The International Journal of Life Cycle Assessment
https://doi.org/10.1007/s11367-024-02319-5

LIFE CYCLE MANAGEMENT

Global state of the art of teaching life cycle assessment in higher education

Tobias Viere[1] · Joshua Lehmann[1] · Zoe Chunyu Miao[2] · Kevin Harding[3] · Philip Strothmann[4] · Steffi Weyand[2] · Laurie Wright[5] · Takunda Y. Chitaka[6] · Guido Sonnemann[6]

Received: 14 February 2024 / Accepted: 17 April 2024
© The Author(s) 2024

Abstract

Purpose Globally, there is an increased demand for education on life cycle assessment (LCA). In response, there has been an increase in course availability, but also a lack of clarity on the comprehensiveness of these offerings and the resulting student competencies.

Methods A global survey was conducted to obtain empirical evidence on teaching LCA. The survey explored the availability of LCA courses globally and the depth of the teaching, including expected core competencies and related teaching and learning workloads. A purposive sampling strategy was adopted wherein eligible participants were approached by the researchers.

Results and discussion According to the survey, annually, over 10,000 students participate in more than 200 LCA courses. The results reflected the interdisciplinary nature of LCA with courses being taught across different disciplines, including engineering, chemical sciences, and economics. Estimated workload demands for achieving different competency levels were significantly lower than those estimated by an expert panel before. This may be attributed in part to respondents not accounting for the full workload beyond classroom interactions. Nonetheless, workload demands increased with competency levels.

Conclusions and recommendations The results emphasize the need for a common understanding of LCA teaching with regard to content, literacy levels, and competencies to avoid false expectations of the labor and research markets in terms of available expertise. Therefore, LCA curriculum development and program planning remain significant challenges and essential tasks for the global LCA community.

Keywords LCA · Life cycle thinking · Learning objectives · Competency levels · LCA teaching

1 Introduction

In the rapidly growing global sustainability consulting market, which is projected to reach US$ 12 billion by 2028 at a compound annual growth rate of 5.2% (QYResearch Group 2023), the demand for life cycle information is increasing at an overwhelming rate. Consumers want reliable information to make informed sustainability decisions, while marketing campaigns are leveraging the environmental benefits of their products as key selling points. As a result, companies are using LCA results to inform their purchasing decisions. Additionally, legislation is evolving to require more and more environmental information from companies and organizations. The renewed urgency to use Life Cycle Management to solve the triple planetary crisis of climate change, environmental pollution, and biodiversity loss (UNEP 2020; Sonnemann and Margni 2015) is raising the demand for education on life cycle assessment

Communicated by Matthias Finkbeiner.

✉ Tobias Viere
tobias.viere@hs-pforzheim.de

[1] Institute for Industrial Ecology (INEC), Pforzheim University, Pforzheim, Germany

[2] Institute IWAR, Material Flow Management and Resource Economy, Technical University of Darmstadt, Darmstadt, Germany

[3] School of Chemical and Metallurgical Engineering, University of the Witwatersrand, Johannesburg, South Africa

[4] Forum for Sustainability Through Life Cycle Innovation (FSLCI), Berlin, Germany

[5] Warsash Maritime School, Solent University, Southampton, UK

[6] Université de Bordeaux, CNRS, Bordeaux INP, ISM, Bordeaux , France

Published online: 25 April 2024

(LCA) and to have experts that can contribute to producing and managing this information.

In line with an international increase in demand for life cycle professionals, an increasing number of courses are offered on Life Cycle Assessment and Management (LCA/LCM). While this is a positive development, these courses often differ substantially in terms of comprehensiveness, duration, learning objectives, and content. Thus, a huge variation exists between students' LCA literacy and experience, potentially resulting in a mismatch between employers' expectations and students' qualifications.

The purpose of the Education Working Group of the Forum for Sustainability through Life Cycle Innovation (FSLCI) is the promotion of education on life cycle assessment. A previous paper of this group (Viere et al. 2021) framed five LCA learning and competency levels that differed in terms of study program integration, workload, cognitive domain categories, learning outcomes, and envisioned professional skills. It furthermore provided insights into teaching approaches and content, including software use, related to these levels. In this way, that paper encouraged and supported higher educational bodies to implement a minimum of "life cycle literacy" into student curriculums across various domains by increasing the availability, visibility, and quality of their teaching on life cycle thinking and LCA. The paper has been accessed over 22,000 times since its release and has been reported to be one of the most downloaded of the International Journal of Life Cycle Assessment. This means that there is a huge interest in the topic. However, feedback received indicated that empirical evidence behind the paper is quite weak.

Therefore, as a follow-up to the paper, the idea was developed by the FSLCI Education Working Group to conduct a survey to broaden empirical evidence of teaching LCA in higher education. A questionnaire was created to firstly gather an overview on global LCA teaching and to secondly test the validity and applicability of the framework for state-of-the-art teaching and learning in LCA developed by Viere et al. (2021). The survey aimed to gather responses from individuals delivering LCA teaching and learning at higher education institutes.

This paper presents the findings of the empirical research, which includes more than 200 different LCA courses from all continents, and discusses lessons learned regarding the availability of LCA courses and the depth of knowledge being instructed at universities around the world. The methods followed for preparing the questionnaire carrying out the survey and evaluating its result are described in the next section. Thereafter, the results are presented and discussed, and we present the conclusions and recommendations of our paper. The questionnaire and two result tables are available as supplementary material.

2 Methods

As there is no universal and undisputable method of identifying academics delivering specific content, determining a definitive population from which to sample LCA teachers in higher education is impossible. This is compounded by the often fluid nature of academic disciplinary boundaries, for example, the traditional disciplinary "home" of LCA may be assumed to be applied science and engineering; however, the same content may be present in chemistry, design, and economic disciplines. A purposive sampling strategy was therefore employed to approach eligible participants representing a broad base of individuals delivering LCA content in higher education. This sampling method (also known as judgmental, selective, or subjective) provides a non-probabilistic sampling method relying on the judgment of the researchers when choosing members of the population to participate in the survey (Palinkas et al. 2015). Participants were invited to participate in the study where they were known by the researchers to be active in the teaching of LCA at an institute of higher education or where they were known as researchers and/or practitioners in the subject (e.g., through publication), and self-declared they were also actively involved in LCA education activity in a higher education institute.

The survey questions were selected in accordance with the research objectives, i.e., to test the validity and applicability of the framework for state-of-the-art teaching and learning in LCA. The questionnaire was composed of four parts (the complete survey is available as supplementary material):

1. Background questions
    - Participant eligibility questions. Participants who did not meet the criteria of being responsible for or participated in the delivery of LCA-related teaching and learning in a higher education establishment were excluded from the survey.
    - Contextual questions regarding individuals and their institutes, including location, institute size, teaching histories, and experiences.
2. Teaching audiences and challenges
    - Questions on subject disciplines, number of students attending, and course level
    - Questions on the perceived challenges in teaching LCA
3. Teaching resources
    - Most commonly used databases or software
    - Textbooks and standards used
4. Structure and content of teaching and learning

- Questions reflecting areas identified in the framework including topics and subjects covered, modes of delivery, respective workloads, and key resources deployed.

Questions were presented as follows:

- "Yes" and "no" scale, with additional "I do not know" or "other" answers. Respondents could choose only one answer to each question.
- Select one or more from a given list, reflecting categories established in the framework.
- Numerical replies. Respondents were asked to provide quantitative answers concerning, e.g., number of students or workload hours.

In addition, four questions were open-ended to enable participants to provide more details if necessary.

A pre-test was conducted in March–April of 2021, with participants drawn from the FSLCI webinar "Teaching LCA in Higher Education," where the framework was presented. Based on the analysis of data and feedback from participants, improvements in layout, language, and user-friendly instruction were implemented.

A list of academics to be invited for the survey was composed based on existing contact lists of academic members and contacts of the Forum for Sustainability through Life Cycle Innovation (FSLCI). In addition, academics that participated in conferences such as the one hosted by the American Centre for Life Cycle Assessment (ACLCA) or the 10th International Conference on Life Cycle Management (LCM 2021) were identified and added to the list together with known personal contacts of the researchers. Contacts were included if they were responsible for, or participated in, the delivery of LCA-related teaching and learning in a higher education establishment. The survey was also promoted at various LCA conferences such as the ones mentioned previously. Beyond these outreach strategies, the survey was further promoted through social media channels (LinkedIn/Twitter/Instagram) of the FSLCI as well as those of various national LCA networks and shared in dedicated LCA forums such as the LCA discussion list offered by PRé Sustainability.

The invitation to participate in the study contained a short description of the project and an invitation to complete the survey online. A short version was used for social media postings, with a link leading to the full invitation and project description. The online survey was made available through SoSci (https://www.soscisurvey.de), an online survey tool for safe data storage and reliable implementation. The survey was available from 02.09.2021 and closed on 31.12.2021 and complied with the General Data Protection Regulations (GDPR) 2008.

Based on the size of the various conferences, mailing lists, etc. where the questionnaire was disseminated, the authors estimate that the questionnaire reached at least a high four-digit number of addresses in the academic area of LCA. Four hundred twenty-seven questionnaires were returned, of which 216 were excluded due to incompleteness (vacant mandatory fields) and 6 due to failing plausibility checks concerning quantitative responses within the questionnaire. The remaining 205 datasets were split based on whether the respondents teach LCA themselves. Fifty-two of the datasets were provided by respondents who do not teach LCA but use LCA and/or have other lecturers at their institution teaching it. All remaining 153 datasets underwent a further plausibility check in which boxplots and minimum and maximum values were used to identify potential outliers. If datasets were considered plausible but individual data points were not, the specific data points were ignored during further data analysis. In one case, the whole dataset appeared to be implausible and was removed. The remaining 152 respondents who teach LCA themselves provided information on 202 different LCA courses, for each of which a course-based dataset was compiled.

Figure 1 depicts the data cleansing process from initial responses to final datasets.

3 Results and discussion

3.1 Respondents' background

The survey covers all continents, although most respondents work in Europe and in Germany in particular (cp. Fig. 2). On one side this reflects the fact that Europe has traditionally been a center of LCA research and academia, but on the other also indicates the non-representativeness of the survey in geographic terms. Compared to overall LCA research, for instance, Japan, the United States, and the People's Republic of China are likely underrepresented. About 18% (27 out of 152) of all respondents preferred not to disclose their country. As there is no universal and undisputable method of identifying academics delivering specific content, determining a definitive population from which to sample LCA teachers in higher education is impossible in any case. Given the large number of distribution channels and high distribution efforts, we nevertheless assume that the study provides a good reflection of reality. A comparison of the geographical distribution of this survey with a recent study on the geographical distribution of LCA research (Moutik et al. 2023) supports this assumption. The visualization of co-authorship countries in LCA publications from 1992 to 2022 (Fig. 6 in Moutik et al. 2023) illustrates the traditional "dominance" of Western European countries, the Anglo-American language area, and Japan, as well as the recently increased importance

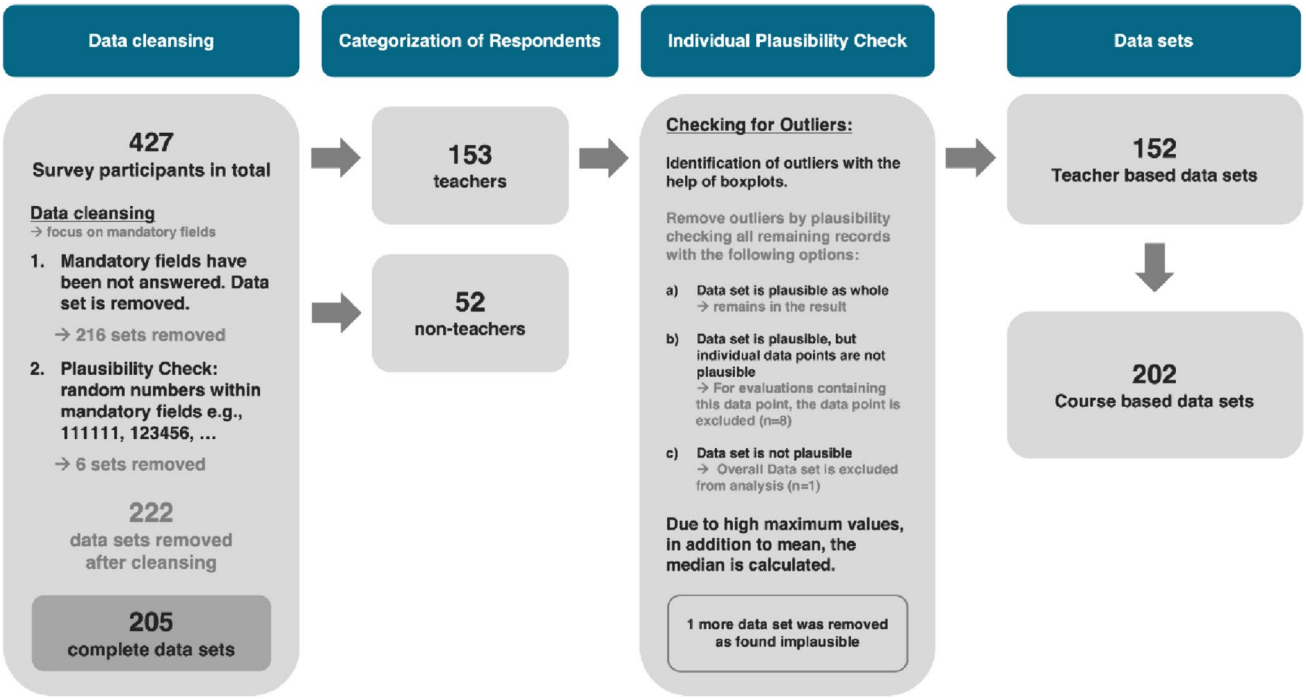

Fig. 1 Data cleansing approach

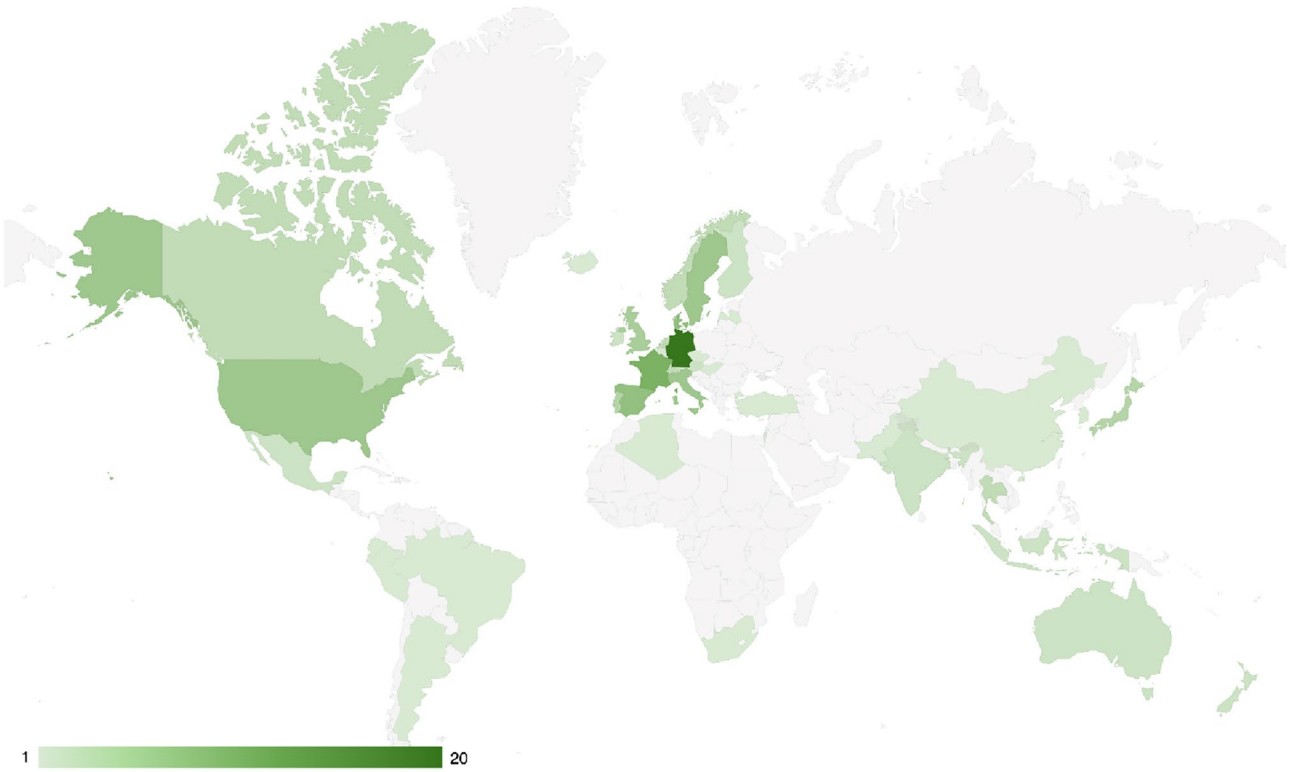

Fig. 2 Global coverage of the survey, number of respondents per country ($N = 152$ respondents)

of China in the field. Eastern European, African, Central and South American, and other Asian countries play a rather minor role in this evaluation of LCA research. Assuming that more research also means more teaching, the observations of Moutik et al. (2023) fit the geographical distribution of this survey. However, it should be noted that LCA teaching programs and LCA research publications are not necessarily related and the assumptions made above should be viewed with caution.

More than 90% of the respondents to the survey have LCA-related teaching experience of more than 2 years with about one-third teaching it for more than 10 years. Roughly half of the respondents are professors or senior researchers and lecturers, while less than 10% of all respondents teach LCA in addition to their work in industry and consulting (cp. Fig. 3).

3.2 Teaching audiences and challenges

According to the survey results, LCA teaching is predominantly an engineering subject. Sixty-four percent (219 of 350 answers) of all LCA courses' subject areas are engineering-based with chemical, process, and energy engineering accounting for 14% alone (50 of 350), while only 5% (19 of 350) relate to business and administrative studies (cp. Fig. 4).

These findings highlight the historic interlinkage of chemical and process engineering within LCA, and with organizations such as the Society of Environmental Toxicology and Chemistry (SETAC), large chemical companies, and physical chemistry experts like Walter Klöpffer, the founding editor of the International Journal of LCA, as early movers in that field. Overall, engineering dominates the subject

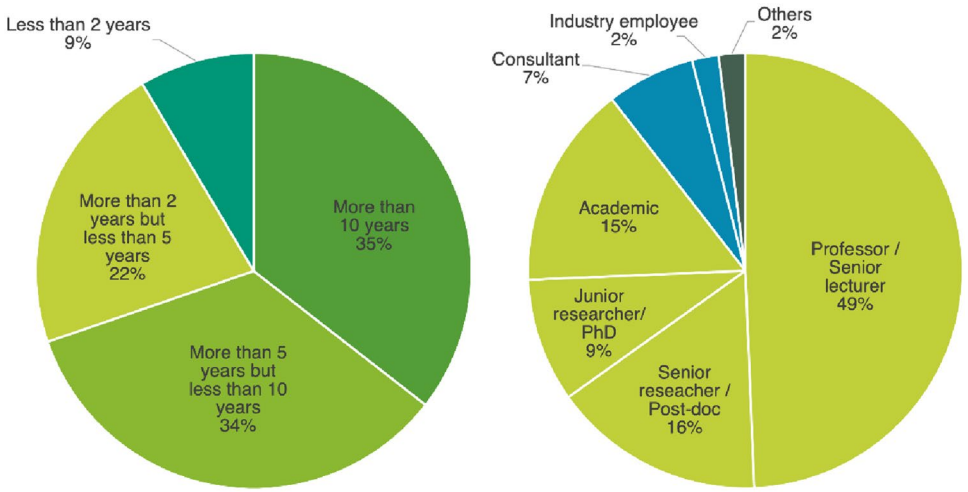

Fig. 3 Teaching experience (left) and work status of LCA teaching respondents (right, $N = 152$)

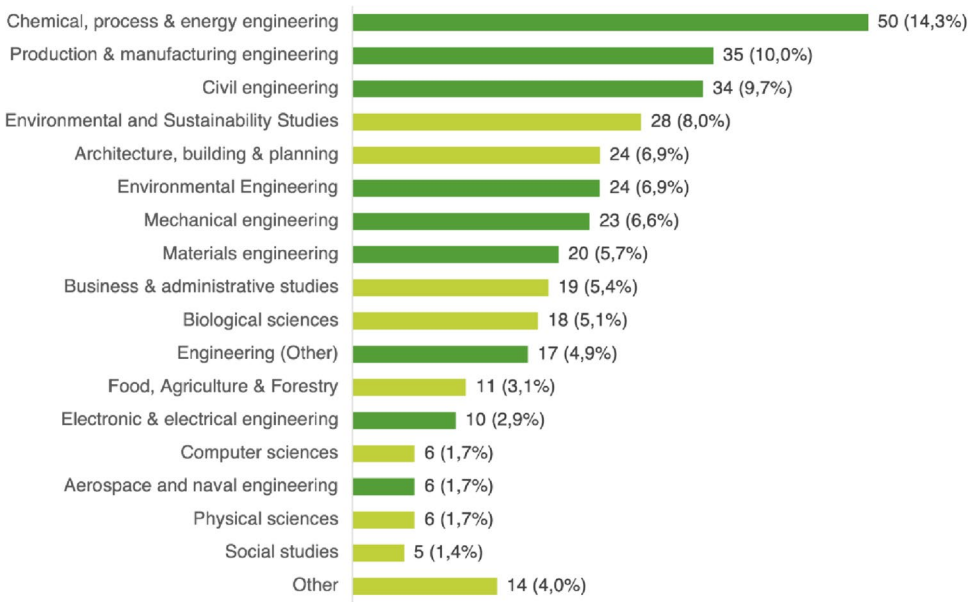

Fig. 4 Subject areas LCA is taught within (a total number of 152 respondents mentioned 350 subject areas, engineering subjects in darker color)

areas LCA is taught within. According to the authors' observations, engineering and environmental and natural sciences are dominant disciplines at many LCA conferences and networks, so the result is not unexpected. In contrast, given the large number of business degree programs at all types of universities globally, their weak representation is surprising. This points to a possible need for further development in the teaching of LCA to address future managers and decision-makers.

According to Table 1, each year about 11,500 students participate in LCA courses included in this survey; this equals an average course size of 57 students per course and year. Almost 50% of all students in LCA courses are at postgraduate or PhD level, while only 24% are undergraduates. Another 27% studies LCA at courses which are open to all academic degrees (cp. Table 1). The average course size (median value) is 30 students for postgraduate and PhD levels, 40 students for undergraduate levels, and 53 for open formats. The average number of students per course is significantly higher when considering the mean instead of the median value. This can be explained by few very large courses with several hundred students while most courses are considerably smaller and closer to the median value.

The pre-test to this survey (see Section 2) was used to compile a list of challenges associated with teaching LCA to be included in the main survey. The interdisciplinary nature of LCA and its interdisciplinary audience (Fig. 4) appear to be essential challenges for LCA teaching. More than one-third of all respondents highlighted their challenges as "Teaching LCA to an audience with diverse backgrounds" (39%) and "Keeping students motivated despite the complexity and challenges of LCA and balancing expectations" (35%). The citing of such challenges is unsurprising as the teaching of sustainability-related subjects was found to be a challenging endeavor by Anastasiadis et al. (2021). Further, other studies have found that students find learning in an interdisciplinary environment to be challenging (Spelt et al. 2009; Self et al. 2019).

More specific to LCA, more than a fifth of all respondents consider the following challenges to be important: "Explaining and using LCI databases" (27%), "Teaching how to use and communicate LCA results" (24%), "Coaching and supervising students' LCA applications" (24%), "Teaching the limitations of LCA" (23%), "Teaching how to integrate LCA with other methods and approaches" (20%), and "Having to come up with different application case studies each semester" (20%). Many of these challenges point to the need for greater guidance in teaching LCA and communicating the nuances.

3.3 Teaching resources

Teaching LCA makes use of textbooks, online resources, standards and guidelines, software, databases, and other material. The survey reveals which types of teaching resources are used most frequently and could therefore provide some orientation for academics that are starting their own LCA courses and teachings.

Almost two-thirds of all respondents make use of the core ISO standards on LCA, ISO 14040 (ISO 2006b) and 14044 (ISO 2006c). This underlines the constitutional character of these standards. The textbook by Hauschild et al. (2018) is used by 28% of the respondents followed by textbooks by Klöpffer and Grahl (2016, 18%), Jolliet et al. (2015, 16%), and the classic "Hitch Hiker's Guide to LCA" (Baumann and Tillman 2004, 15%). About 20% of the respondents make use of UNEP's online teaching resources followed by 19% integrating the online textbook by Matthews et al. (2020) (Fig. 5).

Almost 75% of all respondents make use of the ecoinvent database, followed by the ELCD database (which has not continued since 2018) with 21% and the GaBi databases (18%). Most frequently used software solutions are MS Excel, SimaPro (both 40%), and OpenLCA (34%). Lower numbers of respondents use GaBi (16%), Umberto (7%), Brightway (5%), and Easetech (3%) (Fig. 6). Asked for their rationales for using particular software and database solutions, 80% of the respondents named functionality as a key criterion, followed by accessibility (68%), cost (66%), availability (66%), an already available license (63%), familiarity (60%), performance (51%), and other criteria (21%).

Table 1 Distribution of academic levels, number of courses, and attending students within the survey ($N = 202$ courses; 2 courses excluded for implausibility reasons)

Academic level	Number of courses	Students per year (sum)	Students per year (mean)	Students per year (median)	% of total students
Undergraduate	45	2739	62	40	24%
Postgraduate	113	5247	47	30	46%
PhD	10	426	43	30	4%
Open to all levels	34	3096	91	53	27%
Total	**202**	**11,508**	**57**	**30**	**100%**

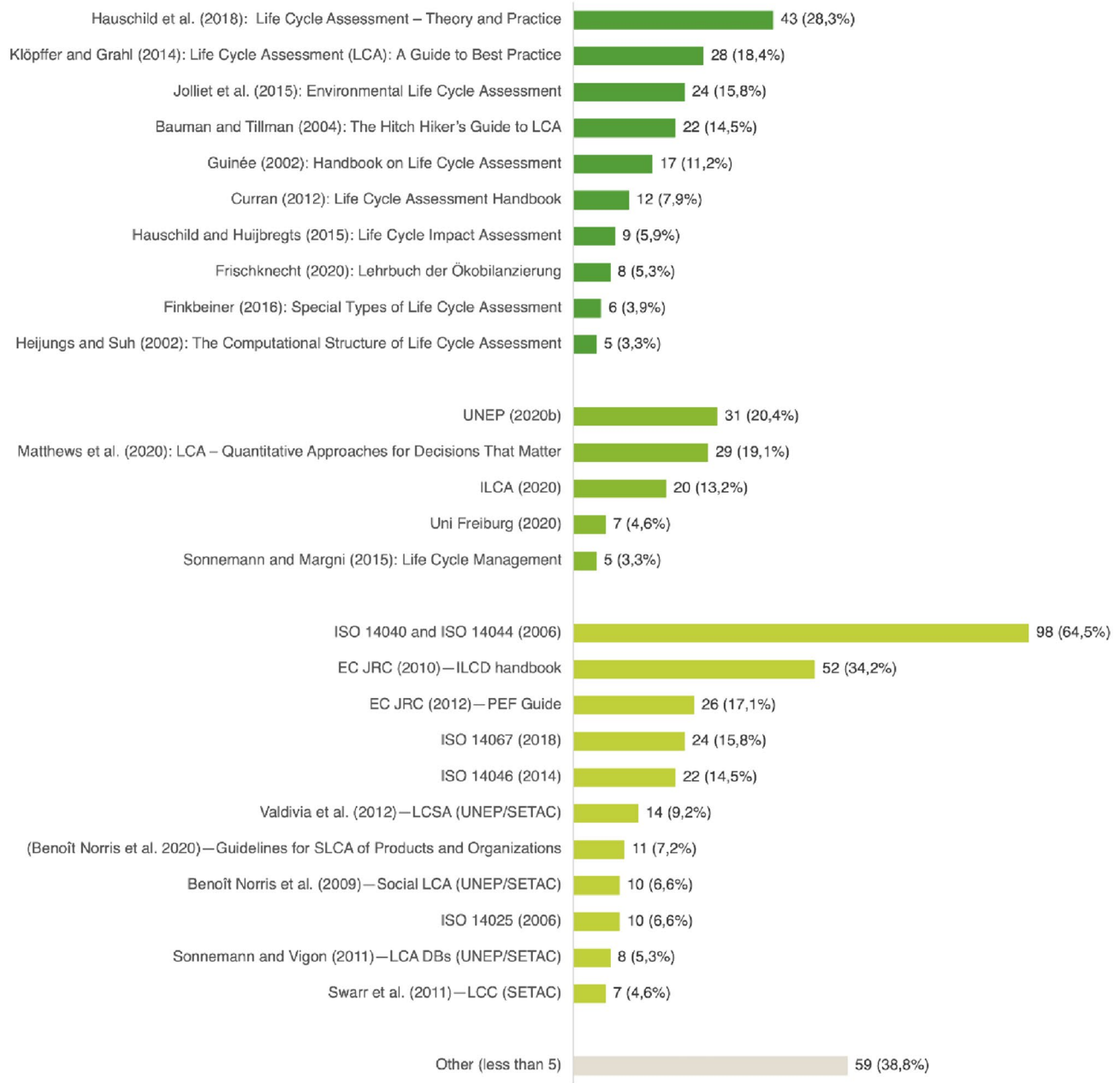

Fig. 5 Teaching resources, grouped into textbooks (dark coloration), online material (medium coloration), and standards/guidelines (light coloration) ($N = 152$ respondents, multiple answers possible)

3.4 LCA competency levels and teaching workloads

Viere et al. (2021) distinguished five LCA competency levels. The learning outcomes at each level are described as follows (p. 519):

- LCA competency level 1: "comprehension of the basic concept of life cycle thinking, its relevance and use in different contexts; awareness of standardized methodologies"
- LCA competency level 2: "comprehension of LCA methodology and essentials of LCA studies; application of specific methodological steps of LCA"
- LCA competency level 3: "design and partial performance of a full-fledged LCA study, incl. analyzing and evaluating the validity of specific steps, the quality and reliability"
- LCA competency level 4: "full performance of LCA studies with possibility to apply and implement specific method development"

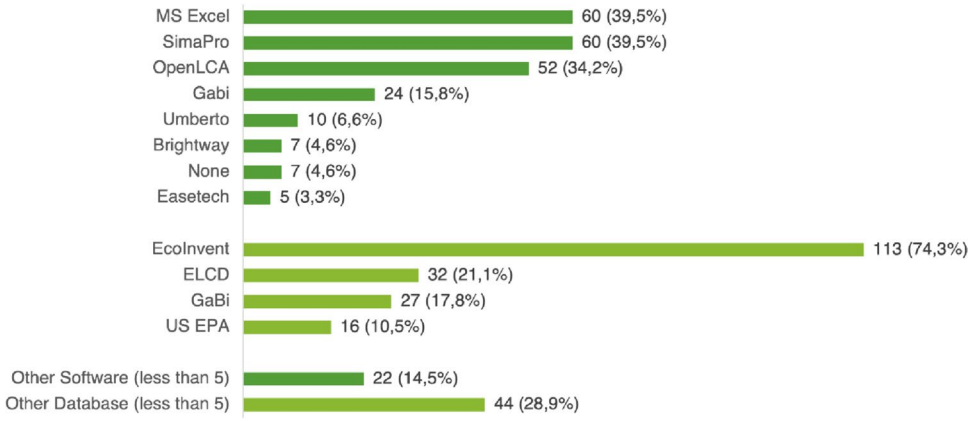

Fig. 6 Software and databases used in LCA teaching ($N = 152$; multiple answers possible; software in dark coloration, databases in light coloration)

- LCA competency level 5: "advancement of LCA methods and development of LCA method extensions on specific aspects of the LCA methodology (inventory, impact assessment, etc.)"

Although the survey overall confirms this LCA learning and competency framework developed by Viere et al. (2021), the respondents associate different workloads to the competency levels. According to the expert panel judgment, competency level 1 demands 30 h of work while level 2 already reaches 176 h (cp. Table 6 in Viere et al. 2021). Consequently, different competency levels require different levels of LCA integration into the respective degree programs. According to this survey, the vast majority of LCA courses (75%) are either single lectures or short lecture series as part of a wider unit or module or standalone modules (Fig. 7). LCA courses offered as a minor, major, or research specialization are a less frequent integration approach within the different degree programs (23.2%). For single lectures or short lecture series, one can assume a workload falling into competency levels 1 and 2.

This assumption can be compared to respondents' answers on the intended LCA competency level at the end of their course. Figure 8 depicts the intended LCA competency level against the respective study program degree and against the integration within the study program (i.e., standalone module, minor specialization). About three-fourths of all undergraduate LCA courses intend level one or two, while at postgraduate courses level two and three are most frequent. At PhD level, the more research-oriented level five and level three dominate. Courses which are open to all academic degrees feature a roughly similar distribution of competency levels as postgraduate courses.

Overall, the survey results confirm the previous assumption that single modules and single lectures are aimed at competence levels 1 and 2, i.e., they primarily want to create awareness for LCA, but do not assume that the students will already be able to carry out LCA studies independently or analyze them comprehensively at the end. At the same time, the relatively high number of responses is surprising, suggesting that levels 3 or even 4 can be achieved even with single lectures or standalone modules given that these competencies comprise the design and partial performance of

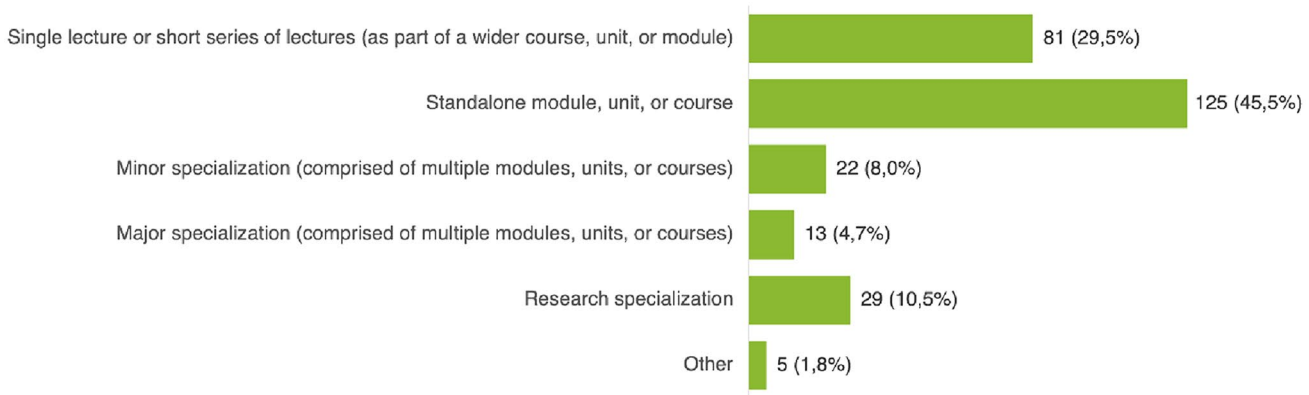

Fig. 7 Type of LCA course integration into study program (multiple answers possible)

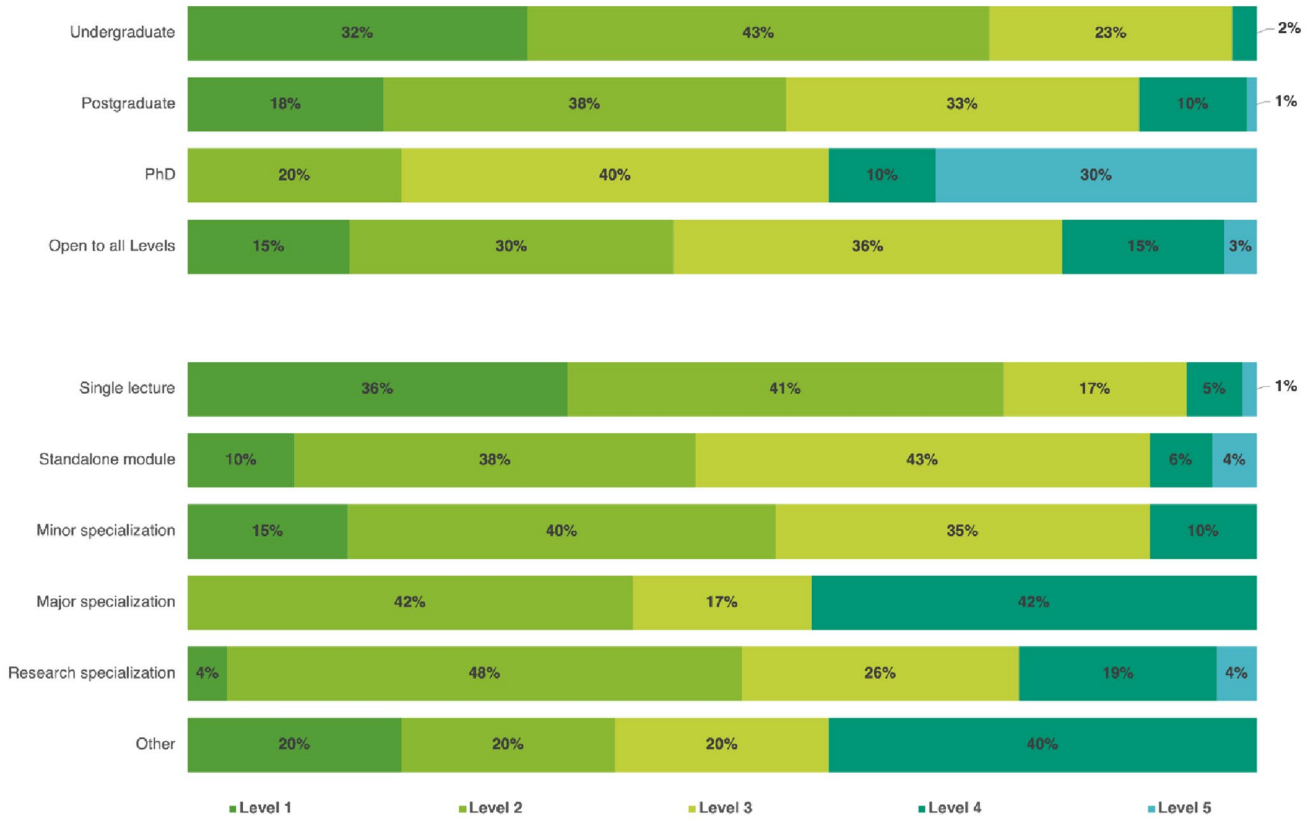

Fig. 8 Intended LCA competency levels depending on academic degree level and program integration level ($N = 196$)

a full-fledged LCA study and the full performance of LCA studies, respectively. One interpretation of these results is the assumption that LCA teachers themselves are not always aware of the complexity of conducting a comprehensive LCA study and therefore partially overestimate the competencies of their students and possibly also their own.

Figure 9 illustrates the discrepancy in the perception of the expert panels from Viere et al. (2021) on the one hand and the survey respondents on the other with regard to the workload to achieve the different competence levels. Overall, the experts assume almost double (level 1) to almost seven times (level 4) the workload.

What the estimates from Viere et al. (2021) and the answers from LCA teachers have in common is a clear increase in the necessary workload from competency level to competency level.

One possible source of error in the survey is the interpretation of the time data for the workload. It was pointed out

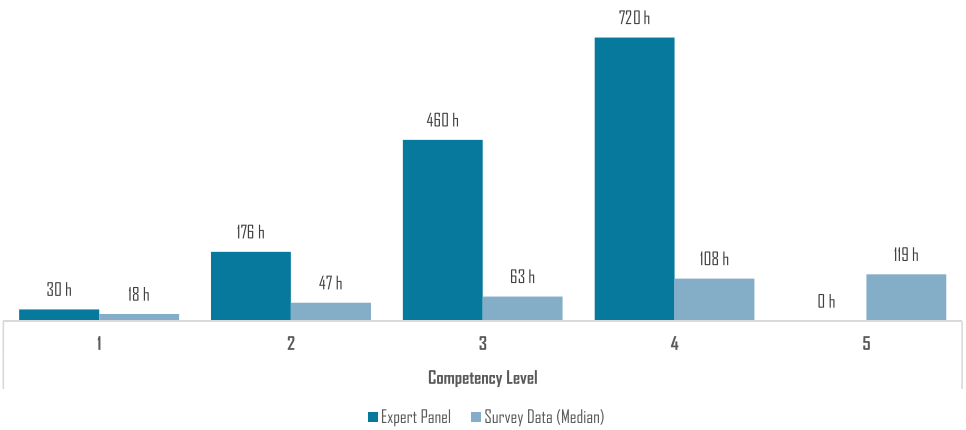

Fig. 9 Workload in hours per competency level (expert panel judgment as stated in Viere et al. (2021); survey $N = 202$; no workload provided for level 5 by expert panel)

that the total workload was asked for, but some comments to the survey suggest that individual respondents indicated the time in the course room and not the total workload. Accordingly, one could interpret the respondents' results and the expert panel results as lower and upper limit of the workload range for the respective competency levels.

Table 2 differentiates the workload further according to individual subject areas of LCA teaching and illustrates the consistently higher workload estimates of the expert panels in comparison to the survey. Overall, the highest differences were observed for competency levels three and four.

Table 2 Workloads in hours—survey results compared to expert panel judgment as stated in Viere et al. (2021) (teaching content details as explained in survey and expert panel): (1) includes basic understanding of environmental impacts and wider context of LCA, e.g., SDGs, resource efficiency, circular economy, environmental management, eco-design, life cycle thinking (holistic understanding of value chains/product systems), purposes and use cases of LCA, trade-offs or burden shifting across life cycles and impacts; (2) includes ISO 14040/44 framework (life cycle phases and process according to ISO), LCA terminology (functional unit, system boundaries, etc.), and goal and scope—definition; (3) includes life cycle inventory (LCI) modeling (fore- and background) and data and multifunctional systems (system expansion, etc.); (4) includes life cycle impact assessment (LCIA), environmental impact assessment methods in particular; (6) includes decision context of LCA (attributional, consequential, etc.), mathematical foundation of LCA, integration of LCA with theories (e.g., micro-economics, behavioral science), and system-analytical tools (material flow analysis, etc.); (7) includes carbon footprints, water footprints, product and organizational environmental footprints, life cycle sustainability assessments, and further special types of LCA; (8) includes use of LCA results for innovation and communication; (9) includes interpretation and reproduction of a given case study and review/meta-analysis of LCA cases; (10) includes data collection and preparation, and own conduct of a case study; (11) includes the use and application of spreadsheets (e.g., Excel) and basic LCA software exercises; (12) includes the use and application of more comprehensive LCA software solutions, sometimes incl. scripting/programming and advanced process modeling; (13) includes exercises in and comparison of LCI databases and/or LCIA methods

LCA teaching content	Workload according to	LCA competency level				
		1	2	3	4	5
(1) Life cycle thinking and LCA context	Survey	1,5	4	3	4	10
	Expert panel	14	30	40	40	n.a
(2) LCA terminology and standards	Survey	1	2	3	3	10
	Expert panel	8	18	24	24	n.a
(2) LCI modeling and data	Survey	1	4	6	8	15
	Expert panel	n.a	18	30	40	n.a
(4) LCIA	Survey	1	4	4	3	10
	Expert panel	n.a	8	16	32	n.a
(5) Interpretation incl. sensitivity and uncertainty	Survey	1	2	4	5	15
	Expert panel	n.a	8	30	44	n.a
(6) Advanced LCA methodology	Survey	0.5	1	2.5	2.5	8.5
	Expert panel	n.a	4	28	52	n.a
(7) Special types of LCA	Survey	1	2	1	2	10
	Expert Panel	n.a	8	16	36	n.a
(8) Life Cycle Management	Survey	1	1	2	3	5
	Expert panel	n.a	16	26	52	n.a
(9) Case study/project work—interpreting given cases	Survey	2	3	3	3	5
	Expert panel	4	24	n.a	40	n.a
(10) Case study/project work—conducting own case studies	Survey	4,5	12	18	35	10
	Expert panel	n.a	30	200	220	n.a
(11) Software use—Excel and simplified approaches	Survey	2	2	2	2.5	0
	Expert panel	4	n.a	n.a	n.a	n.a
(12) Software use—comprehensive LCA software package	Survey	0.5	6	10	32	10
	Expert panel	n.a	12	40	120	n.a
(13) Software use—LCI databases	Survey	0.8	3.5	4	5	10
	Expert panel	n.a	n.a	10	20	n.a
Total workload in h [survey]		17.8	46.5	62.5	108	118.5
Total workload in h [expert panel]		30	176	460	720	n.a

4 Conclusions and perspectives

A survey was carried out to understand the global state of the art of teaching LCA in the world. The survey investigated the offer of LCA courses and the type of the teaching provided, including the expected core competencies and related workloads. At minimum, LCA teaching now reaches over 10,000 students annually in more than 200 courses across a huge variety of subjects and disciplines and at all levels of higher education from bachelor to PhD. The outcomes of our survey, featuring its notable emphasis from the European contexts, yield an insightful overview about the global LCA teaching condition. Often LCA is only integrated to a small extent into existing programs and courses and is offered much less frequently as a specialization or major. The interdisciplinary nature of LCA was highlighted by the survey with reported disciplines including engineering, chemical sciences, economics, and social sciences. While this increases the accessibility of LCA, it also presents a challenge to those teaching it, particularly given that LCA courses are frequently part of higher education curricula, attended by students with foundational knowledges and pre-established viewpoints in certain fields. Additionally, the choice of teaching aids, including reference books, software, and databases, has exhibited a notable variation. Thus, expertise is not only required in LCA but in teaching in interdisciplinary spaces which not all educators may have.

The survey confirms the LCA learning and competency framework developed by Viere et al. (2021). However, regarding the conceptual expectations of teaching and learning efforts required to achieve different competency levels, significant differences were observed between reported workloads and those estimated by experts. Despite the majority of the respondents having over 5 years of teaching experience, this disparity aforementioned indicates the need for a more common understanding of the requirements of each competency level including the teaching and learning expectations.

The study underlines the need for a common understanding of LCA teaching contents and graduates' LCA competencies and literacy levels, among other things, to avoid false expectations of the labor and research market on the one hand and of graduates on the other. This points to the need for greater guidance for teaching LCA and evaluating the competencies of students, for improved harmonization of expectation, and potentially to future external certification of LCA programs and graduates to ensure consistency of outcomes.

That means that LCA teaching now reaches many students in different subjects and disciplines around the world. However, we also observe certain blank areas, partly also due to the non-representativeness of our survey in certain countries. There is a clear need for outreach through organizations like FSLCI, the World Resource Forum, and the UNEP hosted Life Cycle Initiative that has started activities in Africa and the Middle East.

The fact that we have different disciplines in which to develop LCA teaching due to the interdisciplinary character of LCA is a major challenge. The FSLCI Working Group on Higher Education in LCA aims to continue to work on addressing this challenge with a stronger focus on curricula development considering the interdisciplinarity of LCA and aiming at an increased collaboration also with business schools. Developing an open curriculum for universities to base their courses on could also support a harmonization of the way LCA is being taught around the world and allow for an easier categorization of expected learning outcomes and competencies, in line with our framework. Such alignment could in turn benefit students as well as prospective employers, as they would be able to better understand which universities and courses equip their students with which level of LCA literacy.

As a further step, a potential certification scheme for LCA professionals could be envisioned which would allow students to showcase and prove their acquired knowledge and skills vis-à-vis their prospective employers. This in turn would help employers to easier identify suitable candidates to address the current demand for well-equipped LCA professionals. This demand will only continue to rise as in Europe, for example, the Green New Deal is further driving the need for LCA professionals through legislative efforts such as the new Ecodesign for Sustainable Products Regulation (ESPR) or the Corporate Sustainability Reporting Directive (CSRD).

In conclusion, our paper demonstrates that LCA-related curriculum development and program planning remain significant challenges but also essential tasks for the global LCA community in order to mainstream LCA teaching in higher education around the world. To ensure common understanding and provision of the appropriate skills in the workforce, systematic and harmonized curriculum development and implementation tailor-made for different specialties potentially with the development of recognized associated professional certification by governmental agencies are needed to respond to this growing demand.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11367-024-02319-5.

Acknowledgements The authors would like to thank the respondents from teaching institutions all over the world. Throughout the process of designing and executing the survey, the authors received valuable and supportive advice by many colleagues, including, inter alia, Ben Amor, Alexis Laurent, Philippe Loubet, Regula Keller, Sonia Valdivia, and Vanessa Zeller.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability The survey design and questionnaire as well as the complete set of responses to the survey are provided as supplementary material along with this article.

Declarations

Conflict of interest The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Anastasiadis S, Perkiss S, Dean BA, Bayerlein L, Gonzalez-Perez MA, Wersun A, Acosta P, Jun H, Gibbons B (2021) Teaching sustainability: complexity and compromises. J Appl Res High Educ 13:272–286. https://doi.org/10.1108/JARHE-02-2020-0029

Baumann H, Tillman AM (eds) (2004) The hitch hiker's guide to LCA - an orientation in LCA methodology and application. Studentlitteratur AB

Benoît Norris C, Traverso M, Ekener E, Neugebauer S (2009) Guidelines for social life cycle assessment of products. Management

Curran MA (ed) (2012) Life cycle assessment handbook. Life Cycle Assessment Handbook, Wiley. https://doi.org/10.1002/9781118528372

EC-JRC (2010) International reference life cycle data system (ILCD) handbook: analysing of existing environmental impact assessment methodologies for use in life cycle assessment. Eur Comm, p 115

EC-JRC (2012) Product environmental footprint (PEF) guide. European Commission Jt Res Cent, p 154

Finkbeiner M (ed) (2016) Special types of life cycle assessment, LCA compendium – the complete world of life cycle assessment. Springer, Netherlands, Dordrecht. https://doi.org/10.1007/978-94-017-7610-3

Frischknecht R (2020) Lehrbuch der Ökobilanzierung. Springer, Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-54763-2

Grisel L, Osset P (2005) L'Analyse du Cycle de Vie d'un produit ou d'un service. Applications et mise en pratique. Int J LCA. https://doi.org/10.1065/lca2005.04.003

Guinée JB (ed) (2002) Handbook on life cycle assessment: operational guide to the ISO standards. Springer Science & Business Media

Hauschild MZ, Huijbregts MAJ (2015) Life cycle impact assessment. In: International journal of life cycle assessment. LCA compendium – the complete world of life cycle assessment. Springer Netherlands, Dordrecht. https://doi.org/10.1007/978-94-017-9744-3

Hauschild MZ, Rosenbaum RK (eds) (2018) Life cycle assessment. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-56475-3

Heijungs R, Suh S (2002) The computational structure of life cycle assessment, eco-efficiency in industry and science. Springer, Netherlands, Dordrecht. https://doi.org/10.1007/978-94-015-9900-9

ILCA International Life Cycle Academy (n.d.) Teaching materials [WWW Document]. https://ilca.es/teaching-materials/. Accessed 14 Dec 2023

Industrial Ecology Freiburg - University Freiburg (2018) Industrial ecology open online course [WWW Document]. https://www.industrialecology.uni-freiburg.de/teaching.aspx/

ISO (2006a) ISO/FDIS 14025: 2006 - Environmental labels and declarations — type III environmental declarations — principles and procedures. Marquages

ISO (2006b) Environmental management - life cycle assessment - principles and framework (ISO 14040:2006)

ISO (2006c) Environmental management – life cycle assessment – requirements and guidelines (ISO 14044:2006). Assessment. CRC Press. https://doi.org/10.1201/b19138

ISO (2014) 14046:2014 Environmental management. Water footprint principles, requirements and guidelines

ISO (2018) 14067:2018 Greenhouse gases. Carbon footprint of products. Requirements and guidelines for quantification

Jolliet O, Saade-Sbeih M, Shaked S, Jolliet A, Crettaz P (2015). Environmental Life Cycle Assessment. CRC Press, UK, https://doi.org/10.1201/b19138

Klöpffer W, Grahl B (2016) Life cycle assessment (LCA): a guide to best practice. Int J LCA 21:1063–1066. https://doi.org/10.1007/s11367-016-1083-z

Matthews S, Hendrickson C, Matthews D (2020) [WWW Document]. Life cycle assessment: quantitative approaches for big decisions. http://www.lcatextbook.com/

Moutik B, Summerscales J, Graham-Jones J, Pemberton R (2023) Life cycle assessment research trends and implications: a bibliometric analysis. Sustainability 15:13408. https://doi.org/10.3390/su151813408

Palinkas LA, Horwitz SM, Green CA, Wisdom JP, Duan N, Hoagwood K (2015) Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. Adm Policy in Ment Health Ment Health Serv Res 42(5):533–544. https://doi.org/10.1007/s10488-013-0528-y

QYResearch Group (2023) Global sustainability consulting market size, status and forecast 2022–2028. https://www.marketresearch.com/QYResearch-Group-v3531/Global-Sustainability-Consulting-Size-Status-33081391/. Accessed 9 Feb 2024

Schenck R, White P (eds) (2014) Environmental life cycle assessment: measuring the environmental performance of products. American Center for Life Cycle Assessment

Self JA, Evans M, Jun T et al (2019) Interdisciplinary: challenges and opportunities for design education. Int J Technol Des Educ 29:843–876. https://doi.org/10.1007/s10798-018-9460-5

Sonnemann G, Margni M (eds) (2015) Life cycle management. LCA compendium – the complete world of life cycle assessment. Springer, Netherlands, Dordrecht. https://doi.org/10.1007/978-94-017-7221-1

Sonnemann G, Vigon B, Rack M et al (2013) Global guidance principles for life cycle assessment databases: development of training material and other implementation activities on the publication. Int J Life Cycle Assess 18:1169–1172. https://doi.org/10.1007/s11367-013-0563-7

Spelt EJH, Biemans HJA, Tobi H, Luning PA, Mulder M (2009) Teaching and learning in interdisciplinary higher education: a systematic review. Educ Psychol Rev 21:365–378. https://doi.org/10.1007/s10648-009-9113-z

Swarr TE, Hunkeler D, Klöpffer W, Pesonen H-L, Ciroth A, Brent AC, Pagan R (2011) Environmental life-cycle costing: a code of practice. Int J LCA 16:389–391. https://doi.org/10.1007/s11367-011-0287-5

UNEP (2020) The triple planetary crisis: forging a new relationship between people and the earth. https://www.unep.org/news-and-stories/speech/triple-planetary-crisis-forging-new-relationship-between-people-and-earth. Accessed 9 Feb 2024

Valdivia S, Ugaya CML, Hildenbrand J, Traverso M, Mazijn B, Sonnemann G (2013) A UNEP/SETAC approach towards a life cycle sustainability assessment—our contribution to Rio+20. Int J LCA 18:1673–1685. https://doi.org/10.1007/s11367-012-0529-1

Viere T, Amor B, Berger N, Dolfing FR, Horta AR, Keller R, Laurent A, Loubet P, Strothmann P, Weyand S, Wright L, Sonnemann G (2021) Teaching life cycle assessment in higher education. Int J Life Cycle Assess 26:511–527. https://doi.org/10.1007/s11367-020-01844-3

Weidema B, Brandão M (2020) Book review of life cycle assessment: theory and practice, edited by Michael Z. Hauschild, Ralph K. Rosenbaum, and Stig Irving Olsen; Environmental Life Cycle Assessment, by Olivier Jolliet, Myriam Saadé-Sbeih, Shanna Shaked, Alexandre Jolliet, and Pier. J Ind Ecol 24:726–730. https://doi.org/10.1111/jiec.12955

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.