999 with a more science-based approach to the damage modelling (Goedkoop and Spriensma 2000). The early 1990s also saw the birth of a number of life cycle inventory databases managed by different institutes and organisations and covering different industrial sectors. Due to differences in data standards and quality, the resource uses and emissions of a single industrial process could, however, differ substantially in the different databases, but at this point in the development, the focus was on expanding the coverage and for many processes, there were no data at all. This situation was improved in 2003 with the release of the first ecoinvent database (v 1.01) covering all industrial sectors and aiming for consistent data standards and quality (ecoinvent 2016).

In parallel to this development in process-based LCA, a "top-down" approach was developed based on the work of the economist Wassily Leontief on input-output analysis of economies (Leontief 1970). This "top-down" approach to constructing an inventory is based on combining the national statistics of the trade between sectors with information on sector-specific environmental loads to arrive at an environmentally extended input/output analysis (EEIOA see more in Chap. 14).

Inherent in the discussion of LCI data was also a more fundamental difference in the perception of the product life cycle and LCA and its potential application. The attributional perspective aims to quantify the environmental impacts that can be attributed to the product system based on a mapping of the emission and resource flows that accompany the product as it moves through its life cycle, applying representative average data for all processes involved in the life cycle in a book keeping approach. The consequential perspective is concerned with the potential consequences of the decision based on the results of the LCA, and involves modelling of the broader economic system that the decision affects (see Sect. 8.5).

The modelling of increasingly complex product systems and the proliferation of LCI data and impact assessment methodologies created a need for dedicated LCA software and the first versions of both SimaPro and GaBi, two widely used software, were released around 1990 (Thinkstep 2016; PRé 2016).

In the twenty-first century, impact assessment methods have continuously been refined and several methodologies have emerged and are frequently being updated. The first impact assessment methods took into account the often large differences in the environmental hazards of the individual emissions. The realisation that there can be very large differences also in the sensitivity of the environment receiving the impacts lead to the release of the EDIP2003 method (Hauschild and Potting 2005) with spatially differentiated impact assessment methods covering non-global impacts like eutrophication and acidification. With the globalisation of production and an increased focus on biobased products in LCA, methods for impact assessment of extraction-related impacts like water use and land use have seen a lot of activity in the 2000s and 2010s. Hybrid LCA has emerged to reap the benefits of process-based and input/output based inventory analysis. Acknowledging that sustainability also has a social dimension, a growing activity has attempted to develop methods for Social LCA to quantify social impacts of product life cycles. A framework for life cycle sustainability assessment (LCSA) has emerged for performing assessments and aims to take into account an environmental, social and economic dimension of sustainability (see Chap. 5).

3.3 Application

Many of the early process-based LCA studies analysed packaging, which was a great consumer concern around the 1970s. For example, moulded pulp trays were compared to plastic trays and plastic bottles were compared to refillable glass bottles. Studies were typically commissioned by companies producing or using the packaging, such as Coca Cola in a pioneering study in 1969. Rather than disclosing studies directly to consumers, the results were mainly used for internal purposes, such as guiding reduction of life cycle impacts.

LCA also caught the interest of government early on. For example, the US EPA commissioned a large peer reviewed study, which was published in 1974, with the aim of informing regulation on packaging (US EPA 1974). However, at that time the EPA decided that using LCA as a direct regulatory tool was impractical, because it was thought to require LCAs to be carried out on thousands of products followed by extensive micro-managing of private businesses.

During the 1980s, life-cycle-related tools received little attention in North America, but in Europe, a revival started around the middle of the decade with an increased interest in the impacts of milk packaging that inspired a number of large LCA studies performed in different European countries. All studies compared alternative packaging systems for milk distribution to private consumers (Bundesamt für Umweltschutz 1984; Franke 1984; Lundholm and Sundström 1985;

Mekel and Huppes 1990; Pommer et al. 1991). A comparison of the studies shows that although they aimed to answer the same question (is returnable packaging or milk cartons preferable from an environmental and resource perspective?), and although they compared more or less the same packaging technologies, they reached very different conclusions. Rather than disqualify LCA as a serious decision support tool, these findings triggered an international collaboration among scientists and LCA practitioners from industry and consultancy on furthering LCA methodology development and harmonisation, as reflected in the strong international development work and standardisation in the 1990s. Concurrent with the fast methodological development of the 1990s the application of LCA expanded to include numerous other types of products during this decade as reflected in the proliferation of LCA-based ecolabels. The first LCA-supported Nordic Ecolabel was initiated in 1989 to guide consumers towards products with the lowest environmental impacts, and the number of product categories covered by criteria grew rapidly under this and other ecolabels like the European Flower label and the German Blaue Engel (see Chap. 24 on Eco-labelling and environmental product declarations). Several European countries launched national product-oriented environmental strategies with LCA as the methodological backbone, presaging the European Integrated Product Policy(IPP) to be adopted at EU level in 2003 with policy instruments like the aforementioned ecolabels, environmental product declarations, green public purchase and integration of environmental aspects into standards development.

After the turn of the century, product applications continued to grow in number and broaden in scope, also inspired by the increased political focus on LCA in EU and other parts of the world. LCA studies were increasingly used to analyse questions on the macro scale related to, for example, national energy systems and waste management systems. A 2006 survey of LCA practitioners found that LCA results were primarily used in business strategy, research and development and product or process design, but that education, policy development and labelling/product declarations were also frequent uses (Smith Cooper and Fava 2006). A similar survey from 2011 found that most practitioners made LCA studies in the agriculture (56%) and food sectors (62%), while practitioners working with other consumer goods (38%) and energy (37%) industries were somewhat less frequent (Teixeira and Pax 2011). The growth in the private sector's use of LCA in the period is reflected in Fig. 3.1 which shows the development in the total annual number of corporate responsibility reports mentioning LCA.

The year 2008 became an important year in the history of LCA for policy support, as the European Commission initiated its Sustainable Consumption and Production and Sustainable Industrial Policy (SCP/SIP) Action Plan, incorporating the previous IPP and waste and resource strategies and having LCA as the analytical backbone, but this time without the micromanagement regulation scope explored by the US EPA three decades earlier. The use of LCA in policy development is discussed in Chap. 18.

In 2009, The Sustainability Consortium was formed with the US retailer Walmart as a central partner with the mission to create a more sustainable consumer

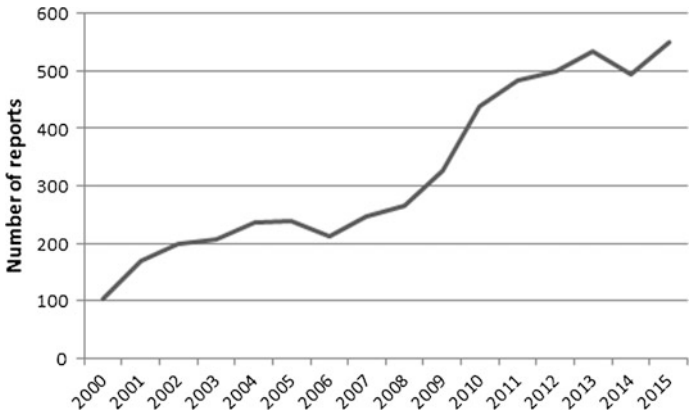

Fig. 3.1 Development in number of published corporate responsibility reports mentioning LCA ("Life cycle analysis" or "life cycle assessment") per year from 2000 to 2015. Based on a search in the PDF Search Tool of CorporateRegister (2016) carried out on April 25th, 2016

goods industry through the implementation of credible, transparent, and LCA-based reporting systems in the value chains of consumer products, targeting both environmental and social impacts. The activities of the sustainability consortium have the potential to strengthen the applicationof LCA further in the main regions supplying consumer products to the North American market, notably China and Southeast Asia.

3.4 International Harmonisation and Standardisation

With the awakening interest in LCA in the late 1980s, it soon became clear that there was a strong need for developing the methodology and harmonising the evolving methods to ensure consistency between studies.

3.4.1 Scientific Collaboration and Consensus Building

The global Society of Environmental Toxicology and Chemistry organised a workshop on "A Technical Framework for Life Cycle Assessment" in 1990 (SETAC 1991). This first event was followed by a series of workshops targeting central elements of the LCA methodology: in Leiden in the Netherlands (1991) (SETAC 1992), Sandestin Florida (SETAC 1993a) and Wintergreen (1992) (SETAC 1994) where central elements of LCA methodology were discussed with the aim of developing a common framework and agree on principles and research needs. The series culminated in a Code of Practice workshop held in Sesimbra,

Portugal, in 1993 leading to the development of the first official guidelines for LCA (SETAC 1993b)—a Code of practice for LCA. Through the rest of the 1990s SETAC working groups in Europe and North America further discussed the methodological elements with particular focus on inventory modelling and life cycle impact assessment, regularly publishing their recommendations in SETAC working group reports presenting the agreed state of the art and delivering recommendations for further research. The working groups helped coordinate the method development and strengthen the collaboration between the different research teams developing the LCA methods and they played an important role in the strong developments in LCA methodology through the 1990s. The work in these international fora was building on several important national and regional methodology development projects like the Nordic LCA Guideline project (Nordic Council of Ministers 1992; Lindfors et al. 1995), The Dutch LCA Handbook (Guinée et al. 2002) and the Danish EDIP project (Wenzel et al. 1997; Hauschild and Wenzel 1998)

In the late 1990s, leading researchers from the SETAC working group on life cycle impact assessment reached out to the United Nations Environmental Program (UNEP) to create a partnership to ensure further development of good LCA practice and global dissemination beyond Europe, North America and Japan, which had thus far been the main activity centres. The UNEP/SETAC Life Cycle Initiative was launched in 2002 and its changing working groups have taken over the method development activities of SETAC and increasingly focused on the dissemination of life cycle practices to the emerging economies through development of training materials and support with access to tools and data. The methodological recommendations have gained a more authoritative status with a formalised review procedure under the UNEP/SETAC Life Cycle Initiative.

3.4.2 International Standardisation

Taking off after the development of the SETAC code of practice for LCA in 1993, a formal standardisation process was initiated under the auspices of the International Organization of Standardization (ISO) to develop a global standard for LCA, building on the previous years' accomplishments in the scientific consensus building. The standard was to meet concerns from industry who increasingly wanted to use LCA for product development and marketing of greener products, but experienced that the lack of a standardised methodology meant that different studies of the same product could give opposite results depending on the concrete methodological choices. The standard development resulted in the adoption and release of four standards over the next seven years, addressing the principles and framework (ISO 14040), the goal and scope definition (ISO 14041), the life cycle impact assessment (ISO 14042) and the life cycle interpretation (ISO 14043). In a 2006 revision, the latter three were compiled in the ISO 14044 standard detailing the requirements and guidelines, without changing any requirements in the standards.

The ISO 14040 series standards concern the LCA methodology, but in the ISO 14000 series of Environmental Management standards, there are also standards and technical guidance reports on the applications of LCA for e.g. eco-design (ISO 14062, ISO 14006), communication of environmental performance (ISO 14020 series on ecolabels and ISO 14063), and greenhouse gas reporting and reduction (ISO 14064).

3.4.3 Standardisation of Methodology Beyond the ISO Standards: The European ILCD

LCA methodology was very young and rather immature while the ISO standardisation process took place in the 1990s, and the resulting standards are therefore not very detailed on specific methodological choices but rather focused on the framework and the fundamental principles of LCA. This is one of the reasons why the work of the UNEP/SETAC Life Cycle Initiative was needed to evaluate alternative practices and develop recommendations from a scientific point of view. It was also the background for a process initiated by the European Commissionin the mid-2000s to develop an International Life Cycle Data System (ILCD) with a database of life cycle inventory data and a series of methodological guidelines. With the development of the Integrated Product Policy and the action plan for Sustainable Consumption and Production, there was a need for a strong methodological basis of the LCA which was the method used for judging alternatives and communicating on the impacts of products and consumption. The ISO standards left too many possibilities for ambiguities in the applied methodology and in a consultation process, the EU Commission's Joint Research Centre's Institute for Environment and Sustainability developed a comprehensive guideline in LCA (EC-JRC 2010) that builds on the ISO 14040 and 14044 standards, and over 394 pages specifies the majority of the methodological choices that are left open by the ISO standards. Adherence to the ILCD guideline is intended to ensure more consistent and reproducible results of LCAs performed by different practitioners and hence increase comparability of LCA results from different studies. We have compiled the central provisions of the ILCD guideline as a Cookbook for LCA in Chap. 37 and the core methodological Chaps. (7–13) are inspired by and consistent with the ILCD guidelines. The ILCD work also involved a comparative analysis of all available LCIA methodologies (around 2008) comparing their approaches to assessment of the different midpoint and endpoint impact categories and identifying a recommendable practice for each impact category. The collection of best practices for each impact category was compiled as the ILCD impact assessment method (EC-JRC 2011). After the release of the ILCD guidelines in 2012, the EU Commission launched the Product Environmental Footprint (PEF) and Organisational Environmental Footprint (OEF) Guidelines as abbreviated and

slightly revised versions of the ILCD guidelines targeting different categories of products or services to be applied by companies and organisations reporting on their environmental performance.

3.5 Dissemination

Early studies commissioned by companies were often not published due to confidential information on industrial processes and the difficulty of communicating results in non-technical language. The first peer-reviewed LCA-like study was the packaging study commissioned by the US EPA (see Sect. 3.2) published in 1974. After the development of the ISO 14040 series standards on LCA, starting in 1997, it became a common practice for companies to publish peer-reviewed LCA reports to document environmental claims, although full disclosure of underlying data is still rare due to confidentiality issues. Academic journals have become an important medium for the dissemination of LCA studies, whether made to support decisions in, e.g. companies, or for research purposes. In 1996, the first academic journal fully dedicated to LCA was born, The International Journal of Life Cycle Assessment. This journal and other journals have seen a sharp increase in the number of published papers related to life cycle assessment, from less than 100 in 1998 to more than 1300 in 2013 as illustrated in Fig. 3.2, which indicates an exponential development of the number of publications in this period. The publication of LCA reports outside academic journals is difficult to map, but is likely to have seen a similar development as indicated by the increase in company use of LCA illustrated in Fig. 3.1.

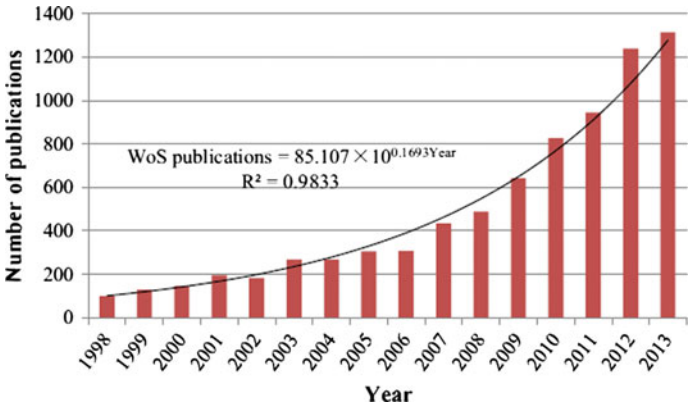

Fig. 3.2 Development in number of published LCA-related academic articles in English per year according to Web of Science (WoS) (Chen et al. 2014). The high R^2 value for the fitted exponential function indicates an exponential development. Reprinted with permission of Springer

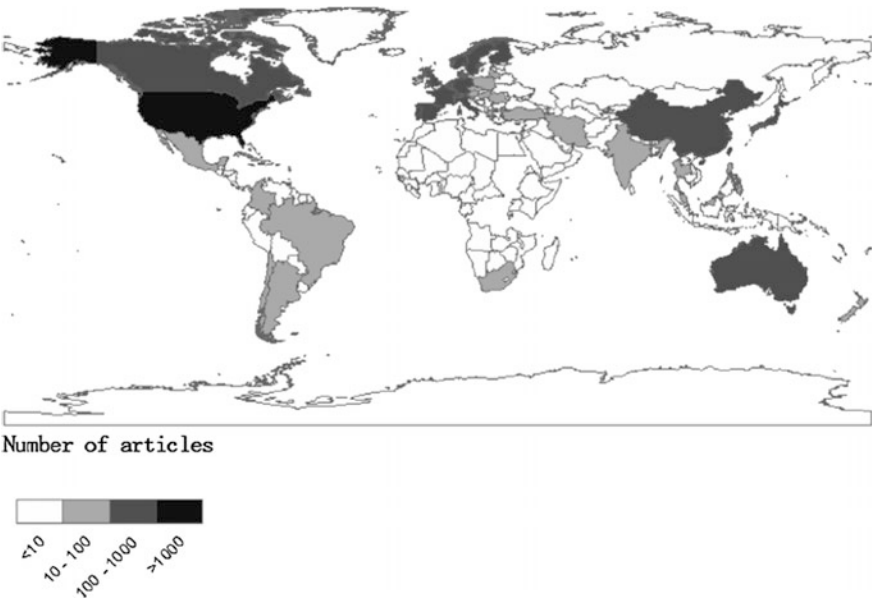

Fig. 3.3 Geographical distribution of articles published from 1998 to 2013 considering primary authors only (Hou et al. 2015). Reprinted with permission of Springer

Figure 3.3 shows that many of the English language LCA-related academic papers originate in the US and Europe, but that countries like Japan, China and South Korea have also had a noticeable publication activity. The limited activity on LCA in most emerging economies is clearly visible. Reasons for this are discussed in Chap. 19 on Globalisation and mainstreaming of LCA. Note, however, that LCA studies published in other languages than English are not included in Fig. 3.3, which therefore may lead to an underestimation of academic publications from emerging economies.

3.6 Concluding Remarks

LCA is a young discipline with 50 years of history and less than 30 years of intense development and application. Over the years, the methodology and applications have matured in the sense that scientific consensus and standards have emerged on how to perform LCA. The field has expanded in other ways when considering the number of publications, application domains and the geographical distribution of LCA competences. Table 3.1 summarises some of the important events in the history of LCA.

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Author Biographies

Anders Bjørn Part of the LCA community since the early 2010s. Main focus is interpretations of sustainability and integration of sustainability targets in LCA to enable absolute sustainability assessments.

Mikołaj Owsianiak Involved in development and application of life cycle impact assessment methods in sustainability assessment of technologies. Has worked on issues associated with: soils (remediation), metals (toxic impact assessment), biodiesel (fate in the environment), and carbonaceous materials (biochar and hydrochar).

Christine Molin Active in the field of LCA since 1992. Special interest in the development and dissemination of LCA and in the use of LCA in small and medium sized enterprises.

Michael Z. Hauschild Involved in development of LCIA methodology since the early 1990s. Has led several SETAC and UNEP/SETAC working groups and participated in the development of the ISO standards and the ILCD methodological guidelines. Main LCA interests are chemical impacts, spatial differentiation and science-based boundaries in LCIA.