Syllabus: EES 8200 – Environmental Systems Analysis

Topics include general systems theory; thermodynamics; process-based (bottom-up), environmental impact assessment (such as lifecycle assessment, LCA); economic input-output (top-down) LCA; hybrid, top-down–bottom-up methods; systems of environmental-economic accounts (SEEA). There will be an emphasis on project work.

Time:	Tuesday, Thursday 2:00 – 3:15pm
Location:	Watt 331
Instructor:	Michael Carbajales-Dale Associate Professor, EEES 346a Brackett Hall 864-646-0523 email: madale@clemson.edu
Office hours:	Thurs 9-11am
Location:	Brackett 346a

Course Description:

A number of methodologies exist for assessing the environmental impact of human activities in a variety of domains and at scales ranging from the local to global. Lifecycle assessment (LCA) is arguably the most famous of these methods. LCA is a computational method based on accounting mass and energy balances across industrial processes and sectors of the economy. The delivery of materials to their point of use within the 'technosphere' requires the extraction and emission of materials (e.g., coal, carbon dioxide) to and from the biosphere, each with an associated environmental impact (e.g. resource depletion, climate change). This course gives a 'deep dive' into the methodological framework for LCA.

Resources:

The course will be managed via Canvas (www.canvaslms.com). Students are expected to enroll and complete assignments (e.g. submitting homework) via Canvas. There is no one text for this course, though much of the content will be available from Matthews et al. (2015) *Life Cycle Assessment, Quantitative Approaches for Decisions That Matter*, available online here (www.lcatextbook.com). Additional readings and handouts will be posted periodically on Canvas. It is recommended that you bring these materials to class in either electronic or paper format. A guide to writing for environmental engineers has been written by Tchobanoglous & Leverenz (2013) A Guidance Manual on the Preparation of Technical Reports, Papers, and Presentations.

Participation:

Attendance at regular scheduled class meetings is expected as well as participation in class discussions. Participation includes being prepared for class (e.g. having done the reading, when required) and engaging in class discussion.

Homework:

Homework will be assigned most weeks (normally Thursday) and will be due electronically the following week the same day as assigned, before the beginning of class. Homework content will include problem solving, reading assignments, written critiques of readings, etc. In addition to formal assignments, students are asked to pay attention to current topics in sustainability issues. Late homework will receive an automatic 5% deduction for every day overdue up to a maximum of 20%. The lowest homework grade will be dropped.

Group Project:

A 1- or 2-person group project will be assigned during the semester. Each group will give a 20 min presentation at the end of the semester and will turn in a final report (10-15 pages).

Exams:

Two midterm exams will be given during the semester. Each exam will have equal value. There will be no final exam.

Bonus credit:

There will be opportunities for bonus credit over the course (e.g. attending relevant activities outside class). These will be determined on an *ad hoc* basis. I will gladly receive proposals for such activities from students.

Assessment criteria:

Breakdown of grade assignment:

1. Participation 10%
2. Homework 20%
3. Project 50%
4. Midterms (2) 20%

Grading scale (no curving will be done):

A. >90%
B. >80%
C. >70%
F. <70%

Class Policy:

- In the event of an unplanned absence by the professor, class will be cancelled after 15 minutes
- Academic honesty is expected. Any violation of Clemson University policy as described in the Student Handbook will not be tolerated and may result in a failing grade.

- Use of electronic device will not be permitted during class, except for the purposes of taking notes.
- Any exam that was scheduled at the time of a class cancellation due to inclement weather will be given at the next class meeting unless contacted by the instructor.
- Class cancellation due to inclement weather will not affect the deadline for electronic submission of homework or project assignments.
- Any extension or postponement of assignments or exams must be granted by the instructor via email or Canvas within 24 hours of the weather-related cancellation.

Academic Integrity:

As members of the Clemson University community, we have inherited Thomas Green Clemson's vision of this institution as a "high seminary of learning." Fundamental to this vision is a mutual commitment to truthfulness, honor, and responsibility, without which we cannot earn the trust and respect of others. Furthermore, we recognize that academic dishonesty detracts from the value of a Clemson degree. Therefore, we shall not tolerate lying, cheating, or stealing in any form.

Accommodations for students with disabilities:

Students with disabilities requesting accommodations should make an appointment with Disability Services (656-6848) to discuss specific needs within the first month of classes. Students should present a Faculty Accommodation Letter from Student Disability Services when they meet with instructors. Accommodations are not retroactive and new Faculty Accommodation Letters must be presented each semester.

Title IX statement:

Clemson University is committed to a policy of equal opportunity for all persons and does not discriminate on the basis of race, color, religion, sex, sexual orientation, gender, pregnancy, national origin, age, disability, veteran's status, genetic information or protected activity (e.g., opposition to prohibited discrimination or participation in any complaint process, etc.) in employment, educational programs and activities, admissions and financial aid. This includes a prohibition against sexual harassment and sexual violence as mandated by Title IX of the Education Amendments of 1972. This policy is located at http://www.clemson.edu/campus-life/campus-services/access/title-ix/. Mr. Jerry Knighton is the Clemson University Title IX Coordinator. He also is the Director of Access and Equity. His office is located at 111 Holtzendorff Hall, 864.656.3181 (voice) or 864.565.0899 (TDD).

Tentative course outline (subject to change)

Week	Topic	HW due	Project deliverable	Reading
1	Introduction & general systems theory	-		Meadows (2008) Thinking in Systems, System lens & The basics Boulding (1956) General systems theory
2	Thermodynamics	1		Edwards (2013) Mark I Universe Boulding (1966) The Economics of the Coming Spaceship Earth Shrodinger (1944) What is life?
3	Introduction to LCA	2		Hunt (1996) LCA - how it came about Matthews (2015) LCA - Quantitative Approaches for Decisions That Matter, Ch. 1 EPA (2006) LCA principles and practice Guinee (2011) LCA past present and future
4	LCA step 1: Goal definition and scope	3	Research question	EPA (2006) LCA principles and practice, Ch. 2 Guinee (2004) Handbook on LCA, pp. 31-40 Tillman (1994) Choice of system boundaries in LCA
5	LCA step 2: Lifecycle inventory (LCI) analysis	4	Goal & scope	EPA (2006) LCA principles and practice, Ch. 3 Guinee (2004) Handbook on LCA, pp. 41-63 Reap (2008) Unresolved problems in LCA
6	**Midterm 1**	-		
7	The computational structure of LCA	5	Literature review	Heijungs & Suh (2002) The computational structure of LCA, Chs. 1 & 2
8	LCA software tutorial	6		Download and install OpenLCA from their website Brandt et al. (2013) Calculating systems-scale energy efficiency and net energy returns
9	LCA step 3: Lifecycle impact assessment (LCIA)	7	LCA model	EPA (2006) LCA principles and practice, Ch. 4 Guinee (2004) Handbook on LCA, pp. 63-70, then choose four impacts Reap (2008) Unresolved problems in LCA – part II
10	LCA step 4: Interpretation	8	LCI analysis	EPA (2006) LCA principles and practice, Ch. 5 Guinee (2004) Handbook on LCA, pp. 97-108
11	**Spring break**	-		
12	Methodological issues in LCA	9	LCIA	Ayres (1995) LCA a critique (22 pages)
13	Economic input-output LCA & Systems of environmental-economic accounting (SEEA)	10		Casler (1984) Energy input-output analysis - a simple guide Joshi (1999) Product environmental LCA using I-O techniques UN (2012) SEEA Central Framework, Ch. 1
14	**Midterm 2**	-		
15	Hybrid LCA	-	Interpretation	Suh (2009) Methods in LCI Mattila (2010) A Comparison of process, hybrid and I-O LCA Kreith (1990) CO2 from fossil and solar power plants
16	**Project presentations**	-	**Presentation**	
17	**Finals week**	-	**Final report**	

Topics covered

- **Week 1: Introduction and General Systems Theory**
  - Cover syllabus
    - Course description
    - Resources
      - *Canvas*
      - *Textbook*
    - Participation
    - Midterms
    - Project
    - Grade breakdown
    - Schedule
  - General systems theory
    - Types of systems
      - *Isolated*
      - *Closed*
      - *Open*
    - Properties of sytems
      - *Feedback*
      - *Complexity*
      - *Self-organization*
      - *Self-regulation*
      - *Emergence*
      - *System hierarchy*
    - Complex system behavior
      - *Exponential growth*
      - *Logistic growth*
      - *Overshoot and oscillation*
      - *Overshoot and collapse*
- **Week 2: Thermodynamics**
  - First law
    - Energy and mass balance
      - *Transfer*
      - *Flow*
    - Boring universe (ex: pendulum)
  - Second law
    - Energy moves down thermodynamic gradients (ex: cereal box)
    - Entropy and exergy (ex: John's spreadsheet)
  - Environmental change
  - Resources far from equilibrium
  - Thermodynamics of living systems
- **Week 3: Introduction to LCA**
  - What is LCA?
  - Uses of LCA
  - Stages of LCA:
    - Stage 1: Goal and scope definition
    - Stage 2: Lifecycle inventory (LCI) analysis
    - Stage 3: Lifecycle impact assessment (LCIA)
    - Stage 4: Interpretation
  - Phases of LCA:
    - Material extraction
    - Material processing
    - Manufacture
    - Use
    - End-of-life
  - Types of LCA
    - Accounting (attributional), change-oriented (consequential)
    - Process, input-output (IO), hybrid
    - Full (ISO compliant)
    - Streamlined
      - *Not all stages*
      - *Not all phases*
      - *Qualitative (matrix)*
    - Lifecycle cost (LCC)
    - Social LCA
  - General critiques of LCA
- **Week 4: Stage 1 - Goal and scope definition**
  - Goal:
    - Aim of study

    - Intended audience
    - What question are we trying to answer?
  - Scope:
    - Product system & purpose
    - Initial flowchart
    - Functional unit
    - Choice and justification for impact categories
    - Method of impact assessment
    - Type of LCA
    - System boundary
      - *Geographical*
      - *Time boundaries*
      - *Related to production equipment, labor, etc (cutoff criteria)*
      - *Related to other products lifecycle (allocation procedure)*
    - Data quality
    - Assumptions & limitations
    - Foreground & background
- **Week 5: Stage 2 - Lifecycle inventory (LCI) analysis**
  - Multiple product systems
    - Physical problem
    - Computational problem
    - Solutions
      - *Partitioning (mass, energy, financial value)*
      - *Subdivision*
      - *System expansion*
  - Open-loop recycling
- **Week 6: Midterm 1**
  - Tuesday:
    - Preparation (see above)
  - Thursday
    - Exam
- **Week 7: The computational structure of LCA**
  - Basics of matrix math
    - Adding and multiplying matrices
    - Solving simultaneous equations
    - Inverting matrices
      - *Non-square matrices*
      - *Invertible vs. non-invertible*
  - Heijungs and Suh matrix methodology
    - Unit processes: the ab vector
      - *Energy and mass balance*
    - Defining the AB matrix
    - Demand vector f
    - Scaling vector s
    - Inventory vector g
- **Week 8: LCA software:**
  - Different LCA software packages:
    - Simapro
    - GaBi
    - OpenLCA
  - LCA Databases
    - Ecoinvent
    - Free LCI resources
  - Building a model
    - Graphical approach
    - Matrix equivalent

- OpenLCA tutorial
- **Week 9: Stage 3: Lifecycle impact assessment (LCIA)**
  - Impact categories (midpoints)
    - Global warming potential (GWP)
    - Abiotic depletion potential (ADP)
    - Acidification potential (AP)
    - Eutrophication potential (EP)
    - Ozone depletion potential (ODP)
    - Human toxicity potential (HTP)
    - Etc.
  - Existing methods:
    - ReCiPe
    - TRACI
    - Ecoindicator
  - 7 steps:
    - Select and define impact categories
    - Classification (LCI results to impact categories)
    - Characterization (convert LCI results into indicators of human and ecological health)
    - Normalization (to compare impact categories)
    - Grouping (impact categories into sets)
    - Valuation (weighting)
    - Evaluate and report results
- **Week 10: Stage 4: Interpretation**
  - Identification of significant issues
  - Evaluation of study
  - Conclusions
  - Limitations
  - Recommendations
- **Week 11: Spring break**
- **Week 12: Methodological issues in LCA**
  - Goal and scope definition
    - Functional unit definition
    - Boundary selection & unit process boundary selection
    - Social and economic impacts
    - Alternative scenario considerations
  - Life cycle inventory analysis
    - Allocation – multiple co-products
    - Negligible contribution ('cutoff') criteria - truncation
    - Local technical uniqueness
  - Life cycle impact assessment
    - Impact category and methodology selection
    - Spatial variation
    - Local environmental uniqueness
    - Dynamics of the environment
    - Time horizons
  - Life cycle interpretation
    - Weighting and valuation
    - Uncertainty in the decision process
  - All
    - Data availability and quality
- **Week 13: Economic input-output LCA & Systems of environmental-economic accounts (SEEA)**
  - Input-output (IO) framework
  - Leontief method
  - Make-use tables

    - Extending IO method to environmental flows
    - Energy IO
    - EIOLCA
- **Week 14: Midterm 2**
    - Tuesday:
        - Preparation (see above)
    - Thursday
        - Exam
- **Week 15: Hybrid LCA**
    - Full monetary analysis
    - Mixed unit analysis
- **Week 16: Group presentations**
    - Students present their project
- **Week 17: Finals week**
    - Final report due