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# Environmental Life-cycle Analysis as a Tool for Sustainability Studies: A Complete Learning Experience

# Środowiskowa ocean cyklu życia jako narzędzie w studiowaniu zrównoważoności: kompletne doświadczenie edukacyjne

**G Venkatesh**

*Department of Engineering and Chemical Sciences, Karlstad University, Karlstad, Sweden – 65188*
*E-mail: venkatesh.govindarajan@kau.se*

## Abstract
This article first presents Environmental Life-Cycle Analysis (E-LCA) as a complete learning experience for university students of environmental science/engineering, enabling the acquisition of the four levels of knowledge, of the Structure of the Observed Learning Outcome (SOLO) taxonomy. The four steps of an E-LCA, interestingly, mirror the hierarchy of knowledge-levels defined by the SOLO taxonomy. In the light of the fact that it is generally difficult to accomplish this ascent from declarative knowledge to functional knowledge, in a systematic manner, in many university courses, the complete learning experience guaranteed by E-LCA must stand out conspicuously.

**Key words:** Structure of the Observed Learning Outcome (SOLO), Environmental Life Cycle Analysis (E-LCA), declarative knowledge, functional knowledge, systems thinking, sustainability

## Streszczenie
W artykule przedstawiono środowiskową ocenę cyklu życia (E-LCA) traktowaną jako kompletne doświadczenie edukacyjne dla studentów uczelni wyższych kierunków nauki o środowisku/inżynieria, pozwalające na zdobycie wiedzy na czterech poziomach ze Struktury Obserwowanych Efektów Kształcenia (SOLO). Cztery kroki E-LCA, odzwierciedlają hierarchię poziomów wiedzy z klasyfikacji SOLO. Wobec faktu, że ogólnie rzecz biorąc trudno jest osiągnąć przejście z wiedzy deklaratywnej do funkcjonalnej, w kwestiach systematycznych, dla wielu kursów uniwersyteckich, pełne doświadczenie edukacyjne gwarantowane przez E-LCA zdecydowanie się wyróżnia.

**Słowa kluczowe:** Struktura Obserwowanych Efektów Kształcenia (SOLO), środowiskowa ocena cyklu życia (E-LCA), wiedza deklaratywna, wiedza funkcjonalna, myślenie systemowe, zrównoważoność

## 1. Introduction and literature review

### *1.1. Teaching and learning outcomes*

The Structure of the Observed Learning Outcome (SOLO) taxonomy of action verbs encompassing the entire learning experience of students in universities is a four-step one, recommending the progress of the student from the *unistructural* level of knowledge through the *multi-structural* and the *relational,* to the *extended abstract* (Biggs and Tang, 2011). As students scale the heights, they ascend from theory to practice/application; from the acquisition of declarative knowledge (cognitive skills) to functional knowledge (psychomotor skills) (see Table 1). The so-called action verbs, used to describe the intended learning outcomes are numerous, and few have been chosen and tabulated in Table 1, primarily for the purpose of presenting Environmental Life-cycle Assessment (E-LCA) as a complete learning experience for students.

Table 1. SOLO taxonomy – unistructural to extended abstract

| Knowledge level | Chosen action verbs |
|---|---|
| Unistructural | Identify, Define |
| Multi-structural | Classify, List |
| Relational | Analyse, Characterise, Compare |
| Extended Abstract | Generate, Create |

*1.2. Sustainability and environmental education in general*

Marshall et al. (2013) observed that there is some degree of change in the integration of sustainability into business schools. They refer to the strand of learning available for all students at the University of Leeds – Creating Sustainable Futures – which is based on the transition from *Learning about sustainability* to *Learning for sustainability*. Acevedo et al. (2013) defined sustainability studies as *a life-long learning process embedding practices and discussing ideas around the socio-cultural, economic and environmental impacts that students, lecturers and practitioners will make in the transformation of current lifestyles and practices.*

Systems-thinking, Creativity and Cooperation stand out as keywords, or rather key constituents of sustainability-education. ACUPCC (2014) has maintained that higher-education curricula need to be updated across a diverse range of academic disciplines to address climate adaptation – from business practices to the ecosystem management, from law to community planning, and from architecture to healthcare. Dobson et al. (2013) pointed out that at the University of Manchester, Sustainable Development is a compulsory component of engineering degrees, for students intending to become chartered engineers. NACUBO, USA / Second Nature, USA (2014) contend that higher education institutions need to lead by example by resorting to on-campus wind and solar energy generation, geothermal and biogas heating/cooling systems, lighting upgrades to improve energy efficiency, water conservation, weather-proofing initiatives, waste minimization and recycling, etc. At the Karlstad University in Sweden (to which the author of the paper is affiliated), it is mandatory for PhD students in the fields of science and engineering, to try to find how sustainability concepts could be incorporated into their research. According to Capra and Luisi (2014), *It will therefore be critical for present and future generations of young researchers and graduate students to understand the new systemic conception of life and its implications for a broad range of professions – economics and management, politics and medicine, psychology and law.* The Department of Chemical and Engineering Sciences at the Karlstad University, offers courses in sustainable development to engineering students from different disciplines at different stages in their bachelors' and masters programmes. In a survey of academicians in the departments of architecture at the Norwegian University of Science and Technology (Trondheim, Norway), and the University of Sarajevo (Sarajevo, Bosnia) – the results of which have been published in Venkatesh and Schwai (2016), most respondents have said that they are aware of the need for life-cycle thinking and believe it is indispensable if sustainability and energy efficiency have to be properly understood. It is good to see that a majority of them always introduce life-cycle thinking to students in their lectures. Of course, the nature of the subjects which the respondents teach, imposes some restrictions on the importance they could give to life-cycle thinking, but certainly the scope always exists.

*1.3. Environmental LCA*

We, humans, are dependent on the environment for our existence and will continue to be dependent on it. Dependence, instead of generating a feeling of gratitude, leads to mishandling and mistreatment and brings about a *taking-for-granted* attitude in its wake, more often than not. That, we have been witnessing around us; and still do, when we encounter self-serving, materialistic narcissists in our daily lives. Now, while it is an indisputable fact that humankind has wreaked some havoc on the environment on which it depends, one may wish to measure this *havoc* and understand what one can do, to hold back the rate at which the damage is occurring. If one can measure, one can manage. This is the philosophical basis of an environmental life-cycle assessment (E-LCA, sometimes also referred to environmental life-cycle analysis) – a basic understanding of our dependence on the environment and its vulnerability; and an ardent desire to set things right. This philosophical basis requires empathy and imagination (strengthening of the emotional and spiritual understanding of the dependence of humankind on the environment, as well as the interdependence among human beings on the planet), which is emphasized in Jensen (2017).

E-LCA, a technique for decision support and learning, is a useful and powerful tool for sustainability analysis, the application of which is taught to students of environmental science/engineering and industrial ecology in some universities around the world (Baumann et al, 2004 and Venkatesh, 2016). The steps to be followed in a systematic E-LCA have been standardized in ISO 14044 (2006), while ISO 14040 (2006) outlines the principles and framework. Let us start off with ISO 14044 (2006). This outlines the four steps in an E-LCA, and is essentially a consolidation of the earlier standards ISO 14041 (1998), ISO 14042 (2000) and ISO 14043 (2000), all three of them taken together. It describes the following:

**Goal and scope definition.** As the name of the step suggests, this is about *defining* why and for whom the E-LCA needs to be carried out and *identifying* the scope, assumptions to be made, limitations and the allocation methods for the analysis. The two action

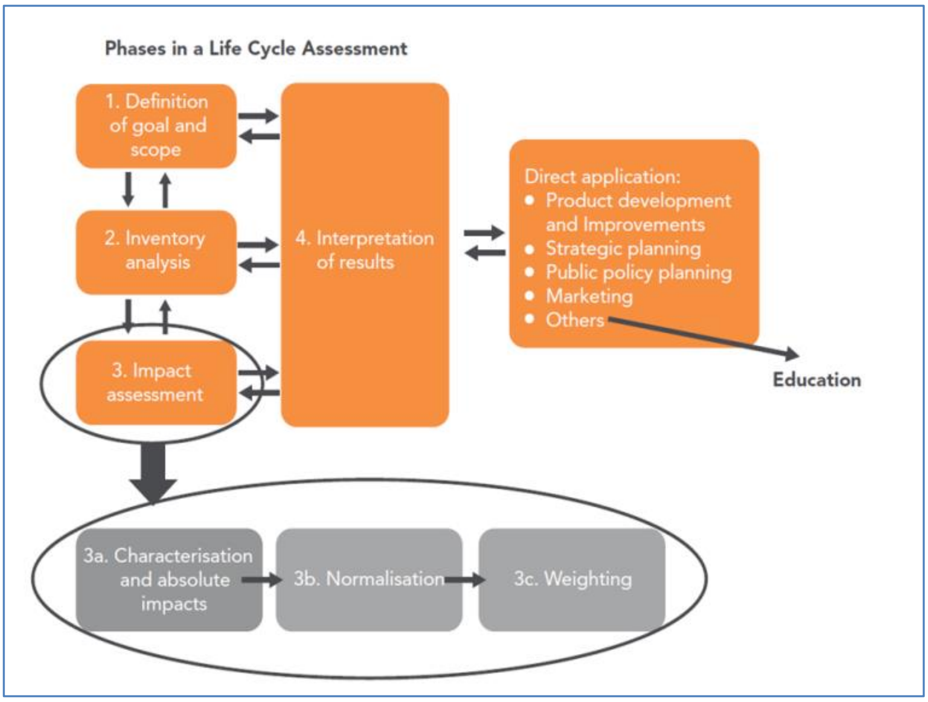


Figure 1. Phases in an E-LCA (Venkatesh, 2016, p. 23)

verbs (intended learning outcomes for students) within quotation marks are of the unistructural knowledge level (Table 1).

**Inventory Analysis**. The word *inventory* at once evokes the action verb *listing*. Even though this step is called an analysis, it is primarily a listing or *categorisation and classification* of the flows of resources (materials and energy) and emissions associated with the processes/products being studied in the E-LCA. Listing and classifying are action verbs of the multi-structural knowledge level.

**Life-Cycle Impact Assessment**, in which one graduates to the relational knowledge level. *Relating* the resource and emission flows to environmental impacts of different kinds, *characterizing* the emissions by using characterization factors, *normalising and weighting* and thereby introducing subjectivity (Venkatesh, 2016; chapters 4,5 and 6). Characterisation factors enable one to express emissions of different substances in terms of equivalents of a chosen substance, quite like expressing all currencies in US-dollar equivalents for example. Normalisation is expressing the environmental impacts from the system or life-cycle being studied as a percentage of the total impacts from a pre-defined larger area. Weighting, as the name implies is assigning relative degrees of importance to different kinds of environmental impact categories.

**Interpretation or Improvement Assessment** – This step is the culmination of the E-LCA, where the inventory analysis and impact assessment lead to an interpretation of the results, which calls for a slightly higher level of knowledge, bordering on the extended-abstract in Table 1. Recommendations and advice are *generated*, possibilities for improvement which may not at once be visible are uncovered. It must be mentioned at this point that *being able to perform a case study* belongs to the extended abstract level and includes the other three sub-levels as requisites. In other words, after learning the four steps of E-LCA, students should be able to perform their own case studies by utilizing all the four levels of knowledge acquired in the process. As gathered from Figure 1, E-LCA is not complete if the final communication is not tailor-made for the intended recipient. Here, we are talking of action verbs on the relational knowledge level – *translate, explain, summarise.*

Teachers often find it challenging to define the learning outcomes of courses in an effective manner. What is on paper is often not achieved. No courses can be structured to enable students to achieve learning outcomes at all the four levels adequately. E-LCA, however, by the way it has been structured and standardized by the ISO, exposes students to all the four levels of knowledge (and thereby both the types – declarative and functional). E-LCA, as mentioned earlier, is an important tool for sustainability studies, which by virtue of its diversified nature, equips learners with a wide range of abilities (defined by the action verbs in the SOLO taxonomy), demonstrating at once that the unistructural ought to be linked up to the extended abstract, to be truly utilitarian and valuable to society, economy and environment.

## 2. Discussion

The author reached across to leading pedagogues in the field of E-LCA around the world, and elicited comments on the *impact and influence of, and inter-*

Table 2. Range of possible expectations which students may have before commencing on E-LCA studies in university

| |
|---|
| • To understand the range of applicability of the tool, in the industry and also how it is actually used in the industry |
| • To learn how the tool is used in practice |
| • To apply the tool to understand one's own lifestyle choices and their impacts on the environment |
| • To learn something new and exciting and relevant both in the present and in the future |
| • To go through completed LCA-studies to understand exactly how analysts had carried them out in practice |
| • To learn how LCA can be useful for a career as engineer in the energy sector |
| • To compare products holistically |
| • To move ahead from the *what* of environmental problems which we had learnt in some earlier courses, to *how* one could tackle them |
| • To do a complete LCA, all by myself, during the module |
| • To understand how human society affects the environment |
| • To master new ways to think and new techniques to apply to understand our relationships with the environment around us |
| • To get a better understanding of what some of the indicators – kg $CO_2$ equivalents – we have introduced to an earlier course, actually meant and how they were derived |
| • To learn to use E-LCA software and gets hands-on experience in this respect |

*est in* E-LCA education and learning. Prof. Shabbir Gheewala (Gheewala, 2017) from King Mongkut's University of Technology Thonburi (Thailand) told the author that he has been using E-LCA as a metaphor for research methodology in general; quite in keeping with the SOLO taxonomy outlined in Table 1. He has promoted this approach to research while making E-LCA a compulsory course for all graduate students, regardless of their actual research topics. Assoc. Prof. Jeroen Guinee (Guinee, 2017) from Leiden University in the Netherlands, which has been in the forefront of developing E-LCA methodology, since the early days of this analytical tool, describes the evolution of E-LCA teaching at the university thus – *It started as a purely theoretical class, shifted towards an online course and can now best be described as an intensive engaging experience for students in which theory and practice are combined to provide students the basis to responsibly perform an LCA study.* The key phrase there is '*theory and practice'*. Theory, after all, cannot be understood without empirical observation (or practice) and vice versa, as Arvidsson et al (2016) have stated, citing another paper. E-LCA is a tool to be applied, and thereby it is very necessary to train the students to do so, and understand the difficulties and challenges they would face out there *on-the-field*. Maybe a few more things...! Assoc. Prof Henrikke Baumann (Baumann, 2017), one of the co-authors of Baumann et al (2004), responded elaborately to the author's e-mail request. She referred to the LC@chalmers network on which E-LCA research and educational issues are discussed frequently. The history of E-LCA teaching in Sweden for instance, can be traced back to 1992 and Chalmers (Tillman et al, 2002). Twenty-five years later, Chalmers is on the verge of launching some advanced PhD courses on more advanced forms of life-cycle modelling, which LCA-enthusiastic students from around the world must look out for. Apart from students and researchers, Baumann thinks, LCA education has to be necessarily imparted to industry professionals and decision-makers in governments; and Chalmers has been organising workshops and online courses to this effect. She outlines many reasons for the necessity of educating and training professionals – one of them being that practitioners tend to be very much tool-focused and in the process, fail to utilise life-cycle thinking in business in the manner it should be used. Professor Arun Kansal from The Energy Research Institute of India (TERI), in his foreword to Venkatesh (2016) writes, *During my teaching career of over 20 years, I have experienced young researchers struggling for guidance to fast-track their understanding of the LCA method and use it as an integral part of their research work. Students grapple with difficulties in defining system boundary, allocating environmental impact of various interactive products or systems and analysing the life cycle inventory*. These are issues to be addressed and borne in mind obviously, while teaching E-LCA. In the Afterword to in Venkatesh (2016), E-LCA practitioner and researcher Dr Geoffrey Guest from *Agriculture and Agri-Food Canada (Ottawa*), opines thus about E-LCA *What was once a rather unpopular, academic and, if I may dare to say, geeky system of accounting turned into the go-to approach for corporate and government initiatives to measure, disclose, inform policy and improve the 'cradle-to-grave' environmental impacts of existing products.* Håvard Bergsdal (Bergsdal, 2017), a consultant from Norway tells the author how he began LCA studies in the late 1990s with a case study on diapers; and charts out his evolution to an LCA consultant carrying out sophisticated LCA analyses of large infrastructure systems.

These action verbs (Table 2) – *master, understand, do, get, move ahead, compare, learn, go through, apply* – can be correlated with the ones in Table 1, and slotted into the appropriate categories.

Table 3. Gleanings about E-LCA

- *It is imperative to impress upon the generations to come, the value of the resources they use. In fact, the more we go into the future, the more imperative it would get.*
- *It is important for youngsters to understand that the life of a product need not end when it is of no use anymore to the first user.*
- *The knowledge and understanding of E-LCA will be important and very useful in Sweden and the world in general, in the years to come.*
- *Even if someone will not be performing E-LCA in his/her career, knowledge is necessary to be able to read and follow reports prepared by analysts.*
- *Why youngsters, even older people must be encouraged to learn about E-LCA, before adding something to, or changing something in the anthroposphere.*
- *If little children could be made to understand in offbeat ways how their toys and clothes are made – the life-cycles of these products in other words – they would grow up to respect the limits to growth.*
- *It would be good if E-LCA is taught right from the beginning of the 5-year engineering programmes and not later on towards the end of it.*
- *With the passage of time, sustainable development would have been firmly entrenched in society and economy. Therefore, I will have no option other than to encourage my children in the future to develop an interest in systems thinking and tools like E-LCA.*
- *It is good if knowledge about how human actions impact the environment – positively or negatively – is inculcated to children by their parents and school-teachers in creative ways. I will support this in the future.*
- *The earlier the better. As all of us have to contribute to sustainable development, it is imperative that youngsters begin their contributions right from their primary school days. The positive effects of creating this mentality early enough cannot be overemphasized.*
- *Of course, I would certainly vouch for E-LCA as a tool to be learnt by students in the future, as it is likely to become more sought-after in the years to come.*
- *I think it takes a long time to understand E-LCA thoroughly and thereby earlier the learning starts, the better. E-LCA will help one to convince children why they should not waste energy or water or resources in general.*
- *Discussing about the life-cycle environmental impacts of products with children will make them grateful for what they have, and they will definitely pass on this wisdom to the generation after them.*
- *E-LCA, in principle, will enable one to make youngsters comprehend the truth behind the proverb 'Little drops of water make a big ocean'. It will also help in the application of another one – Prevention (of environmental damage) is much better than reacting after the damage has been done.*
- *In elementary school, environmental awareness and life-cycle thinking must be mandatory subjects just like mathematics and languages.*

As one moves up the *analysis cone* from characterisation and classification to normalisation, weighting and aggregation to a single index, communicability of the results becomes easier, while accuracy and the details get compromised. A single index is easier for non-experts to identify with and use as an input for decision-making, while researchers, analysts and scientists ought to know the *story behind the index*. Readers may refer to Venkatesh (2014), which exemplifies one possible output of E-LCA results – the definition and calculation of a so-called Green City Index, which makes cities compete to outperform the ones above them in the ranking. There is also the observation that the right questions need to be asked at the outset (harking back to the interesting Preface of Baumann et al (2004)), and the fact that the answers would change depending on the questions asked must be conveyed to the recipient of these answers – the decision-makers in government for example. Even for a layperson, who may perhaps decide to utilise the information obtained from E-LCA in the choices he/she makes in his/her daily life, the knowledge that two similar-looking products at the factory-gate, could have entirely different life-cycles and contribute differently to life-cycle environmental impacts depending on how and how long they are used and handled at the ends of their respective life times, can be a veritable eye-opener. The role of the media in disseminating findings from E-LCA reports, in a reader-friendly manner, should not be overlooked, though this would make it necessary for the media-persons to make sure that they are interpreting the results correctly.

With the aid of graphs and flowcharts, communication of information to the layperson can be simplified and a person who does not even realise that a product he/she is consuming is indirectly and directly responsible for several hundreds of kilometres of road/air/sea-travel and thereby transport-related GHG emissions, can at once be enlightened. The communicator has a responsibility on his shoulders, which he needs to fulfil. He cannot misinterpret. If he interprets right, he cannot misguide the listeners/readers. Just labelling the electric car as an environmental-friendly alternative to diesel cars because it does not emit anything when it is on the road may make people who do not think beyond what they see/read/hear, believe without questioning or probing. Systems thinking in this case would entail understanding where the electricity that charges the batteries of the electric cars in the city comes from. Statistics however are misleading…in the communication step, E-LCA results may sometimes be *twisted* to look better than what they actually are. Neutral reviews of reports are therefore indispensable, in order to ensure that faith is never lost in the deliverables of this valuable tool.

## 3. Conclusions

Focusing only on *teaching to do* or *learning how to do* will get students and teachers only that far. *Learning how to do* is the first step, but that needs to be followed *de rigeur* by *re-learning by doing and re-doing*. It is necessary to make sure that whatever is taught to students about E-LCA must teach them something new and generate greater interest in them to learn E-LCA in greater *depth and width* in the future.

E-LCA can be looked upon as something that needs to be handed down the generations, like an heirloom to be developed and adapted to changing times. In universities, its importance is passed on by word-of-mouth from seniors to juniors. Out in society, life-cycle thinking has to be taught by parents and elders to youngsters. Table 3 lists some viewpoints of the students at Karlstad University to whom E-LCA was introduced by yours sincerely last autumn.

The leitmotif of this article was the presentation or interpretation of E-LCA as a complete learning experience for university students of environmental science/engineering, enabling the acquisition of the four levels of knowledge, of SOLO taxonomy – unistructural, multi-structural, relational and extended abstract; the graduation upwards from identifying to creating. The steps in an E-LCA (ISO 14044, 2006) neatly mirror these four levels of the said taxonomy. Selected reviews of published papers, books and documents on sustainability and environmental education, and e-mail communications with some E-LCA pedagogues and practitioners helped to set things in perspective.

E-LCA is indeed a useful and powerful tool in the hands of researchers, industry professionals and decision-makers in the government (if the last-named wish to acquire some knowledge about it). Life-cycle and systems thinking is gradually entrenching itself firmly and tools like E-LCA will continue to support decisions which would lead societies and economies of the world towards sustainability.

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