ENVR/ENRG 638: LIFE CYCLE ASSESSMENT

SPRING 2025
Monday & Wednesday 4:40 – 5:55 p.m.
Carol A. Hee, Ph.D., MBA
cah115@duke.edu
Office Hours by Appointment

TA: Anisah Zarif (anisah.zarif@duke.edu)

COURSE DESCRIPTION

Sustainability managers commonly employ a life cycle perspective to comprehensively assess environmental impacts at all stages, including its design, transportation, raw materials acquisition, manufacturing, distribution, sale, consumer use, and fate at its end of life. In this class, students will learn (1) how companies use the life cycle framework to formulate corporate sustainability strategy and to inform product improvement/innovation; (2) details about the international standard that defines how to conduct a rigorous life cycle assessment; (3) about ecoinvent, the internationally recognized primary LCA data repository; and (4) how to use screening-level and best-in-class life cycle assessment software.

Specific learning outcomes include that students will be able to do the following:

1. Articulate the value of a Life Cycle Analysis (LCA) to business and the environment
2. Describe the theory of an LCA
3. Outline the steps to conduct attributional and comparative LCAs
4. Define a goal and scope of an LCA
5. Build a life cycle inventory (LCI) from primary and secondary data
6. Understand the connection between LCI and damage mid- and endpoints
7. Describe common environmental impacts assessed through various impact assessment methodologies
8. Understand the structure and function of ecoinvent
9. Use ecoinvent to find impact factors and use these to construct an LCA
10. Conduct a screening-level life cycle assessment with LCA software
11. Evaluate interpret, critique, and communicate LCA results
12. Enumerate the requirements that must be met for an LCA to be compliant with ISO standards
13. Explain the difference between an LCA, carbon footprint, and water footprint and between product- and corporate-level environmental assessments
14. Understand the limitations of LCA and the problems with normalization and weighting
15. Extrapolate learnings from LCA studies published in the scientific literature
16. Approach complex problems with a system-thinking mindset
17. Create data displays that clearly communicate the implications of life cycle analysis

IMPORTANT MATTERS NEEDING TO BE ADDRESSED UP FRONT

1. Basic Needs

Any student who faces challenges securing their food, housing, or other basic needs and believes this may affect their performance in the course is urged to contact the Dean of Students for support.

Any student who faces challenges accessing course material and/or attending class sessions should bring this to my attention. Accommodation can be made so that your participation and other grades do not suffer as a result of issues beyond your control.

The most important thing you can do if/when you face issues is to communicate these to me as soon as possible.

2. Solidarity and Anti-Racism

I, Professor Carol Hee, respect the inherent dignity of all people, especially my students, and know that long-standing and ever-present issues of systemic racism, anti-LGBTQ sentiment, and other forms of exclusion and injustice cause harm to many and all-to-often go unacknowledged. I have undergone unconscious bias training and am actively educating myself about how I can best be anti-racist and an ally to the marginalized. I endorse the Nicholas School's commitment to diversity, equity, and inclusion (https://nicholas.duke.edu/about/diversity-equity-inclusion). As an educator, I know that one of the most useful things I can do to support equity is to utilize the pedagogical methods known as "Inclusive Teaching." Inclusive teaching requires students to take an active role in efforts to create and maintain a culture of inclusion. I count on every student to uphold the values espoused here. I remain open to learning and making changes, so students are welcome to discuss their ideas and concerns with me.

In accord with Title IX, Duke prohibits discrimination and harassment based on any protected status—i.e., race, religion, gender, ethnicity. Discriminatory or harassing behavior will not be tolerated in this class. If a student is experiencing harassment, they should feel welcome to discuss this problem with Professor Hee who is willing to serve as an advocate on their behalf.

Duke University exists on land that was originally the territory of several Native nations, including the Shakori, Catawba, and Eno peoples and, to a large extent, was built by slave labor. One way to give honor to those who suffered injustices related to the creation of our university is for you to make the most of your education—to be the best student you can be, as I will strive to be the best teacher I can be, and to use what you learn at Duke to make the world a better place. In the words of Peter Parker's uncle "With great power, comes great responsibility." The goal that drives me to teach this course is to empower you with knowledge, insight, and confidence that will empower you to drive change. Being a student at Duke is a great privilege that comes with great responsibility.

3. Physical and Mental Health

Many of my past students have benefited from counselling through University Health Services. I personally was a beneficiary of this support while a graduate student at UNC in the late 1990s and remain a strong supporter of having professional support for one's mental health in the same way people have a primary care physician for their physical health. You may find helpful support starting at this website: https://students.duke.edu/wellness/

If your health or concern about the health and well-being of a loved one is getting in the way of you doing your best work in this class, *please communicate this to me sooner rather than later.* Across my 14 years of teaching, I have worked with many students to devise ways to meet course requirements in light of

hardships. Please do not wait until the end of the semester to contact me. Own your power and advocate for yourself. I am one of many who stand ready to do what we can to help.

Duke offers several resources for all students to seek assistance and to nurture daily habits that support overall well-being such as the following:

- *DuWell* (link)
  DuWell provides Moments of Mindfulness (stress management and resilience building) and meditation programming (Koru workshop) to assist students in developing a daily emotional well-being practice. All are welcome and no experience necessary.

- *DukeReach* (link)
  DukeReach provides comprehensive outreach services to identify and support students in managing all aspects of well-being.

- *Counseling and Psychological Services (CAPs)* (link)
  CAPS services include individual and group counseling services, psychiatric services, and workshops. CAPS also provides referral to off-campus resources for specialized care.

- *TimelyCare (formerly known as Blue Devils Care)* (link)
  An online platform that is a convenient, confidential, and free way for Duke students to receive 24/7 mental health support through TalkNow and scheduled counseling.

4. Academic Support (link)

The Academic Resource Center (the ARC) offers services to support students academically during their time at Duke. The ARC can provide support with time management, academic skills and strategies, course-specific tutoring, and more. ARC services are available free to any Duke student.

If you are a student with a disability and need accommodations for this class, it is your responsibility to register with the Student Disability Access Office (SDAO) and provide them with documentation of your disability. SDAO will work with you to determine what accommodations are appropriate for your situation. Please note that accommodations are not retroactive and disability accommodations cannot be provided until a Faculty Accommodation Letter has been given to me. Please contact SDAO for more information: sdao@duke.edu or access.duke.edu.

5. Sick Absences and Inclement Weather

In the event of inclement weather or other connectivity-related events that prohibit class attendance, I will notify you how we will make up missed course content and work. Asynchronous catch-up methods may apply, and we may rely on Duke's designated make-up days.

To keep the university community as safe and healthy as possible, please do not come to class if you have cold symptoms. Please inform me of your absence and plan to complete any missed work. Students who encounter short- and long-term medical issues or instances of personal distress or emergency can seek academic support if needed.

COURSE INFORMATION

COURSE MATERIALS

Required Software: You must purchase a student license for Sustainable Minds at this website: http://www.sustainableminds.com/get-started. ($49)

Textbook: FREE LCA textbook "Life Cycle Assessment: Quantitative Approaches for Decisions that Matter" by H. Scott Matthews, Chris T. Hendrickson, and Deanna H. Matthews. Available at in multiple languages https://lcatextbook.com/

*Note that the website for this e-book also has a page of links for finding LCA jobs.

Additional Readings: Posted on Canvas and linked to through this syllabus.

PARTICIPATION (16%)

Participation in this course is defined as a combination of attendance and contributions to class discussions.

Attendance (8%)

If you are unable to join class for whatever reason, please do the professional and courteous thing and send our TA, Anisah Zarif (anisah.zarif@duke.edu) an email *before class*. If you have more than two absences, your participation grade will decrease according to the following scale:

0 or 1 absence: 8/8
2 absences: 6/8
3 absences: 4/8
4 or more absences: 0/5

This policy allows for students to miss one class due to sickness or a scheduling conflict without penalty and for missing 2 classes with minimal affect on one's final grade. If illness prevents you from missing class more than twice, a doctor's note will be required to avoid penalty.

"Being a Beneficial Presence" (8%)

This class is designed as a synchronous course in order to enable real-time discussion. Active, participation is expected. By actively participating in discussion, you will be a "beneficial presence": you, your peers, and your professor will all learn more.

Please remember: (1) quality is more important than quantity and (2) silence is not a reliable indicator of preparation or thoughtfulness. Excellent comments possess one or more of the following attributes: (1) they offer an original and relevant perspective on the issue, (2) they move the analysis forward by building on previous contributions or by revealing fresh insights, (3) they transcend the "I feel" syndrome by including evidence that is based on more than personal experience — in other words, your thinking should reflect and integrate examples from other contexts. Please do not hesitate to ask for clarification or for something to be repeated when you need it; chances are several others are in the same position as you.

If you are not comfortable volunteering to participate, taking this class will provide you with the opportunity to gain experience and confidence doing so. It is important for your long-term career success to practice speaking up as a way to demonstrate that you are a beneficial presence. I encourage participation from all students, but ***the burden of participating remains with you.***

One recommendation is to prepare in advance one point or one question you would like to contribute; another is to set a personal goal of volunteering to make contributions at least once a week. This syllabus contains discussion questions for most days meaning that you can prepare and even write an answer to one or more of these questions in advance to proactively share with the class.

- Students who do not participate and are only silent observers will earn 0/8.
- Contributions made only rarely and only when called upon will earn 2/8.
- Contributions made only occasionally will earn 4/8.
- Contributions made on an approximately weekly basis will earn 6/8.
- Contributions made on an approximately daily basis will earn 8/8.

QUIZZES AND ASSIGNMENTS

See Canvas for due dates

- Quizzes **cannot** be completed late.
- Due dates are **Non-Negotiable**, so please plan accordingly.
- Submissions for items other than quizzes will be accepted up to one week late with a **20% penalty** for lateness.
- **After one week**, submissions will no longer be accepted.

QUIZZES ON CANVAS (Total to 20% of course grade)

ASSIGNMENTS (Total to 64% of course grade)

1. **Review of a published LCA (5%)**
2. **LCA of Student-selected product in Sustainable Minds (14%)**
3. **LCA of Pinewood Derby Car in Excel (25%)**
4. **LCA of Cleaning Product in Standard and Refill Packaging (20%)**

GRADING SCHEME

Raw scores in points will be converted to percentages.
Percentages will be converted to letter grades using this table:

94.0	≤	**A**	≤	100	73.0	≤	**C**	<	76.9
90.0	≤	**A-**	<	93.9	70.0	≤	**C-**	<	72.9
87.0	≤	**B+**	<	89.9	67.0	≤	**D+**	<	69.9
83.0	≤	**B**	<	86.9	63.0	≤	**D**	<	66.9
80.0	≤	**B-**	<	82.9	60.0	≤	**D-**	<	63
77.0	≤	**C+**	<	79.9	0	≤	**F**	<	60

ACADEMIC INTEGRITY

All activities of Nicholas School students, including those in this course, are governed by the Duke Community Standard, which states:

> Duke University is a community dedicated to scholarship, leadership, and service and to the principles of honesty, fairness, respect, and accountability. Citizens of this community commit to reflect upon and uphold these principles in all academic and nonacademic endeavors, and to protect and promote a culture of integrity. To uphold the Duke Community Standard:
> - I will not lie, cheat, or steal in my academic endeavors;
> - I will conduct myself honorably in all my endeavors; and
> - I will act if the Standard is compromised.

COURSE POLICY ON ARTIFICIAL INTELLIGENCE

This course's policy is VERY RESTRICTIVE: Students are **not allowed** to use advanced automated tools (artificial intelligence or machine learning tools such as ChatGPT or Dall-E 2) to generate content for assignments in this course.

Each student is expected to complete each assignment ***without substantive assistance*** from automated tools for content.

Students MAY use tools such as Grammerly, SpellCheck, and Chat GPT ***to improve the grammar*** of text they have written independently of such tools.

For example, you may ask Chat GPT "What is a clear way to say ____ ?" You may NOT ask AI questions relevant to the prompt for any assignment.

COURSE SCHEDULE

The instructor reserves the right to adapt the course schedule as necessary throughout the semester.

1. Wednesday, January 8

Topic: Introductions, course details, and plans

Assignments:

a) Review course syllabus and come to class with any questions you have

b) Complete the draft of your personal page in the slide deck available at: https://docs.google.com/presentation/d/1Lm1FMgs-gR9XlH3m3nO5PRMl8DFJHBWiUaPJyRDSrkc/edit?usp=sharing

2. Monday, January 13

Topic: Continuation of introductions

Assignments:

a) Review course syllabus and come to class with any questions you have

b) Complete the draft of your personal page in the slide deck available at: https://docs.google.com/presentation/d/1Lm1FMgs-gR9XlH3m3nO5PRMl8DFJHBWiUaPJyRDSrkc/edit?usp=sharing

c) READ the following sections in our **Textbook's** Chapter 1:

- A History of Life cycle Thinking and Life Cycle Assessment (pages 19-21)
- Decisions Made without Life Cycle Thinking (pages 21-23)
- What Life Cycle Thinking and Life Cycle Assessment is Not (page 29)

3. Wednesday, January 15

Topic: Assessing Life Cycle Impacts at the Individual Scale, Food Miles, and Implications for Life Cycle Analyses

Assignments:

a) **Calculate** your own carbon footprint using the **"Advanced calculator"** at https://depts.washington.edu/i2sea/iscfc/calculate.php.

You should do TWO scenarios: using numbers based on your life as a NSEO student and what you think your "non-student" life as a "full-time working professional" will be like.

b) **Record** your data so you can share your numbers with the class on this Google Sheet: https://docs.google.com/spreadsheets/d/1_ESm26hdJdebzu3O2dU_4eCxeL4PV5kv6tY8vlzyZ50/edit?usp=sharing

c) **Highlight** in yellow what component contributed the most.

d) **Read** "Food Miles or Poverty Eradication? The Moral Duty to Eat African Strawberries at Christmas." (Access and download publication from Link)

Questions to prepare in advance of class: (You will be asked to share your answers during class.)

1. What did you learn that was most surprising / most interesting from calculating your carbon footprint?
2. What differences did you notice between the two scenarios you calculated (student vs. full-time professional)?
3. What factors contributed most to the observed differences? Which of these factors are out of your direct personal control?
4. What, if any steps do you presently take to limit your carbon footprint? Which of these efforts did the calculator show are most effective? What if any changes will you try to make in the future to reduce your carbon footprint?
5. What did you find challenging about filling out the calculator?
6. What insights can you extrapolate from the exercise of calculating your personal carbon footprint to a company that wishes to understand its carbon footprint or the eco-impact of its products and services throughout their life cycle?
7. Do you try to eat locally grown food? If yes, what is reason for doing so?
8. What does the author of the African Strawberries article want you to remember?
9. What lessons does the African Strawberries article hold for managers who want to reduce the eco-impact of their business' products and services?

X. Monday, January 20 = MLK Day of Service and Reflection

4. Wednesday, January 22

Topic: What LCAs teach us and how companies use LCA-generated information

Read:

- "Strategic Sustainability Uses of Life-Cycle Analysis" by Gregory Unruh. *MIT Sloan Management Review*. September 22, 2015. (Link or **Canvas**)
- "Enhancing the value of life cycle assessment" by Sanjay Agarwal et al. Deloitte Consulting. 2012. (Link or **Canvas**)
- "Creating business value with life cycle analysis" by Holger Buxel et al. Business Horizons. 58: 109-122. 2015. (**Canvas**)

Questions to prepare in advance of class:

1. What are the corporate and societal benefits of using LCAs as Unruh describes "in the now" and "in the next"?
2. Unruh asserts that a large number of companies employ LCAs in their sustainability work. What companies besides Apple and Unilever have you seen use LCAs?

5. Monday, January 27

Topic: LCA-Informed Strategy at Nike

Guest Speaker: Adam Brundage, Nike Global Sustainability.
Director of Data and Analytics Insights
https://www.linkedin.com/in/adam-brundage/

6. Wednesday, January 29
Topic: Introduction to the ISO LCA Standard – Goal and Scope

Read:

- **Textbook** Chapter 4 "The ISO LCA Standard—Goal and Scope" page 80 to top of page 87, at the conclusion of the section on SDP 1 about the Goal and Scope
- Refer to the "Assignments" section of Canvas to find which of the following LCAs you have been assigned.
    1. "LCA of Italian Lager Beer"
    2. "Life Cycle Assessment of Peach Transport in Japan"
    3. "Assessing the Carbon Footprint of The Transport Sector in Shenzhen China"
    4. "Life Cycle Analysis of Algae Biodiesel"
- Briefly SKIM your paper; you do not have to read it all. Instead, focus on the Abstract and Introduction
- Answer these questions in today's QUIZ on Canvas. Due by 3pm.
    - What is the study's goal? & Why is the study significant?
    - What type(s) of environmental impact were the focus of the study?

7. Monday, February 3
Topic: The ISO LCA Standard – Setting Boundaries

Read:

- Section "SDPs 3 and 4. Product System and System Boundaries" in Textbook Chapter 4, bottom of page 89 to middle of page 94.
- Chapter 2 "Scope and Scope Definition" from Klopffer and Grahl **(Canvas)**

8. Wednesday, February 5
Topic: Defining the Functional Unit
Read:

- **Textbook** Chapter 4, Section on "SDP 2. Functional Unit" page 87 to middle of page 89

Complete the Canvas Quiz assigned for today!

The quiz asks you:
…for the LCA you were assigned:

1. Identify the functional unit used. What alternative functional units could have been chosen? What difference would it have made if a different functional unit was selected?
2. What system boundaries were defined? What was the logic behind this decision?

9. Monday, February 10
Topic: The ISO LCA Standard – Step 2: Inventory Analysis

Read:

- **Textbook Chapter 5 "Life Cycle Inventory Analysis"** pages 101-112
- "Life Cycle Assessment of the FairPhone2" **(Canvas)**
  …paying particular attention to the Executive Summary, Section 2—Goal and Scope Definition, and, ***most importantly, Section 3—Life Cycle Inventory***

- "Environmental Impacts of Cultured Meat Production" **(Canvas)**
  …paying particular attention to the Abstract, Introduction, and Materials and Methods, and, ***most importantly, Figure 1 and Table 2***

Questions to prepare in advance of class:

1. Make notes of the functional unit and how the analysts built the Life Cycle Inventory
2. What components are included in each study's Life Cycle Inventory?
3. Considering the data in each study's Inventory, what do you believe are major challenges to completing an accurate LCA? What types of products would be particularly difficult to study? Why?
4. How could you complete an LCA if you didn't have detailed data like was available in these two studies?

10. Wednesday, February 12

Topic: The ISO LCA Standard – Step 2: Inventory Analysis - *Continued*

- Today is a catch-up and review day.
- No new work assigned ahead of today's class.
- Come to class with any questions about Steps 1 and 2.

11. Monday, February 17

Topic: Conducting a Screening-Level LCA Using a BOM (Bill of Materials)

Watch:

- "Overview & Tour of Sustainable Minds": https://youtu.be/z_aCvUc-YjA (2:30)
- "Sustainable Minds LCA Demo": https://youtu.be/hzKN5Tb4W7U (9:47)

Read this short webpage:

- "Assessment Process Overview:" https://app.sustainableminds.com/learning-center/conducting-sm-lca/assessment-process-overview

Pay for a student subscription to Sustainable Minds if you have not done so already: http://www.sustainableminds.com/ ($49)

12. Wednesday, February 19

Topic: The ISO LCA Standard – Steps 3 & 4: Impact Assessment and Interpretation

Read:

- **Textbook** Chapter 10 "Life Cycle Impact Assessment" pages 366-382
- **Textbook** Chapter 2, page 50-61 and Chapter 7
- View the Impact Assessment Steps in Sustainable Minds and read the short paragraph on: https://app.sustainableminds.com/learning-center/methodology/methodology-in-detail

13. Monday, February 24
Topic: Characterization, Normalization, Weighing, and the 2 Most Commonly Used Impact Assessment Methodologies

Read:

- Web page about **ReCiPe** at https://www.rivm.nl/en/life-cycle-assessment-lca/recipe
- Web page about **TRACI** at https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci
- TRACI User Manual by J. C. Bare. **(available through TRACI link above)**
    - Read the Abstract, Introduction, Inventory, Interpretation, and Summary sections (pages 6-9;15-16)
    - If you are unfamiliar with any of the Impact Categories and why they are categories of concern (e.g., Eutrophication or Ozone Depletion…), you should also read the section describing that Impact Category.
- Read more details about each of these topics related to impact assessment:
    - Characterization: https://app.sustainableminds.com/learning-center/methodology/impact-characterization
    - Normalization: https://app.sustainableminds.com/learning-center/topic/normalization
    - Weighting: https://app.sustainableminds.com/learning-center/methodology/weighting

Additional Resources on Canvas:

- Updated US and Canadian normalization factors for TRACI 2.1
- Life cycle impact assessment weights to support environmentally preferable purchasing in the United States
- Global emissions normalization factors
- Normalisation and weighting as applied in Environmental Footprint by the European Commission's Science & Knowledge Service

14. Wednesday, February 26
Topic: Conduct your own LCA using Sustainable Minds

To prepare for class:

- Select a product for which you would like to conduct an LCA !
- If possible, bring the product to class so we can take it apart and weigh its components
- Please chose a product with **ONLY A FEW PARTS** so that it is possible to do the LCA in SM
- To ensure success, verify SM contains the "ingredients" of your product
- If you have a kitchen scale – **PLEASE** bring it to class!

15. Monday, March 3
Topic: Communicating LCA Results

Read:

- Heijungs, R. Ten easy lessons for good communication of LCA. *International Journal of Life Cycle Assessment* 19, 473–476 (2014). https://doi.org/10.1007/s11367-013-0662-5 (Link)

16. Wednesday, March 5
Student product wrap-up

March 10 – March 16: Spring Break! Enjoy, Rest, and be Safe!

17. Monday, March 17
Topic: Modeling Recycling and Handling Co-Products with Allocation

Read:

- Allocating Environmental Impact in LCA: Physical vs. Economic Approaches (follow hyperlink)

Questions to prepare in advance of class:

- Think of two other common examples of products that are co-created from the same source besides the examples in your reading. What allocation method would be most useful for each?

18. Wednesday, March 19
Topic: ecoinvent – Day 1

19. Monday, March 24
Topic: ecoinvent – Day 2

20. Wednesday, March 26
Topic: ecoinvent – Day 3

HW due Friday, March 28

21. Monday, March 31
Topic: Introduction to Anthesis' PortfolioPro LCA software

HW due Friday, April 4

22. Wednesday, April 2
Topic: Sphera's LCA FE/GaBi – Day 1

23. Monday, April 7
Topic: Sphera's LCA FE/GaBi – Day 2

24. Wednesday, April 9
Introduction to EarthShift's Matter PD LCA software

25. Monday, April 14
Topic: Sphera's LCA FE/GaBi – Day 3
Sphera Guest Speaker

26. Wednesday, April 16
Course wrap up

Back Up Plans

(for use if Professor Hee must travel for work)

OPTION 1: Learn the GHG Protocol's Corporate Standard for Greenhouse Gas Accounting
Over two days,

- Complete training on the GHG Protocol's Corporate Standard via recorded webinars available at https://ghgprotocol.org/Corporate-Standard-Training
    - Day 1 link
    - Day 2 link
    - Day 3 link
- Complete Scope 2 training available at link

Additional Resources:

- "A Guide to Carbon Footprinting for Businesses" by The Carbon Trust. (**Canvas**)
- "The Greenhouse Gas Protocol" by WBCSD and WRI. (Download pdf available at Link).

OPTION 2: Learn how to use SimaPro LCA Software
Over two days,

- Apply for then download a trial version of SimaPro by visiting https://simapro.com/try/
- Complete the tutorial described in the PDF manual available at https://support.simapro.com/s/article/SimaPro-Tutorial