LCA in the Field of Safety at Work: A New Engineering Study Subject

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Abstract Life cycle assessment (LCA) is a standardised and comprehensive approach for evaluation of environmental impacts within the material and energy flows associated with various human activities and through the life cycle stages. Besides environmental impact evaluation, with LCA, costs, social impacts, impacts on workers, organisations and others can also be assessed. This paper focuses on development of educational framework for evaluation of occupational safety based on LCA. The goal is to develop a new study subject "LCA in the field of safety at work" for the occupational safety engineering master study programme at the Faculty of Technical Sciences in Novi Sad. New study subject is based on LCA approaches that evaluate the occupational safety and impact on workers. Based on the previous research of LCA in the field of occupational safety, the goal, outcome, content and realisation are defined for the new study subject.

1 Introduction

Life cycle assessment (LCA) has been in education process at the University of Novi Sad for more than 20 years, since the foundation of the Department of Environmental Engineering at the Faculty of Technical Sciences. The starting point was a teaching topic within the environmental engineering study programme, the subject mechanical engineering in environmental protection. Today, LCA is studied in several courses at bachelor, master and PhD levels of environmental, occupational safety, mechanical and civil engineering study programmes. The result is a growing number of bachelor, master and PhD theses in the field of LCA, eco-labelling and eco-design. Considering the importance of occupational safety in engineering and aiming to fulfil the expectations of organisations operating on the labour market, besides the environmental engineering, since 2010 occupational safety engineering study programme has been established at the Faculty of Technical Sciences.

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Besides environmental LCA, life cycle costing and social LCA (S-LCA) emerge in order to provide sustainable LCA, where S-LCA is the youngest methodology. Within the S-LCA [1], impact on workers' health and safety during the life cycle is a group of stakeholder impact categories that can provide information on accident rates at workplace (non-fatal and fatal), occurrence of various diseases and injuries, disability-adjusted life years (DALYs), presence of safety measures, etc. Working environment LCA (WE-LCA) [2] aim to compile and evaluate potential working environmental impacts on humans of a product system throughout its life cycle. The impact categories in WE-LCA can be expressed through evaluation of potential accidents and diseases: fatal accidents, total number of accidents, central nervous system function disorder, hearing damages, cancer, musculoskeletal disorders, airway diseases (allergic and non-allergic), skin diseases and psychosocial diseases. Furthermore, damage to human health attributable to the work environment can be assessed as DALYs [3].

Table 1 provides several approaches for WE-LCA. Schmidt et al. [2] developed one of the first WE-LCA approaches. This WE-LCA approach is based on EDIP life cycle impact assessment method and contains a small life cycle inventory (LCI) database with more than 80 activities. Pettersen and Hertwich [4] focused on evaluation of safety issues related to offshore crane lifts working environment. Kim and Hur [5] developed two working environment indicators in context of LCA: occupational health and occupational safety. One of the first S-LCA case studies that followed the UNEP/SETAC S-LCA guidelines [1] was presented transparently and in detail was realised by Ciroth and Franze [6]. Group of authors [3, 7] provided two papers published in 2013 and 2014 and used national occupational safety and health industry statistics for United States of America to express the impact on working environment through the WE-DALY units. For WE-DALY indicator, they [3] provided 127 working environment characterisation factors linked with various industry sectors. Kijko et al. [8] also used DALY units to assess health impacts from occupational exposure to chemicals. Khakzad et al. [9] used LCA and quantitative risk assessment methods in parallel to obtain the environmental and safety assessment. Monetary valuation, Canadian dollar (CAD) units were used for both methods in order to have comparable outputs from LCA and quantitative risk assessment.

It can be noted that all approaches in Table 1 have the following common characteristics:

- Compatible with ISO 14040 LCA phases and environmental LCA.
- National statistic records of safety issues through the industrial sectors are used to evaluate safety at work, or to assess the risk of injuries and illness.
- Although developed on national level, all approaches have the potential for universal worldwide use.

Considering that the working environment indicators are relatively new topic in LCA, and that research in the field of S-LCA is an actual topic nowadays, this paper focuses on development of educational framework for LCA in the field of safety at work and working environment in LCA. The goal of this paper is to develop a new study subject on a master study programme of occupational safety engineering at

Table 1 LCA approaches to evaluate safety at work

Approach	Working environment in life cycle assessment	Human health impact indicator for offshore crane lifts	Hybrid input-output analysis
Acronym	WE-LCA	–	Hybrid IOA
Reference	[2]	[4]	[5]
Developing basis	EDIP[b] method	LCA and DALY[d] units	LCA and IOA method
Problem-solving	Impacts on workers/universal	Development of a human health impact indicator for offshore crane lifts	Assessment of occupational health and safety
Geography	Denmark	United Kingdom	Korea
Characterisation	Based on statistics on work-related accidents and reported diseases from the Danish Labour Inspectorate and Statistics on the amounts of produced goods in Denmark	Based on number of crane lift incident injuries and expressed in DALY per crane lift	Linking the LCI[a] data with 28 basic industrial sectors classified by the Bank of Korea for occupational health and Korea Occupational Safety and Health Agency for occupational safety
No. of impact categories	10 – fatal accidents, total number of accidents, hearing damages, cancer, musculoskeletal disorders, airway diseases (allergic), airway diseases (non-allergic), skin diseases, psychosocial diseases, CNS function disorder	1 – health burden per crane lift	2 – occupational health (number of workers affected by certain hazardous items) and occupational safety (number of workers at certain magnitude of disability)
Normalisation	Yes – 2 sets: Danish population (person equivalents) and Danish work force (worker equivalents)	Yes – number of lifts performed per hour	Yes – total national lost work days from the occupational diseases by hazardous items during the given period of time divided by the total number of the workers
Developed and provided LCI[a] database	Yes – more than 80 activities based on DB93[c] industry sectors	No	No

[a]LCI, life cycle inventory
[b]EDIP, Danish Environmental Agency
[c]DB93, Danish nomenclature for industry sectors (identical to the EU NACE-code system)
[d]*DALY* disability-adjusted life years

the Faculty of Technical Sciences in Novi Sad in order to produce occupational safety engineers that will be able to assess the impacts on workers' health and safety with LCA approach.

2 Methodology

The study programme of the graduate master academic studies in Occupational Safety Engineering presents the continuation of the undergraduate academic studies of Occupational Safety Engineering at the Faculty of Technical Sciences, University of Novi Sad [10]. Engineering and technical disciplines are incorporated into the realisation of the curriculum of the undergraduate and graduate academic studies of Occupational Safety Engineering, thus representing a highly multidisciplinary and interdisciplinary programme. The study programme prerequisites for the enrolment are completed undergraduate studies with at least 240 ECTS and the passed enrolment examination. General information on Master in Occupational Safety Engineering study programme are provided in Tables 2 and 3.

Distribution of ECTS points in master academic studies in occupational safety engineering is provided in Fig. 1. The other study subjects (curriculum) on occupational safety engineering study programme tackle topics such as hazardous materials and hazardous waste, occupational risk assessment, statistical advanced models, occupational medicine, chemical risk assessment of fire and explosion, system regulations and EU practice in occupational health and safety, occupational noise and human vibration in industry, accidental risk management and the environment, product safety and user/consumer protection and sociological and legal aspects of occupational safety. On the other side, none of the current subjects cover the safety at work from life cycle perspective.

According to the previously defined study subject topic, the goal, outcome, content and realisation of new study subject will be defined in results section.

3 Results

Based on the previous literature, the new study subject LCA in the field of safety at work has to cover the following topics (Fig. 2):

- LCA according to ISO 14040 and 14044 international standards
- Relationship between WE-LCA and other LCA approaches: the environmental LCA, S-LCA, life cycle costing organisational LCA and sustainability LCA
- S-LCA for workers stakeholder group: goal and scope definition, S-LCI, social life cycle impact assessment methods and interpretation
- Software support for S-LCA: S-LCA software and S-LCI databases
- Evaluation of products life cycle impact on workers through WE-DALY approach

Table 2 LCA approaches to assess safety at work (continued)

Approach	Social life cycle assessment	Work environment disability adjusted life year	Occupational LCA	Accident risk-based life cycle assessment
Acronym	S-LCA	WE-DALY	–	ARBLCA
Reference	[6]	[3, 7]	[8]	[9]
Developing basis	LCA	LCA and DALY units	LCA and DALY	LCA and quantitative risk assessment
Problem-solving	Evaluation of social impacts through the product's life cycle	Waste management – landfilling and incineration	Assessment of health impacts from occupational exposure to chemicals	Green and safe fossil fuel selection
Geography	Worldwide	United States of America	North American	Canada/ potentially worldwide
Characterisation	Assessment of the performance of the sectors and companies, respectively, based on the status of the indicators taking the performance of the sector/company in relation to the situation in the country/region into account	Characterisation factors are obtained from US industry-level occupational safety and health data (work-related fatal and non-fatal injuries and illnesses) and the physical quantities of goods produced by these industries	Based on labour hours and indoor intake concentration	IPCC[d]
No. of impact categories/ indicators	8 – within workers' stakeholder category, the subcategories are the following: freedom of association and collective bargaining, child labour, forced labour, fair salary, working time, discrimination, health and safety, social benefits/ social security	1 – work environment DALY[b] (WE-DALY)	1 – occupational exposure to chemicals expressed in DALY/h	2 – GHG[e] (CO_2) emissions converted to CAD[f] by carbon tax for LCA, and 5 risk loss categories in CAD[f]

(continued)

Table 2 (continued)

Approach	Social life cycle assessment	Work environment disability adjusted life year	Occupational LCA	Accident risk-based life cycle assessment
Normalisation	Yes – each subcategory is assessed twice with a colour system ranging from very good performance to very poor performance and very negative impacts to positive impacts	No	No	British Colombia province carbon tax (30 CAD[f] per metric ton of CO_2 equivalent)
Developed and provided LCI[a] database	LCI database is not provided in the particular study; however, S-LCA databases exist	Yes – 127 WE characterisation factors linked with NAICS[c] industry sectors	Yes – for various NAICS [c] industry sectors, characterisation factors have been developed for 19069 organic chemical/sector combinations	None

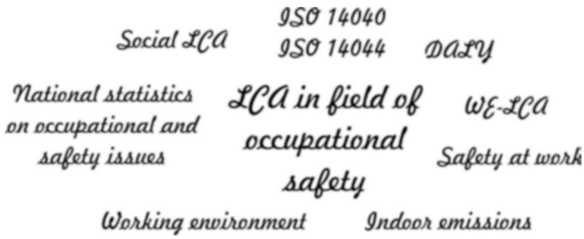
[a]LCI, life cycle inventory
[b]*DALY* disability-adjusted life years
[c]*NAIC*, North American Industry Classification System
[d]*IPCC* Intergovernmental Panel on Climate Change
[e]*GHG* greenhouse gases
[f]*CAD* Canadian dollar

Table 3 General information on master in occupational safety engineering study programme [10]

Type of studies	Master academic studies
Academic degree	Master in Occupational Safety Engineering (M. Occ.Saf.Eng.)
Educational field	Technical-Technological Science
Scientific, professional or art field	Environmental and Occupational Safety Engineering
Duration (year/sem)	1 year/2 semesters
Total European Credit Transfer System (ECTS) points	60
Web address containing study programme information	http://www.ftn.uns.ac.rs

Fig. 1 Distribution of ECTS points in master academic studies in occupational safety engineering

Fig. 2 Topics in study subject LCA in the field of occupational safety



- Evaluation of products life cycle impact on workers through the WE-LCA approach

Fundamentals for teaching will certainly include recommendations for LCA from ISO 14040 and 14044. These standards provide basics for environmental LCA and are nowadays incorporated in other LCA approaches. Historical development, similarities and differences between the various LCA approaches are interesting starting point for better understanding of LCA in the field of safety at work. Within S-LCA, besides other social issues, evaluation of occupational safety is expressed through the workers stakeholder impact category. Software support for S-LCA enables practical calculations of social impacts, supply chain modelling and connection between the industry sectors and countries. Therefore, S-LCA software can be used for performing exercises in computer classrooms with students. WE-DALY and WE-LCA approaches have their LCI database which also can be used for exercises in computer classrooms with students.

The new subject LCA in the field of safety at work on a master study programme of occupational safety engineering at the Faculty of Technical Sciences in Novi Sad has been developed and applied for the accreditation programme for the new 2020/2021 academic year. Goal, outcome, content and realisation of this subject are provided in the following part:

- Goal: Acquisition of knowledge, competences and academic skills in field of safety at work and product's life cycle. Development of creative capabilities, academic and practical skills for implementation of life cycle assessment of processes and products from aspect of impact on the worker;

- Outcome: Ability to solve real problems in the field of life cycle assessment of product's impact on worker. Mastering methods and procedures for life cycle assessment of product's impact on worker. Development of skills for life cycle assessment of product's impact on worker with respecting the sustainable development principles. Ability to critically and self-critically think within interpretation of product's and process's life cycle assessment results.
- Content: Product's life cycle. Life cycle assessment in the field of environmental protection and safety at work. Sustainable development, economic, social and environmental dimension within the life cycle assessment. Defining goal and scope of study. Life cycle inventory. Life cycle inventory databases. Life cycle impact assessment on worker. Methods for life cycle impact assessment of products and processes on worker. Interpretation of results.
- Realisation: Lectures are interactive in the form of lectures, auditory, laboratory and computer practice. During the lectures, theoretical part of the course is presented followed by typical examples for better understanding. During the auditory practice, typical problems are solved and the knowledge is deepened. During the computer practice, information communication technologies are applied in order to master the knowledge of the observed field. Besides lectures and practice, consultations are held on a regular basis.

Besides the lectures, this study subject is based on exercises where students can obtain practical knowledge. The exercises have to be based on interactive relationship between the lecturer and students and use of modern educational equipment, computers and the Internet. Mastering methods from this study subject will enable students to perform and develop skills for LCA of product's and process's impact on worker health and safety.

4 Conclusions

Although the environmental LCA is well known, the social LCA and LCA in the field of safety at work are starting to gain their momentum in scientific community. The new study subject LCA in the field of safety at work on a master study programme of occupational safety engineering at the Faculty of Technical Sciences in Novi Sad aims to enable students to master these methods and to perform and develop skills for LCA of product's and process's impact on worker health and safety. The objective is to achieve student's scientific competencies and academic skills in the field of LCA and occupational safety. One of the specific objectives is to develop students' awareness of the need for continuous education in the field of occupational safety and the development of a society in general.

The educational framework in this paper is developed for the purposes of occupational safety engineering study programme at the Faculty of Technical Sciences in Novi Sad. However, this framework can be applied at other study programmes and universities with certain modifications according to their specific needs. Further development directions will be detected after implementation of LCA in the field of safety at work study subject.

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