# AC 2012-4103: "LIFE CYCLE SUSTAINABILITY ECONOMICS" MODULE

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# "Life Cycle Sustainability Economics" Module

**Abstract**

For engineering products and designs to be sustainable, it is critically important to educate all engineers, regardless of specialty, about conducting economic analyses that consider environmental impacts. If engineers do not include environmental impacts in their economic analyses, they are more likely to choose alternatives that are cheaper up front but have adverse environmental impacts over the long-term.

The module discussed in this paper is thus designed to teach engineering students ways to consider environmental impacts in economic analyses. The module provides a brief introduction to how traditional economics falls short of sustainability, through the Tragedy of the Commons and externalities. It then discusses several solutions, including triple bottom line accounting, life cycle cost analysis, and inclusion of environmental benefits in cost-benefit analysis. The module includes objectives, PowerPoint lecture slides, discussion questions, homework problems, and assessment questions, all available for engineering economy instructors to download from the internet in a "grab-and-go" ready format, for easy incorporation into their courses.

The module, which requires one class period, has been implemented for 4 semesters at the University of Texas at Arlington, in two junior-level courses: "Economics for Engineers," a required course in Industrial Engineering, and "Construction & Value Engineering," a required course in Civil Engineering. Student surveys conducted for 3 of these semesters indicate that for 5 of the 7 module objectives, at least 50% of students were "Strongly Confident" or "Confident" of their ability to address the objective. These relatively low levels of confidence were likely due at least partially to the fact that the project PIs and graduate students presenting the module were guest instructors in the engineering economics classes. This meant that the instructors typically did not assign the module homework problems or use the module assessment questions in their exams. If the engineering economics course instructor were implementing the module, and assigning associated homework problems, student confidence would presumably increase. Moreover, we plan to modify the module to focus on micro-economic objectives, thus covering fewer objectives but covering them more effectively.

In addition, a pre-test and post-test were administered for 2 semesters in the industrial engineering course, to assess the degree to which module objectives were achieved. The mean of the post-test scores exceeded that of the pre-test scores by 97.5% and 99.5% levels of confidence in the two semesters.

The "Life Cycle Sustainability Economics" module was one of 11 sustainability modules developed and implemented in undergraduate engineering courses as part of the Engineering Sustainable Engineers program at University of Texas at Arlington, sponsored by National Science Foundation. The program was designed to improve undergraduate student knowledge of and competency in addressing sustainability issues in engineering design and problem solving, and involves collaboration among faculty in Civil, Industrial, and Mechanical Engineering.

**Introduction**

Sustainability has been identified as one of the global grand challenges of the 21st century. In order for future generations to enjoy a satisfactory quality of life, the current generation must find ways to meet humanity's needs for energy, shelter, food and water in ways that are environmentally, economically, and socially sustainable.

Sustainable engineering may be defined as engineering for human development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1] Due to population growth and expanded global development, the next generation of engineers must be able to design with fewer resources for a wider variety and greater number of end users.[2] According to National Academy of Engineering (NAE) President Charles M. Vest, macroscale issues of great societal importance, like energy, water, and sustainability, will dominate 21st century engineering.[3] According to the NAE report *The Engineer of 2020*, engineers of the future must gain a holistic understanding of sustainable economic growth and development, in order to solve society's pressing environmental problems.[4]

Regardless of their specialty (e.g. civil, chemical, mechanical), engineers must conduct economic evaluations in designing and constructing/producing structures and products. Economic analysis is often used to choose among several design alternatives. If engineers include environmental impacts in their economic analyses, they are more likely to choose alternatives that are environmentally sustainable over the long-term. Conversely, if engineers do not include environmental impacts in their economic analyses, they are more likely to choose alternatives that are cheaper up front but have adverse environmental impacts over the long-term. For example, a building designed with superior insulation may cost more initially; however, if building operating costs are included in the life cycle cost analysis, the building may be considerably cheaper over the long term, since electricity bills for heating and cooling would be lower. Not only would a building with high quality insulation would be more cost effective over the long-term, but it would also be environmentally superior because of its lower energy requirements. Lower energy requirements mean lower emissions of traditional air pollutants and greenhouse gases from burning fossil fuels to generate electricity.

Thus, for engineering products and designs to be sustainable, it is critically important to educate all engineers, regardless of specialty, about conducting economic analyses that consider environmental impacts. The module discussed in this paper attempts to do just that. It is designed to be covered in one class period, and is available for engineering economy instructors to download from the internet in a "grab-and-go" ready format, for easy incorporation into their courses.

The "Life Cycle Sustainability Economics" module was one of 11 sustainability modules developed and implemented in 17 undergraduate engineering courses as part of the Engineering Sustainable Engineers program at University of Texas at Arlington, sponsored by National Science Foundation. The program was designed to improve undergraduate student knowledge of and competency in addressing sustainability issues in engineering design and problem solving, and involves collaboration among faculty in Civil, Industrial, and Mechanical Engineering. Many faculty members in these departments, besides those who were Co-PIs on the project,

embraced the Engineering Sustainable Engineers concept, and were very willing to incorporate the sustainability modules into their courses. The sustainability modules will likely continue to be presented in these courses, past the grant period. Certain instructors, however, would likely not have allowed us to present the module in their courses if it had not been part of an NSF-sponsored project. Presentation of modules these courses will likely not continue after the grant period.

## Objectives

The objectives of the work described here were:
1. To develop a 1-class module on sustainability economics for inclusion in traditional engineering economy classes;
2. To evaluate the module's effectiveness via surveys and pre- and post-tests.

## Methods

*Methods for Module Development.* Many undergraduate engineering programs require students to take a junior level engineering economy class. Based on micro-economics, such courses are typically very practically oriented, focusing on economic analysis techniques that students as future engineers will likely use in their work: present worth, annual payments, and future worth analysis; rate-of-return analysis; and cost-benefit analysis. Before beginning development of the "Life Cycle Sustainability Economics" module, the authors informally surveyed some of the topics typically included in environmental economics classes, and found that these usually deal with macroeconomics issues, with a heavy emphasis on theory. A pure macro-economics, theoretical approach would not mesh well with the micro-economics, practical approach typical of most engineering economics classes. We thus decided to develop a hybrid module, which would draw on macro-economics and environmental economics theory to motivate the need for the sustainable solutions, by showing how traditional economics falls short of protecting the environment. The module would then focus on practical ways that students as future practicing engineers could incorporate environmental impacts in their micro-economic analyses.

Information for the module was assimilated from internet searches, textbooks, and the authors' own knowledge about the content.

*Methods for Module Evaluation.* The "Life Cycle Sustainability Economics" module has been implemented for 4 semesters at UT Arlington, in the junior level "Construction & Value Engineering" course in civil engineering, and the junior level "Economics for Engineers" course in industrial engineering. Both are required courses for students in the major. The number of students exposed to the module each semester is shown in Table 1.

**Table 1**. Implementation of "Life Cycle Sustainability Economics" Module at University of Texas at Arlington

| Course | Implementation – Number of Students | | | | |
| --- | --- | --- | --- | --- | --- |
| | Spring 2010 | Fall 2010 | Spring 2011 | Fall 2011 | Total |
| CE 3310 Construction & Value Engineering | 27 | 21 | 30 | 23 | **101** |
| IE 3312 Economics for Engineers | 79 | 84 | 70 | 50 | **283** |
| TOTAL | **106** | **105** | **100** | **73** | **384** |

During Spring 2010, Fall 2010, and Spring 2011, a survey was administered to students at the end of each course to assess the degree to which *they perceive* themselves to have achieved the module learning objectives. During Fall 2010 and Spring 2011, a pre-test and post-test were administered to students in the industrial engineering course, to assess the degree to which module objectives were achieved. In Fall 2010, the pre- and post-tests were administered via computer using WebCT educational software. Students were given a password and allowed to complete the tests on their own time outside of class. The tests were timed to allow students a maximum of 30 minutes to input their responses. In Spring 2011, the university changed from WebCT to Blackboard instructional software. Rather than convert our tests to Blackboard format, we chose to administer paper copies of pre- and post-tests during classes. The tests were not administered in the civil engineering course due to difficulty in coordinating with the course instructor.

**Results and Discussion**

*Module Description*. The module was designed to be "grab-and-go" ready for faculty. The module includes the following components:
• Unit objectives written in behavioral language (things students should be able to do by the end of the unit);
• PowerPoint lecture slides with notes, example problems, discussion questions, and active learning activities;
• Homework practice problems; and
• Assessment tools (test questions).

The module thus contains everything a faculty member needs to present a lecture, lead discussions, conduct active learning activities, assign homework exercises, and assess student learning. Use of the module will thus require minimal preparation time.

According to module objectives, by the end of the unit, a student should be able to:
1. Give an example of a Tragedy of the Commons and a possible solution.
2. Give an example of pollution creating an externality and a possible solution.

3. Compare advantages and disadvantages of traditional emission limits and emissions trading systems.
4. Compare advantages and disadvantages of triple bottom line accounting.
5. List phases of a project or product life to consider in life cycle cost analysis.
6. Perform a life cycle cost analysis.
7. Explain how one might determine the value of environmental benefits.
8. Perform a cost-benefit analysis that includes environmental benefits.

To motivate the need to include environmental impacts in economic analysis, the PowerPoint lecture slides first discuss the Tragedy of the Commons and externalities, two ideas from macro-environmental economics, which show how traditional economics falls short of protecting the environment. According to the Tragedy of the Commons, multiple individuals, each acting in his/her own economic self-interest, will ultimately deplete a shared limited resource, such as a forest or a clean river. Depletion of the resource, however, is not in anyone's long-term interest. Environmental externalities are environmental impacts on a third-party that the decision-maker does not pay for. For example, a company may decide to emit air pollution from a factory. Even though the pollution may cause a nearby resident to go to the hospital because of an asthma attack, the company that owns the factory does not have to pay the hospital bill. Thus, the factory air pollution and its impact on nearby residents represent an environmental externality.

The PowerPoint lecture slides then present two solutions to the problems of the Tragedy of the Commons and externalities which must be implemented by government on a large scale: emission fees and emission trading systems. Emission fees make it cheaper to treat rather than discharge harmful pollutants. Emission trading systems place a cap on regional emissions. Each company is initially assigned a certain number of pollution credits. Companies that need to pollute more must buy credits from those who pollute less. Companies that can reduce their emissions most cost-effectively will do so (theoretically) and sell credits to companies that cannot reduce cheaply, achieving the pollution reduction at the lowest cost to society. These solutions, although implemented on a state or national scale, may nonetheless impact how individual companies deal with their emissions, and are thus useful for students as future company engineers to know about.

Finally, the module discusses several economic solutions that individual companies could implement on their own (although government incentives or mandates to do so would still be helpful):
• triple bottom line accounting,
• life cycle cost analysis,
• quantifying environmental benefits, and
• using a lower discount rate.

Triple bottom line accounting involves measuring company success using not only profit but also impacts on the environment and society. Life cycle cost analysis includes all phases of a product or structure's life cycle (materials acquisition, production/construction, use, and disposal/demolition) in cost analysis. Quantifying environmental benefits provides a way for such benefits to be considered in life cycle cost analysis or cost-benefit analysis. For example, installing an air pollution control device would have a quantifiable health benefit of fewer people

missing work; a dollar value can be assigned to missed work using salaries. Using a lower discount rate when possible means that future environmental benefits will not be discounted as heavily. Using triple bottom line accounting and quantifying environmental benefits would require support on a company level. It is our hope, however, that individual engineers working for a company that does not include sustainability as a core value could still choose to use life cycle cost analysis and lower discount rates in their own economic analyses.

The PowerPoint lecture slides contain instructor notes, viewed in "Notes Page" View. These notes include several active learning activities, an example of which is given in Figure 1.

**Figure 1**. Example Module Active Learning Activity

Have students in groups of 2 or 3 brainstorm as many methods of quantifying environmental benefits in 1 minute as they can. Then go around the room, soliciting one idea from each group and writing it on the board, until all reasonable ideas have been exhausted.

Most of the module's example problems and homework problems focus on life cycle cost analysis, and cost-benefit analysis that includes environmental benefits. An additional homework problem asks students to read and respond to questions concerning Garrett Hardin's "Tragedy of the Commons" article that appeared in *Science* in 1968.[5]

**Figure 2**. Example Life Cycle Cost Analysis Homework Problem

1. A company is considering two roadway asphalt pavement alternatives. Although it has a higher up-front cost, Alternative 2 is designed to be more sustainable:
   - It can be more easily re-used to make asphalt shingles (and thus has a higher salvage value).
   - It is designed to have a longer lifetime, which reduces long-term the need for paving materials.
   - It requires less maintenance, which reduces energy and materials consumption, as well as maintenance costs.

   For the two alternatives shown below and assuming a 24-year time span and i=6%, perform an equivalent annual cost comparison.

   |  | Alternative 1 | Alternative 2 |
   |---|---|---|
   | Initial cost | $100,000 | $150,000 |
   | Salvage value | $10,000 | $20,000 |
   | Life | 8 years | 12 years |
   | Annual operation & maintenance | $8000 | $4000 |

Module components are posted on the project web site at http://www.uta.edu/ce/ese/Learning%20Modules.htm. The web site is designed so that a user can download the entire module as a zip file, or individual module components. An "Introduction to Sustainability" module is also posted on the website. This short set of PowerPoint slides can be used by an instructor of any course as a review of basic sustainability concepts, prior to covering the sustainability module specifically related to the course.

Since the module includes present/annual/future worth analysis and cost-benefit, it would fit best in a course after these topics have been discussed. It can serve as a useful review of these topics, in context of practical applications.

*Module Evaluation*. Table 2 below shows results from the student survey concerning how well they perceive themselves to have achieved module learning objectives. Students were not asked about their ability to conduct a life cycle cost analysis, because this was added as a unit objective after the surveys were administered, although the module covered life cycle cost analysis from the first semester it was introduced. For 5 of the 7 questions, at least 50% of the students were confident or strongly confident of their ability to achieve the objective. For the other 2 questions, almost 50% (49.6% and 46.2%) of students were confident or strongly confident of their ability to achieve the objective.

**Table 2**. Student Survey Results Concerning "Life Cycle Sustainability Economics" Module

| | Question | Semester | Strongly Not Confident | Not Confident | Confident | Strongly Confident | Confident or Strongly Confident |
|---|---|---|---|---|---|---|---|
| 1 | I can give an example of a Tragedy of the Commons and a possible solution. | Spring 2010 | 10 (21.7%) | 11 (23.9%) | 23 (50.0%) | 1 (2.2%) | |
| | | Fall 2010 | 14 (24.6%) | 15 (26.3%) | 16 (28.1%) | 12 (21.1%) | |
| | | Spring 2011 | 5 (29.4%) | 5 (29.4%) | 6 (35.3%) | 1 (5.9%) | |
| | | **Overall** | **29 (24.4%)** | **31 (26.1%)** | **45 (37.5%)** | **14 (11.8%)** | **49.6%** |
| 2 | I can give an example of pollution creating an externality and a possible solution. | Spring 2010 | 7 (15.2%) | 12 (26.1%) | 22 (47.8%) | 5 (10.9%) | |
| | | Fall 2010 | 5 (8.8%) | 14 (24.6%) | 30 (52.6%) | 8 (14.0%) | |
| | | Spring 2011 | 0 (0.0%) | 6 (35.3%) | 7 (41.2%) | 4 (23.5%) | |
| | | **Overall** | **12 (10.0%)** | **32 (26.7%)** | **59 (49.2%)** | **17 (14.2%)** | **63.3%** |
| 3 | I can compare advantages and disadvantages of triple bottom line accounting. | Spring 2010 | 7 (15.2%) | 18 (39.1%) | 13 (28.3%) | 7 (15.2%) | |
| | | Fall 2010 | 10 (17.5%) | 21 (36.8%) | 12 (21.1%) | 14 (24.6%) | |
| | | Spring 2011 | 2 (11.8%) | 6 (35.3%) | 6 (35.3%) | 3 (17.6%) | |
| | | **Overall** | **19 (16.0%)** | **45 (37.8%)** | **31 (26.1%)** | **24 (20.2%)** | **46.2%** |
| 4 | I can compare advantages and disadvantages of traditional emission limits and emissions trading systems. | Spring 2010 | 7 (15.2%) | 14 (30.4%) | 15 (32.6%) | 10 (21.7%) | |
| | | Fall 2010 | 8 (14.0%) | 20 (35.1%) | 20 (35.1%) | 9 (15.8%) | |
| | | Spring 2011 | 4 (23.5%) | 5 (29.4%) | 7 (41.2%) | 1 (5.9%) | |
| | | **Overall** | **19 (15.8%)** | **39 (32.5%)** | **42 (35.0%)** | **20 (16.7%)** | **51.7%** |
| 5 | I can explain a way to determine the value of environmental benefits. | Spring 2010 | 4 (8.7%) | 6 (13.0%) | 23 (50.0%) | 11 (23.9%) | |
| | | Fall 2010 | 7 (12.3%) | 8 (14.0%) | 28 (49.1%) | 14 (24.6%) | |
| | | Spring 2011 | 2 (11.8%) | 3 (17.6%) | 9 (52.9%) | 3 (17.6%) | |
| | | **Overall** | **13 (11.0%)** | **17 (14.4%)** | **60 (50.8%)** | **28 (23.7%)** | **74.6%** |
| 6 | I can list phases of a project or product life to consider in life cycle analysis. | Spring 2010 | 5 (10.9%) | 5 (10.9%) | 22 (47.8%) | 12 (26.1%) | |
| | | Fall 2010 | 4 (7.1%) | 14 (25.0%) | 27 (48.2%) | 11 (19.6%) | |
| | | Spring 2011 | 0 (0.0%) | 4 (23.5%) | 8 (47.1%) | 5 (29.4%) | |
| | | **Overall** | **9 (7.7%)** | **23 (19.7%)** | **57 (48.7%)** | **28 (23.9%)** | **72.6%** |
| 7 | I can perform a cost-benefit analysis that includes environmental benefits. | Spring 2010 | 6 (13.0%) | 14 (30.4%) | 10 (21.7%) | 14 (30.4%) | |
| | | Fall 2010 | 5 (9.1%) | 13 (23.6%) | 19 (34.5%) | 18 (32.7%) | |
| | | Spring 2011 | 2 (11.8%) | 4 (23.5%) | 7 (41.2%) | 4 (23.5%) | |
| | | **Overall** | **13 (11.2%)** | **31 (26.7%)** | **36 (31.0%)** | **36 (31.0%)** | **62.1%** |
| **TOTAL** | | | **114 (13.8%)** | **218 (26.7%)** | **330 (39.8%)** | **167 (20.1%)** | **60.0%** |

We plan to revise the module to focus on Objectives 5-8 listed earlier in the article, which are the micro-economics objectives. These objectives are most important for future engineers, because they involve ways to consider environmental impacts in their economic analyses. The micro-economics objectives correspond to Questions 5-7 in Table 2; students were more confident of

their ability to achieve these objectives, compared with Objectives 1-4. Objectives 1-4 related primarily to macro-economics and large-scale solutions; they are less critical for engineering students from a practical viewpoint.

Deleting module information related to Objectives 1-4 will provide more time to focus on Objectives 5-8. We thus plan to cover fewer objectives, but cover them well. Extending the module to two class periods would provide additional time for active learning activities and working problems associated with Objectives 5-8. This would likely increase student confidence in their ability to achieve these objectives.

It is also important to note that the project PIs and graduate students presenting the module were guest instructors in the engineering economics classes, which meant that the instructors typically did not assign the module homework problems or use the module assessment questions in their exams. If the engineering economics course instructor were implementing the module, they would presumably assign homework problems and cover the module material on exams, which would give students more familiarity with the material and presumably increase student confidence in their ability to achieve module objectives.

Table 3 presents module pre- and post-test results. A one-tailed matched pairs t-test was conducted to determine whether the post-test mean score exceeded the pre-test mean score.

**Table 3**. Summary of Module Pre- and Post-Test Assessment Results

| Module | | | | | Mean Points Scored | | | Level of confidence that post-test mean > pre-test mean |
| No. | Title | Course | Semester | No. of students | Pre-Test | Post-Test | t value | |
|------|-------|--------|----------|-----------------|----------|-----------|---------|----|
| 3 | "Life Cycle Sustainability Economics" | IE 3312 | Fall 10 | 6 | 10.3 | 14.2 | 2.89 | 97.5% |
| | | | Spr. 11 | 31 | 11.6 | 18.4 | 7.32 | 99.5% |

The mean of the post-test scores exceeded that of the pre-test scores by a 97.5% and 99.5% level of confidence in Fall 10 and Spring 11, respectively. In Fall 10, 84 students were enrolled in IE 3312; although 57 completed the pre-test, only 6 completed the post-test; in Spring 11, 70 students were enrolled in IE 3312; 35 completed the pre-test, but only 31 completed the post-test. The pre-test was administered earlier in the semester, when students had more time available. The post-test was administered at the end of the semester, when students experience more time constraints (multiple projects due, exams, etc.) Not only did fewer students complete the post-test, but the students also seemed less thorough in their responses.

## Conclusions

If engineers include environmental impacts in their economic analyses, they are more likely to choose alternatives that are environmentally sustainable over the long-term. Accordingly, a "Life Cycle Sustainability Economics" module was developed to teach engineering students ways to consider environmental impacts in economic analyses. The module includes objectives, PowerPoint lecture slides, discussion questions, homework problems, and assessment questions, all available for engineering economy instructors to download from the internet in a "grab-and-go" ready format, for easy incorporation into their courses.

The module, which requires one class period, has been implemented for 4 semesters at the University of Texas at Arlington. Surveys showed that at least 50% of students were "Confident" or "Strongly Confident" of their ability to meet 5 of 7 module objectives surveyed. In response to the relatively low confidence level of the students, we plan to modify the module to focus on micro-economic objectives, thus covering fewer objectives but covering them more effectively. Pre- and post-tests showed a significant improvement in post-test average scores, to 97.5% and 99.5% levels of confidence for two semesters.

## Acknowledgments

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