Learning-by-doing: experience from 20 years of teaching LCA to future engineers

Purpose: In support of the sustainable development of our societies, future engineers should have elementary knowledge in sustainability assessment and use of life cycle assessment. Publications on pedagogical experience with teaching life cycle assessment (LCA) in high-level education are however scarce. Here, we describe and discuss 20 years of experience in teaching LCA at MSc level in an engineering university with the ambition to share our insights and inspire teaching of LCA as part of a university curriculum. Methods: We detail the design of an LCA course taught at the Technical University of Denmark since 1997. The course structure relies on (i) a structured combination of theoretical teaching, practical assignments and hands-on practice on LCA case studies, and (ii) the conduct of real-life LCA case studies in collaboration with companies or other organisations. Through the semester-long duration of the course, students from different engineering backgrounds perform full-fledged LCA studies in groups, passing through two iterations—a screening LCA supporting a more targeted LCA. Results and discussion: The course design, which relies on a learning-by-doing principle, is transparently described to inspire LCA teachers among the readers. Historical evolution and statistics about the course, including its 192 case studies run in collaboration with 105 companies and institutions, are analysed and serve as basis to discuss the benefits and challenges of its different components, such as the theory acquisition, the assignment work, the LCA software learning, the conduct of case studies, the merits of industrial collaborations and grading approaches. Conclusions: We demonstrate the win-win situation created by the setting of the course, in which the students are actively engaged and learn efficiently how to perform an LCA while the collaborating companies often get useful insights into their analysed case studies. The course can also be an eye opener for companies unfamiliar with LCA, who get introduced to life cycle thinking and the potential benefits of LCA. We have no hesitation in recommending industries and LCA teachers to engage into such collaborations even in the fundamental teaching of LCA techniques.
The chapter gives examples of applications of LCA by the central societal actors in government, industry and citizens, and discusses major motivations and challenges for the use of LCA to support science-based decision-making from their
respective perspectives. We highlight applications of LCA in policy formulation, implementation and evaluation, present different purposes of LCA application in industry at both product and corporate levels, and discuss challenges for LCA applications in small- and medium-sized enterprises. Our synthesis demonstrates the importance of LCA as a tool to quantify environmental impacts of products and systems and support decisions around production and consumption and highlights factors that prevent its even more widespread application.

LCA History
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.
Main Characteristics of LCA

Life cycle assessment (LCA) has a number of defining characteristics that enables it to address questions that no other assessment tools can address. This chapter begins by demonstrating how the use of LCA in the late 2000s led to a drastic shift in the dominant perception that biofuels were “green”, “sustainable” or “carbon neutral”, which led to a change in biofuel policies. This is followed by a grouping of the LCA characteristics into four headlines and an explanation of these: (1) takes a life cycle perspective, (2) covers a broad range of environmental issues, (3) is quantitative, (4) is based on science. From the insights of the LCA characteristics we then consider the strengths and limitations of LCA and end the chapter by listing 10 questions that LCA can answer and 3 that it cannot.

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How to consistently make your product, technology or system more environmentally-sustainable?

Human activities are currently unsustain able, causing many damages to ecosystems, human health and natural resources. In this setting, the development of new products and technologies has been increasingly required to relate to sustainability and ensure that such development goes hand-in-hand with low environmental impacts, low-carbon emissions, low environmental footprints or more sustainability as a whole. To enable a scientifically-sound and consistent documentation of such sustainable development, quantitative assessments of all environmental impacts are needed. Life cycle assessment (LCA) is recognized as the most holistic tool to address that need. LCA has two main strengths: (1) the ability to quantify all relevant environmental impacts – not just climate change, but also metal depletion, water use, toxicity exerted by pollutants on ecosystems and human health, etc.; and (2) making the assessment of the product/technology in a life cycle perspective, from the extraction of raw materials through production and use/operation of the product up to its final disposal. Fully embracing these 2 features enables to minimize the risk of burden-shifting, e.g. if impacts on climate change are being reduced while increasing other relevant environmental impacts or if impacts are shifted from the use stage of a product to the manufacturing stage as a result of a change in the product composition. Here, we provide a glimpse at how LCA can help for eco-design purposes, moving towards the use of low-impact materials, identifying environmental hotspots parts of the life cycle with largest environmental impacts), making prospective simulations through scenario analyses, comparing and selecting most environmentally-friendly product/technology alternatives, reporting on the environmental performances of the system. We rely on state-of-the-art science in the food sector, the aquaculture sector and the energy sector to showcase and illustrate the potential of LCA to undertake the environmental sustainability challenge and support product/technology/system development.

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**Mapping and characterization of LCA networks**

**Purpose:** The aims of this study were to provide an up-to-date overview of global, regional and local networks supporting life cycle thinking and to characterize them according to their structure and activities.

**Methods:** Following a tentative life cycle assessment (LCA) network definition, a mapping was performed based on (1) a literature search, (2) a web search and (3) an inquiry to stakeholders distributed via the two largest LCA fora. Networks were characterized based on responses from a survey.

**Results and discussion:** We identified 100 networks, of which 29 fulfilled all six criteria composing our tentative network definition (the remaining fulfilled four to five criteria). The networks are mainly located in Europe and the USA, whilst Africa, the Middle East and Central Asia are less covered regions. The survey results (from 25 network responses) indicate that LCA networks appear to be primarily small- to medium-sized (<100 members) and to include a large proportion of academia and industries, including small- and mediumsized enterprises, with much less involvement of authorities and non-governmental organisations. Their major activities relate to knowledge sharing and communication, support of case studies, and development of life cycle inventories and impact assessment methods. Networks in developing economies have different structures and activities than networks in developed economies and, for instance, more frequently have members from non-governmental organisations. Globally, an increasing trend in the formation of LCA networks over time is observed, which tends to correlate with the number of LCA scientific publications over the same time period. Continental distributions of networks also show a correlation with the number of LCA publications from the same region.

**Conclusions:** The provided list of LCA networks is currently the most comprehensive, publicly available mapping. We believe that the results of this mapping can serve as a basis for deciding where priorities should be set to increase the dissemination and development of LCA worldwide. In this aim, we also advocate the creation of an online, regularly updated database of LCA networks supplemented by an online platform that could facilitate network communication and knowledge sharing.

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Defining and mapping LCA networks: Initial results

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Mapping and characterization of LCA networks

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Engineering for Sustainable Development - An obligatory Skill of the Future Engineer
The LCE-seminar in Copenhagen 2003 succeeds a long line of LCE-seminars under the auspices of CIRP. The seminar proceedings 2003 comprises topics as Eco-design, Life Cycle Management, LCA-application, Integrated Product Policy, and software demonstrations. Within the topics there are keynotes from Delft University of Technology & Environmental Competence Centre, Philips Consumer Electronics (The Netherlands), from Aarhus School of Business, Department of Accounting and Auditing, (Denmark). From The Swedish Environmental Protection Agency, and from European Commission DG RTD- G2, Bruxelles (Belgium). Department of Manufacturing Engineering and Management hosted a mini-tutorial on Courses and Curricula in Sustainable Development and Environmental Management at the Technical University of Denmark. The proceedings comprise papers from universities and institutions in many countries and in a number, which fully substantiates the commitment and the engagement in the LCE- disciplines all over the industrialized world.
The NATO/Committee on the Challenges of Modern Society third Pilot Study meeting on Clean Products and Processes was held in Copenhagen, Denmark on May 7-12, 2000. This meeting maintained the momentum generated during the of the first two years of the pilot study, focusing on progress made on several pilot projects being implemented by participating nations and continuing to build a program of collaborative endeavors. This meeting featured a special topical seminar titled, Product Oriented Environmental Measures, which focused participants' attention on advances in product design and use. The meeting featured several guest lectures on significant developments in government programs, academic research and industrial applications. The report presents the ideas and views shared by the delegates and invited participants at the Copenhagen meeting. The full report can be viewed on the US EPA homepage.

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Project