Teaching Life-Cycle Assessment with *Sustainable Minds*©- A Discussion with Examples of Student Projects

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Abstract

When the Department of Geography at the University of Oklahoma expanded its undergraduate degree options to include Environmental Sustainability in 2011, it was faced with the question of how should the Life-Cycle Assessment (LCA) core course be taught, and what aspects of LCA should it cover. In addition to the textbook selected for the classroom, it was clear that students would also need to get hands-on experience using LCA in a manner that reinforced and extended the themes taught in class. This dual challenge was resolved with the selection of a readable and easily understood text and the adoption of *Sustainable Minds* software for the conduct of student projects. In this paper, we describe the manner in which LCA is taught in the classroom and the important role that LCA software has played to help students acquire a working understanding of the merits of the technique as well as its limitations. Examples of student projects that were completed as course assignments are used to illustrate the scope of student interests and accomplishments.

Keywords: Life-Cycle Assessment, Sustainability Education, LCA software, Case Study, Student LCA Projects

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Introduction

In 2011 when the Department of Geography at the University of Oklahoma expanded its undergraduate degree options to include Environmental Sustainability, it was faced with the question: How should the required Life-Cycle Assessment (LCA) core course be taught, and what aspects of LCA should it cover? Though LCA had been utilized by faculty members in various research projects, there had not yet been a course on campus that was dedicated to student education about LCA and how it could be applied. Thus, it became clear to the instructor that whatever textbook was selected for the classroom, students would also need to get hands-on experience using LCA in a manner that reinforced and extended the themes they learned in class. This dual challenge was resolved with the selection of a readable and easily understood text and the adoption of *Sustainable Minds* (Sustainable Minds 2014) software for the conduct of student projects. In this paper, we describe the manner in which LCA is taught in the classroom and the important role that LCA software has played to help students acquire a working understanding of the merits of the technique as well as its limitations. Examples of student projects that were completed as course assignments are used to illustrate the scope of student interests and accomplishments.

Designing the Course

Life-Cycle Assessment is an analytic technique that provides a uniform basis for assessing the environmental impacts associated with the complete design, build, operate, disassemble and disposal stages of technical products. With its focus on the system-wide effects of products and processes over their technical lifetimes, LCA is both an essential concept and a practical application for undergraduate classes in sustainability (Cooper and Fava, 2000, 2001; Crossin et al., 2011; Finnegan et al., 20130. Popularized by writers such as William McDonough and Michael Braungart (McDonough and Braungart, 2002) who explained the importance of *cradle-to-cradle* thinking, LCA has become an appealing pedagogical technique for educators of sustainability.

Accordingly, LCA provides students with the dual benefit of comparing the system-wide environmental effects of alternative products and processes, and also helps in identifying the most appropriate materials for designing more environmentally-friendly, or *green*, technologies. Students who have not had classroom experience with LCA cannot be reasonably expected to compete as well for green jobs against those who have had an LCA course (Crossin et al, 2011; Finnegan et al., 2013). In addition, student understanding of LCA theory and practice serves to facilitate a deeper understanding of related sustainability courses that examine current corporate, governmental, and social issues. When the University of Oklahoma Geography Department faculty decided to develop a new undergraduate degree in Environmental Sustainability, these issues helped determine how a new course in LCA could be effectively designed and taught.

In general terms, LCA is understood to be a four-step analysis: 1) Goal and Scope Definition; 2) Inventory Analysis; 3) Impact Assessment; and 4) Interpretation. This generic framework has arisen through widespread practice and has been subsequently codified through the International Organization for Standardization protocol 14040 (ISO 2006). Standardization of the technique has proven to be very beneficial. Due to the wide latitude in how problems were defined and the array of inputs and outputs that were subject to inventory and analysis, comparison of LCAs done on similar products frequently led to different findings. More troubling for widespread use was the dearth of easily accessible and timely reference data that are required in the Inventory Analysis step (Cooper and Fava, 2001). Analysts confronted with data gaps or out-of-date data sets are less likely to achieve sufficient credibility with their results. In addition, the policy implications of a properly done LCA may need to be carefully interpreted so that the technique is not misused or misapplied. Both technical and nontechnical expertise are important aspects of the LCA process and merit close attention.

In recent years, advances in data-base development and close adherence to ISO 14040 standards have enabled instructors to adopt a variety of LCA software programs for research and classroom instruction. When offered together with a good introductory LCA textbook, computer-based instruction can provide students with a wide selection of subjects to investigate in greater detail. For a core undergraduate course, the preferred textbook is one that offers students an understanding of LCA principles with case study applications that cover several different fields. The book selected for the University's new course was written by a team of Australian researchers (Horne et al., 2009) who not only explain the historical development of LCA and its guiding criteria, but also provide readers with a large number of actual case studies in waste reduction, packaging, water use, energy use, buildings, and agriculture. In addition, the authors provide perspectives on the opportunities and limitations of LCA and address current analytic and policy issues.

Picking the Software

Finding the best fit between the available commercial LCA software and the needs of the new course was a challenge. While the instructor wanted students to gain experience with LCA applications, the new undergraduate degree program did not presume that entering students would have had prior coursework in scientific or technical subjects. As a result, the LCA software that has been used in engineering classes on campus, for example, would most likely not be easy to use by the Department's sustainability students. In addition, the existing computer labs, which were used primarily for Geographic Information Systems (GIS) classes, were limited in their number of terminals. Should the new LCA course grow as rapidly as the program envisioned, the number of computer stations could serve as a limiting factor on future enrollments, and possibly encounter time-of-use conflicts with existing GIS and remote-sensing classes. Moreover, the cost to acquire a site license to download LCA software to the lab was not inexpensive. Should class sizes remain small enough to fit in the computer lab, the cost for acquiring the software would be significant, and might deter the department from acquiring a site license.

With these constraints in mind, a careful search revealed the existence of promising LCA software that offered none of these perceived handicaps. First, the *Sustainable Minds* software operates in the *cloud*, or through remote servers, and would therefore relieve students of the obligation to use a designated computer lab, but would allow them to access the software from any computer they wanted. Second, *Sustainable Minds* offered a free 30-day trial period, which was very appealing at the time, but which was subsequently reduced to 15 days. In addition, *Sustainable Minds* provides a very easy-to-use format and an instructional video that allows students to learn how to use the software by redesigning a common household appliance, the toaster.

Other features that made *Sustainable Minds* appealing for instructional purposes include the connection that links any change in input materials to its subsequent impact in a variety of environmental impact areas that cover resource depletion, public health, and ecological damage. More important, the software is formatted along the lines of a generic LCA. The first setup step includes a project definition, goal definition, and assessment scope. The second step includes an inventory analysis and assessment steps by which the student builds a reference concept, details the bill of materials used in the reference, and is then able to make a variety of material substitutions that instantly reveal the relative impact of specific changes. The software provides students with understandable graphics that can be exported or printed for presentation or included in reports. Finally, the materials database is fairly large and continually growing. This feature enables students to select from among a wide variety of topics.

Student Case Studies

The semester-long LCA course has been taught for the last three years in two phases. In the first phase, students are assigned readings from the textbook for classroom discussion. They are also told that they need to subscribe to *Sustainable Minds* for the duration of the course. The student subscription fee for one semester ($49) is about the cost of an average paperback book. After a couple of weeks they are asked to begin their term assignment by logging onto *Sustainable Minds* and performing an LCA on a toaster, which is employed as a *Sustainable Minds* teaching example to familiarize subscribers with the software. Students are asked to watch the *Sustainable Minds* video presentation and then carry out their own analysis in accordance with the instructions provided. In brief, students are asked to improve a toaster for a client and seek to advance three specific goals: Reduce the carbon dioxide footprint; Reduce the amount of material that ends up in a landfill; and Reduce the human health impacts. After setting up a toaster reference case, the students make material and transportation substitutions whose overall effect can be readily seen through the graphical imagery provided by the software. For many students, this exercise is educational as well as entertaining.

Upon completion of the toaster project, students are asked to review the published literature to identify an LCA of a product or process that interests them. This approach enables students to address individual topics that may differ from those covered in the text and class discussions, and offers a degree of creativity to the students' activities. Students are instructed to select case studies in which the life-cycle inventory used in the analysis is complete, thereby reducing the level of uncertainty for the student. They are asked to create a reference product with the published data and attempt to improve its overall environmental quality as reflected by any three *Sustainable Minds* performance criteria they wish to use. Once a selection has been made, students have a month of class time to work on their project which they can do individually, or in groups of two to three. Should they elect to work as a group, they are asked to write out the respective obligations for each team member as part of their final report.

Completed student projects reflect the variety that the software facilitates and the degree of creativity that undergraduates in a first course can display. Some projects have used LCA to conduct comparative product evaluations while others have explored innovative design options that might improve a product's inherent sustainability. A short list of completed projects from Spring, 2013 includes:

- Air Hand Dryer Redesign.
  Based on the information provided by the manufacturer's website, alternative hand dryer designs were configured for the wider use of ceramics, silicone, and plastic, respectively. Renewable energy sources (e.g. wind) for power were also examined. Impact assessments were measured for human toxicity, human carcinogens, and ecotoxicity.

- Artificial Christmas Tree Analysis.
  This project examined four different artificial Christmas Trees based on a published LCA report. The four alternative designs addressed reducing the impact of human carcinogens, reducing carbon use in the manufacturing and transportation stages, reducing the overall impacts for each tree, and designing a more environmentally-friendly yet practical tree.

- Energy-efficient Refrigerator Comparison.
  This project used both Japanese-made and American-made refrigerators as reference concepts. Alternate designs were developed to demonstrate the average power use of a more recent U.S. model with an earlier version and a rebuilt older U.S. model with all recycled or secondary materials. The goal was to compare both the Japanese and American models with respect to their power use, and the overall efficiency gains that the use of recycled and secondary materials might provide. Impact assessment was based on measures of overall efficiency, ecotoxicity, and global warming potential.

- LED Light Bulb Design.
  This project examined alternative designs to reduce the very large amount (98.62%) of ecotoxicity impacts that are generated by LED light bulbs. Using a recent (~2012) U.S. Department of Energy LCA, three alternative light bulbs designs were created that examined alternative materials, transportation, and end-of-life aspects. The best alternative reduced ecotoxicity to 54.02% from the reference concept.

- Surfboard LCA.

Based on a recent (~2009) master's thesis that examined surfboards from cradle to grave, this project created a reference concept of a standard foam surfboard and three alternative designs that included different types and amounts of wood substituted for foam. Impact categories included ecotoxicity and human carcinogens.

- Sustainable Mattress Design.
  This project was based on a consultant's report on mattresses to the European Commission that was conducted to assign an ecolabel. Two alternative designs were keyed to attain significant reductions in ecotoxicity, human carcinogens, and human toxicity. The use of all natural materials in the second design led to the highest reduction in impacts (88%, 97%, 95%, respectively), however the cost of the replacement materials was unknown.

To better illustrate how well the *Sustainable Minds* software helps students explore alternative designs, we will consider the Eco-friendly Coffee Maker project in detail. The student's goal was to examine ways to redesign a coffee maker and associated bean grinder to reduce the overall environmental impact of the widely used appliances. First, he assembled a complete LCI through an Internet search and formatted the materials to be appropriate for his analysis. After specifying his reference coffee maker and bean grinder options, he developed four different design alternatives. One focused on metals replacement, a second focused on plastics replacement, a third addressed metals, plastics, and packaging, and a fourth assessed stainless steel replacement. The *Sustainable Minds* graphical representation of the fourth alternative bill of materials is shown below in Figure 1 below.

The fourth alternative is based on the substitution of stainless steel with austenitic stainless steel. This type of steel has a high corrosion resistance which is excellent for the coffee maker. The plastic components were switched out with acrylonitrile butadiene styrene due to their low carbon dioxide emission and because it is recyclable. The production performance impact was improved by 64% from the reference coffee maker; carbon dioxide was reduced by 55% from the reference, and 35% from the first alternative.

Name	Material/Process	Qty	Amt	Unit	mPts	CO_2 eq. kg	MS	Part ID	
− Grinder		1			18.0	1.66	E		Part + S.-Asmbly. +
+ Large Spring	Stainless steel (austenitic)	1	0.00075	kg	0.0392	0.00250	E		Process +
+ Coffee Contai	Stainless steel (austenitic)	1	0.0351	kg	1.31	0.0982	E		Process +
+ Spring Holder	Stainless steel (austenitic)	1	0.005	kg	0.167	0.0156	E		Process +
+ Fasteners	Stainless steel (austenitic)	1	0.015	kg	0.785	0.0501	E		Process +
+ Lid	Acrylonitrile-butadiene-styr	1	0.055	kg	0.247	0.0940	E		Process +
+ Casting	Acrylonitrile-butadiene-styr	1	0.135	kg	0.607	0.231	E		Process +
+ Motor Casting	Stainless steel (austenitic)	1	0.209	kg	7.80	0.585	E		Process +
+ Spindle w/ Gri	Stainless steel (austenitic)	1	0.005	kg	0.124	0.0118	E		Process +
+ Plastic Level	Acrylonitrile-butadiene-styr	1	0.00075	kg	0.00877	0.00414	E		Process +
+ Buttons	Acrylonitrile-butadiene-styr	1	0.0008	kg	0.00936	0.00442	E		Process +
+ Motor Rotor	Stainless steel (austenitic)	1	0.064	kg	3.35	0.214	E		Process +
Conducting Le	Copper, secondary, from e	1	0.0351	kg	0.0325	0.00183	E		Process +
Strain Relief	Natural rubber, certified (N	1	0.02	kg	0.0137	0.00708	E		No Processes available
PCB	Glass reinforced polyester	1	0.008	kg	0.457	0.0439	E		No Processes available
Capacitor	Polyethylene terephthalate	1	0.006	kg	0.0471	0.0183	E		Process +
Motor Stator	Stainless steel (austenitic)	1	0.12	kg	2.98	0.282	E		Process +
− Coffee Maker		1			10.5	1.82	E		Part + S.-Asmbly. +
+ Cable Core, 1	Copper, secondary, from e	1	0.035	kg	1.45	0.108	E		Process +
+ Other Compor	Acrylonitrile-butadiene-styr	1	0.04	kg	0.180	0.0683	E		Process +
+ Cable Sheath,	Acrylonitrile-butadiene-styr	1	0.12	kg	0.183	0.0608	E		Process +
+ Housing	Acrylonitrile-butadiene-styr	1	0.91	kg	1.86	0.705	E		Process +
Small Alumin	Aluminum, secondary, old	1	0.08	kg	0.588	0.0550	E		Process +
Plug pins	Copper, secondary, from e	1	0.03	kg	0.0278	0.00156	E		Process +
Glass Jug	Glass for bottles	1	0.33	kg	1.36	0.233	E		Process +
Plug body	Phenol formaldehyde	1	0.037	kg	0.406	0.170	E		No Processes available
Small Steel p	Stainless steel (austenitic)	1	0.12	kg	2.98	0.282	E		Process +
Heating Elem	Stainless steel (austenitic)	1	0.026	kg	1.42	0.135	E		Process +
− Packaging		1			0.140	0.127	E		Part + S.-Asmbly. +
+ Padding	Polystyrene, general purpc	1	0.015	kg	0.134	0.0649	E		Process +
Box	Corrugated board, recyclec	1	0.125	kg	0.00619	0.0623	E		No Processes available
	Manufacturing total				28.6	3.61	E		

Figure 1. Bill of Materials for Coffee Maker Alternative #4.
Source: Justin Henry, GEOG 4543 term report using *Sustainable Minds*.

The *Sustainable Minds* graphical imagery for performance improvement of the fourth alternative is illustrated in Figure 2 below. Note that the performance improvement is clearly seen below which are listed the impact categories for ecological damage, resource depletion, and human health damage.

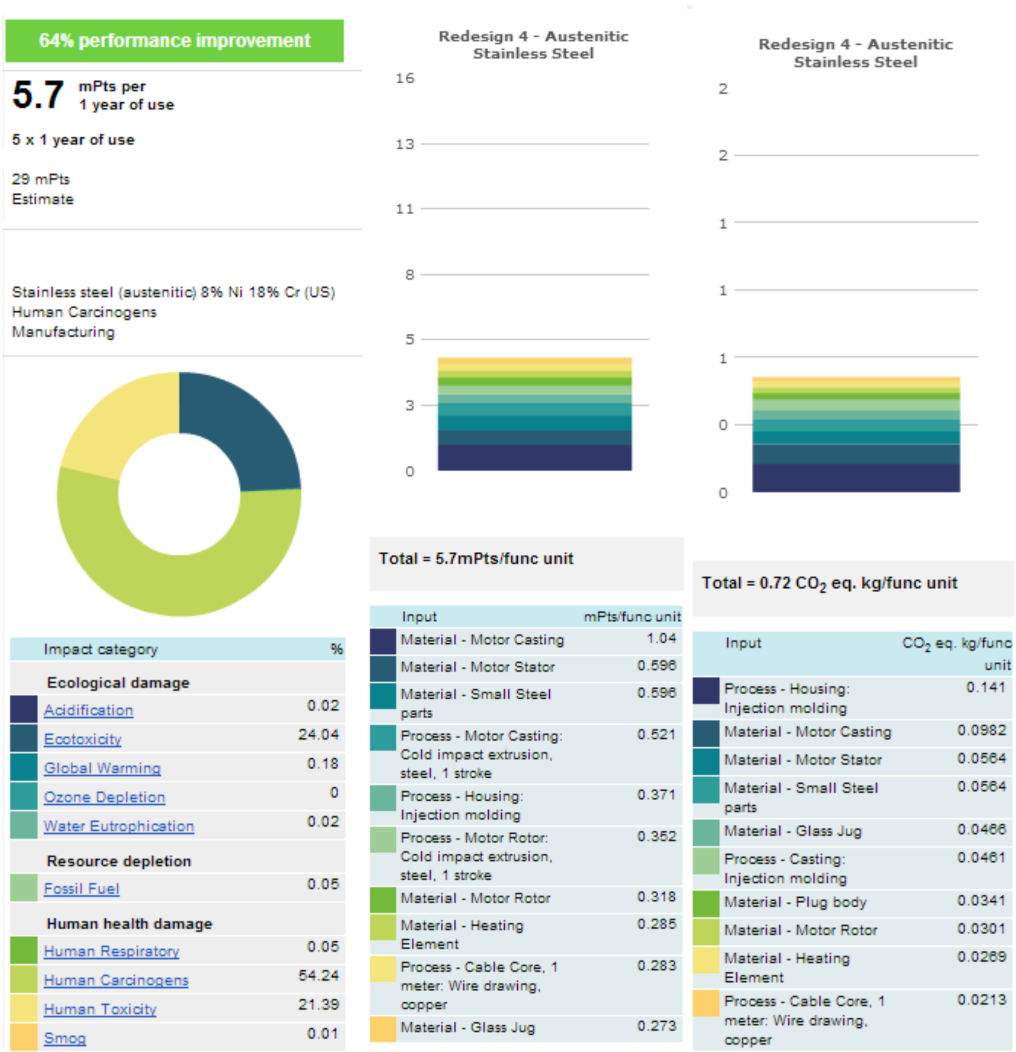

Figure 2. Performance improvement and impact assessment for Coffee Maker Alternative #4. Source: Justin Henry, GEOG 4543 term report using *Sustainable Minds*.

The *Sustainable Minds* graphical presentation of the overall comparison of the four alternative coffee maker designs is shown in Figure 3 below. The final selection is Redesign 4, the stainless steel replacement option. This stems from the student's belief that it provides the best ratio of overall quality to carbon dioxide emission. The austenitic stainless steel can be recycled after it reaches end of life, along with the plastic components.

Functional unit: 1 year of use Create a new Concept +	Impacts / functional unit mPts/func unit	CO_2 eq. kg / functional unit CO_2 eq. kg/func unit	Performance improvement from reference mPts	Performance improvement from reference %	Units of svc delivered Svc. Units	Assessment type
Reference Coffee maker w/ grinder Reference Copy Declare as: | Final	16	1.6			5	Estimate
Final Redesign 4 - Austenitic Stainless Steel Copy | Delete Declare as: Reference	5.7	0.72	+10	+64%	5	Estimate
Lowest impact Redesign 3 - Metals replacement + plastic replacement Copy | Delete Declare as: Reference | Final	2.9	0.43	+13	+82%	5	Estimate
Redesign 1 - Metals replacement Copy | Delete Declare as: Reference | Final	4.9	1.1	+11	+69%	5	Estimate
Redesign 2 - Plastic Replacement Copy | Delete Declare as: Reference | Final	14	1.0	+1.9	+12%	5	Estimate

Figure 3. Comparison of Coffee Maker Alternatives.
Source: Justin Henry GEOG 4543 term report using *Sustainable Minds*.

Conclusions

Students taking the LCA course have used the *Sustainable Minds* LCA software to greatly improve their understanding of LCA and have become more familiar with ways to help improve the environmental quality of product designs. In the four years that the course has been taught, student enrollment has increased. The amount of time allocated to the term project appears to be suitable once students complete their initial assignment to redesign the toaster. For the instructor, the features that *Sustainable Minds* built into its software have made it extremely inviting for students who may lack a technical or scientific background. The graphical presentations of alternative product configurations, along with their impact scores, have helped students to gain a clearer appreciation of cradle to cradle thinking, and have provided some students with a clearer sense of what career options would be attractive to them. Based on the student projects completed so far, the course has been the subject of student conversation outside the classroom, and has helped to generate interest in the new undergraduate degree program.

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