Sustainability and Life Cycle Assessment in Engineering Curriculum

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WIP: Sustainability and Life Cycle Assessment in Engineering Education

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The motivation for including LCA and sustainability in engineering education

Today's engineers must be aware of environmental impacts as a result of their work [1], with a cradle-to-grave mindset during the design, creation, use, and disposal of products and infrastructure. Based on a thorough literature review of sustainability in engineering education[1], we found that life cycle assessment (LCA) and/or sustainability is often missing across most engineering disciplines, and/or only taught in specific programs or upper-level courses. LCA is a mindset and tool via which students can add a quantitative aspect (e.g., carbon footprint) to their design choices [2], including seemingly qualitative decisions. Furthermore, students might not be aware of the applications, tools, or contexts surrounding environmentally-minded design [3]. To address the need for more sustainability in engineering education, we developed a new LCA module for our first-year engineering program at Ohio Northern University. We want our students to develop a big-picture understanding about everything that happens during the design process. Through our module, students are encouraged to think holistically about engineering.

LCA module development and classroom dissemination

Within Ohio Northern University's TJ Smull College of Engineering, students take a first-year engineering sequence: Foundations of Design 1 (ENGR 1041) and Foundations of Design 2 (ENGR 1051). Both courses are hands-on, project and team based courses with units on crucial aspects of engineering design (e.g., test plan development, data collection and analysis, ideation, and more). Broader impacts of engineering design and decision-making is also a focus of the class, and the vehicle through which LCA has been introduced into the curriculum.

In creating the LCA module, the research team, consisting of a faculty member and three undergraduate research students, examined previous course inclusion of broader impacts. We found and/or created examples and activities that help reinforce those topics, including associated readings on LCA. A homework assignment was developed to reinforce key LCA and broader impacts topics (see next section). A discussion of the two-day module follows.

Within the LCA course module, students first learn about LCA as a tool, and complete associated readings on wind turbine production, material usage, and recycling. Having previously completed a wind turbine unit in the fall of the first-year course, students have background knowledge to better understand wind turbines as a case study for LCA. On the first day of the module, students are reminded of key stakeholders and stakeholder roles in engineering, which has been previously covered in both first-year courses. New to the stakeholder discussion are the many ways to look at environmental impact. In class, students go through activities which quantify their water usage and carbon footprint using freely available online tools [4, 5]. Earth Overshoot Day [6] is mentioned as another way to view society's environmental impact.

On the second day of the module, students are taught when and how to use LCA within the context of engineering design. Within the assigned homework, students are provided several example calculations for material usage and the associated CO_2eq [7]. Additional lecture content

[1] Review paper on LCA in engineering education currently in preparation

on using the equation editor in MS Word, and other calculable environmental impacts (e.g., eutrophication) complete the in-class portion of the module. With the LCA information and examples provided, students should better understand the broader impacts their design decisions have on the planet and the people around them. Life cycle assessments are a technical way to truly dissect practices and the impact that those practices have on the world.

Excerpt from LCA homework background section, with example calculation

"Every day, we depend on energy, water, tech gadgets, and a variety of foods to keep us going in our busy lives. What you might not realize is that every single item or process with which we interact has an environmental impact. For example, if you printed the instructions for this activity, the piece of paper was made from trees. Beyond that, it took energy to grow, harvest, and process the trees into paper pulp. Water was also used in the process, as well as many additives and chemicals. All of these inputs to produce a single sheet of paper can be calculated into CO_2 equivalents, as well as other environmental metrics. A CO_2 equivalent (CO_2eq) is a means by which to compare the greenhouse gas emission equivalent, in terms of weight of CO_2, that a product or process produces through its creation, use, and/or disposal [7]. In other words, the CO_2 that is emitted/produced as a result of the product or process, whether directly or indirectly. Be aware that several versions of CO_2 equivalence exist. For simplicity, we'll use the CO_2eq which is a simplified 1:1 comparison of CO_2 emissions that would be generated for a given weight of material. In other words, the creation, use, and disposal of an item has an equivalent mass (kg) of CO_2 that is released into the atmosphere."

Example 1: Calculate the Environmental Impact (CO_2eq) of Paper Use Compared to Electricity

To determine the environmental impact, as measured by CO_2 equivalents, of producing paper, we have the following information: 1 kg of paper = 2.42 kg of CO_2 (also known as a CO_2 equivalent, CO_2eq). This number is an average value and includes all the inputs to produce the paper. Different data sets will have different parameters and values depending upon which inputs were included. With the CO_2eq information (1 kg of paper = 2.42 CO_2eq) [8], we can do some quick calculations.

- The average American uses roughly 700 pounds of paper per year [9], though estimates vary widely
- 1 kg = 2.2046 lbs (simple conversion factor)
- 1 kg of paper = 2.42 CO_2 equivalents [8]

$$\frac{700\ lbs\ paper}{person/yr}\ x\ \frac{1\ kg}{2.2046\ lbs}\ x\ \frac{2.42\ CO_2eq}{1\ kg} = \frac{768\ CO_2eq}{person/yr}$$

Anticipated goals of LCA module

A holistic approach to engineering can alter our landscape of technical advancement. In the past, innovation and progress were pushed, typically at the expense (directly or indirectly) of the environment. As society and science have advanced, long term consequences of design decisions are better understood. Today, data is more easily accessible and possible to assemble and analyze, including information such as water, energy, and carbon footprints of actions (e.g., drive vs. fly) and material choices (e.g., aluminum vs. plastic). Once students are armed with knowledge of environmental impacts of engineering, via modules like the one we developed, they are more likely to be motivated towards action [10]. As such, students will be better prepared to make environmental and ethical decisions which will meet the needs of the NSPE Code of Ethics, particularly code III, 2d [1]. Furthermore, students who learn about sustainability and LCA better understand how each topic will play a role in their future careers [11].

Future assessment of LCA module

In the first iteration of the new module, no quantitative assessment has been performed other than grading of the homework assignment as part of students' course grades. This past year (spring semester 2023) was a trial run of the new module, though a generic version of the LCA module did exist the previous year. For the new module, qualitative feedback was collected from course instructors and teaching assistants on pain points and overall student performance. The module development team will revise the module based on the qualitative feedback, and include the updated version in ENGR 1051 this coming academic year (spring semester 2024).

To ascertain the effectiveness of the module on student understanding of broader impacts and sustainability, a module pre- and post-test will be performed. The tests will include word cloud creation to ascertain common themes, as well as developing a bipolar scaling method questionnaire (Likert scale) to determine changes in understanding of LCA methods, uses, and impact on engineering design. To further enhance student learning, better integration of broader impacts into group project requirements, with the LCA module as background material, is also anticipated.

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