Life Cycle Assessment and Ecosystem Services

Bhavik R. Bakshi

William G. Lowrie Department of Chemical and Biomolecular Engineering
The Ohio State University, Columbus OH 43210, USA

Tools for Measuring Sustainability - Professional Development Workshop
Agricultural, Environmental and Development Economics, The Ohio State University
May 19, 2016
Outline

- Life Cycle Assessment
  - Motivation
  - Approach
  - Applications
  - Shortcomings
- Ecosystem Services in LCA
  - Techno-Ecological Synergy
  - Applications
- Challenges and Opportunities
Motivating Questions

- Are paper grocery bags environmentally superior to plastic bags?
- How about electric cars versus gasoline powered ones?
- Are plastics from biomass better?
- Is it better to replace solvent-based reactors with solvent-less and microwave based systems?
- How about using supercritical CO$_2$ instead of HCFCs as a blowing agent for insulating foam?
- Are nanocomposites better than traditional materials for automotive body panels?
- Money is an incomplete measure since externalities are often ignored in market prices
Indirect Effects

- Consider entire life cycle from “cradle to grave”
- Energy required to travel 1 mile by car =
  - Fuel burned
  - plus energy required to extract, refine, transport the fuel
  - plus energy to manufacture car (mile equivalent)
  - plus energy to build and maintain roads
  - plus energy to maintain auto repair shops, govt. regulation, registration services, traffic police, etc.
  - plus energy to produce and maintain that portion of health system used to care for the consequences of auto accidents and auto-related health problems
  - plus ...

- Indirect effects go on forever and can be significant
Steps in Sustainability Assessment

1. **Goal and scope definition**
   - Functional unit
   - Analysis boundary

2. **Inventory analysis**
   - Obtain data of relevant processes available at multiple scales
   - Allocation

3. **Impact assessment**
   - Assess impact of emissions and resource use

4. **Improvement analysis**
   - Explore ways of reducing environmental impact
Step 1: Goal Definition and Scope

- Identify reasons for conducting the LCA
- Define products to be analyzed
- Determine system boundaries
  - Narrow boundary provides misleading results
    - Claims about zero emission vehicles
  - Broad boundary requires too much data
  - All activities are inter-connected
- Select functional unit
  - Necessary for determining equivalence between choices
    - 1 paper bag = 2 plastic bags = 0.0001 cloth bag
    - 10 incandescent bulbs = 1 fluorescent bulb
Boundary Selection - LCA of Paper Bag
Life Cycle Methods

- Process LCA
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes
Life Cycle Methods

- **Process LCA**
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes
Life Cycle Methods

- Process LCA
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes
Life Cycle Methods

- Process LCA
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes

- Input-output LCA
  - Uses aggregate data about economic sectors
  - Comprehensive but coarse
Life Cycle Methods

- Process LCA
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes

- Input-output LCA
  - Uses aggregate data about economic sectors
  - Comprehensive but coarse
Life Cycle Methods

• Process LCA
  • Includes “most important” processes
  • Relies on average data about typical processes
  • Ignores many processes

• Input-output LCA
  • Uses aggregate data about economic sectors
  • Comprehensive but coarse

• Hybrid LCA
  • Combines process and IO models
Life Cycle Methods

- **Process LCA**
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes

- **Input-output LCA**
  - Uses aggregate data about economic sectors
  - Comprehensive but coarse

- **Hybrid LCA**
  - Combines process and IO models

---

LCA & Ecosystem Services
Life Cycle Methods

- **Process LCA**
  - Includes “most important” processes
  - Relies on average data about typical processes
  - Ignores many processes

- **Input-output LCA**
  - Uses aggregate data about economic sectors
  - Comprehensive but coarse

- **Hybrid LCA**
  - Combines process and IO models

- **These models are linear, empirical and aggregated**
Step 2: Inventory Analysis

- Obtain material and energy data for all flows of processes in life cycle
- Commercial and public domain databases are available
  - Ecoinvent (paid)
  - National Renewable Energy Laboratory (free)
  - GREET (free)
  - EIOLCA, Eco-LCA (free)
- Need to allocate inventory between multiple products
  - Partition in proportion to mass, energy, monetary value
  - Subjective approach
Step 3: Impact Assessment

- LCI result
- Raw mat. Land use
  - CO2
  - VOS
  - P
  - SO2
  - NOx
  - CFC
  - Cd
  - PAH
  - DDT

- Human health
  - DALY
  - Ecosystems
    - Species yr
    - Surplus cost

- Resources
  - Damage

- Environmental Mechanism Part 1
  - Environmental Mechanism Part 2
  - Endpoint

- LCA & Ecosystem Services
Step 4: Improvement Analysis

- Has not received much attention in LCA
- Relies on use of methods from engineering design
Tools for LCA

- **Software** is essential for managing life cycle inventory data and applying various methods

- **Process LCA**
  - Relatively accurate data, regularly updated
  - Complicated modeling, expensive
  - OpenLCA, SimaPro, GaBi

- **Input-Output LCA**
  - Easy to use, free, comprehensive
  - Coarse model, crude, old data
  - Economic Input-Output LCA (EIOLCA) (www.eiolca.net)
  - Ecologically-based LCA (Eco-LCA) (resilience.osu.edu/ecolca)
Application of LCA - Grocery Bags

- Reusable PET bag looks best, but not in all categories
Carbon-Nitrogen Nexus of Transportation Fuels

- Gasoline
- E10 Corn
- E10 Yellow Poplar
- E10 LIHD
- E10 MSW
- E10 Newsprint
- E85 Corn
- E85 Yellow Poplar
- E85 LIHD
- E85 MSW
- E85 Newsprint as Waste
- Diesel
- B20 Soybean
- B100 Soybean
- E10 Stover Mass Allocation
- E10 Stover Thermo Mass Allocation
- E85 Stover Mass Allocation
- E85 Stover Thermo Mass Allocation
- Butanol Mass Allocation
- B20 Stover Mass Allocation
- B100 Stover Mass Allocation

Carbon footprint kg/km vs. Nitrogen footprint kg/km

Sustainability Assessment  Applications

Singh, Gibbemeyer, Tam, Urban, Bakshi, 2015
Shortcomings of LCA

- Focus of LCA is mainly on reducing impacts and the chance of shifting them along the life cycle - doing “less bad”
- Many requirements of sustainable systems are ignored
  - Effect of human behavior and economic aspects
  - Dynamics of coupled socio-ecological-technological systems
  - Supply of ecosystem services
- On-going research is attempting to address these challenges
LCA and Ecosystem Services

Meta-principle for environmental sustainability
For a system to be sustainable, it should not demand more from nature than can be supplied

LCA quantifies the demand of only some ecosystem goods and services. It ignores the capacity of ecosystem to supply demanded ecosystem goods and services. Two shortcomings of ignoring nature's capacity: Decisions meant to reduce environmental impact may unintentionally increase demand for scarce ecosystem services. Fail to benefit from nature's ability to satisfy human needs in an economically and environmentally superior manner.
LCA and Ecosystem Services

Meta-principle for environmental sustainability

For a system to be sustainable, it should not demand more from nature than can be supplied

- LCA quantifies the demand of only some ecosystem goods and services
- It ignores the capacity of ecosystem to supply demanded ecosystem goods and services
LCA and Ecosystem Services

Meta-principle for environmental sustainability

For a system to be sustainable, it should not demand more from nature than can be supplied

- LCA quantifies the demand of only some ecosystem goods and services
- It ignores the capacity of ecosystem to supply demanded ecosystem goods and services

Two shortcomings of ignoring nature’s capacity

- Decisions meant to reduce environmental impact may unintentionally increase demand for scarce ecosystem services
- Fail to benefit from nature’s ability to satisfy human needs in an economically and environmentally superior manner
Ecosystem Services in LCA: Till versus No Till Farming

- LCA considers only emissions: finds farming with tillage to be better.
- Accounting for demand and supply finds no-till to be better.
- Both methods are locally sustainable.
- Both are globally unsustainable.
Ecosystem Services in LCA: Till versus No Till Farming

- LCA considers only emissions: finds farming with tillage to be better
LCA considers only emissions: finds farming with tillage to be better
Ecosystem Services in LCA: Till versus No-Till Farming

- LCA considers only emissions: finds farming with tillage to be better
- Accounting for demand and supply finds no-till to be better
• LCA considers only emissions: finds farming with tillage to be better
• Accounting for demand and supply finds no-till to be better
Ecosystem Services in LCA: Till versus No Till Farming

- LCA considers only emissions: finds farming with tillage to be better
- Accounting for demand and supply finds no-till to be better
- Both methods are locally sustainable
Ecosystem Services in LCA: Till versus No Till Farming

- LCA considers only emissions: finds farming with tillage to be better
- Accounting for demand and supply finds no-till to be better
- Both methods are locally sustainable
Ecosystem Services in LCA: Till versus No Till Farming

- LCA considers only emissions: finds farming with tillage to be better
- Accounting for demand and supply finds no-till to be better
- Both methods are locally sustainable
- Both are globally unsustainable
Techno-Ecological Synergy

- Eco-efficiency, life cycle design

Techno-Ecological Synergy

- Eco-efficiency, life cycle design
- Circular economy, industrial symbiosis, byproduct synergy

Techno-Ecological Synergy

- Eco-efficiency, life cycle design
- Circular economy, industrial symbiosis, byproduct synergy
- Techno-ecological synergy

Techno-Ecological Synergy

- Eco-efficiency, life cycle design
- Circular economy, industrial symbiosis, byproduct synergy
- Techno-ecological synergy
- Sustainable TES

TES of Biofuel Life Cycle

Life cycle of corn ethanol is locally and globally unsustainable.
TES of Biofuel Life Cycle

-0.203
-0.094
-0.843
-0.843

Life cycle of corn ethanol is locally and globally unsustainable.
Life cycle of corn ethanol is locally and globally unsustainable.
Local TES Opportunities Across the U.S. for SO$_2$

- Combine data about air emissions, emissions uptake capacity, revegetation opportunities
Local TES Opportunities Across the U.S. for SO$_2$

- Combine data about air emissions, emissions uptake capacity, revegetation opportunities
Local TES Opportunities Across the U.S. for SO₂

- Combine data about air emissions, emissions uptake capacity, revegetation opportunities

- **Orange** dots: $V_k > 0$ with **existing vegetation** within 500 m
- **Yellow** dots: $V_k > 0$ with **restored native vegetation** within 500 m
Designing Techno-Ecological Synergies at Local Scale

Diverse applications

- **Biodiesel** manufacturing
- **Biosolids** management in Central Ohio
- Single-family **home** and **yard**
- **Agricultural** landscape design
Designing Techno-Ecological Synergies at Local Scale

Diverse applications

- **Biodiesel** manufacturing
- **Biosolids** management in Central Ohio
- Single-family **home** and yard
- **Agricultural** landscape design

![Graph showing Env. Impact vs. Cost with the Space of conventional designs highlighted]
Designing Techno-Ecological Synergies at Local Scale

Diverse applications

- **Biodiesel** manufacturing
- **Biosolids** management in Central Ohio
- Single-family **home** and yard
- **Agricultural** landscape design

![Diagram showingEnv. Impact vs Cost with Space of conventional designs](image)
Designing Techno-Ecological Synergies at Local Scale

Diverse applications

- **Biodiesel** manufacturing
- **Biosolids** management in Central Ohio
- Single-family **home** and yard
- **Agricultural** landscape design

---

**Advantages of including nature in design**

- Discovers innovative designs by expanding the design space
- New designs can be "win-win"
- Need new tools and methods to realize these benefits

---

![Graph showing additional design space due to Techno-Ecological Synergies with cost and environmental impact dimensions.](image-url)
Designing Techno-Ecological Synergies at Local Scale

Diverse applications

- **Biodiesel** manufacturing
- **Biosolids** management in Central Ohio
- Single-family **home** and yard
- **Agricultural** landscape design

Advantages of including nature in design

- Discovers **innovative** designs by expanding the design space
- New designs can be “**win-win**”
- Need **new** tools and methods to realize these benefits
Benefits and Barriers to TES

**Benefits**
- Toward human activities that respect and account for nature
- Innovative and “win-win” solutions
- Possibility of absolute sustainability

**Barriers**
- Technical: Design and operation of TES systems
- Economic: Account for the monetary value of ecosystems
- Educational: Ecological literacy has been declining
- Behavioral: From dominating nature to respecting nature
Summary

• Life Cycle Assessment is a popular method for preventing shifting of environmental impacts
  • Goal Definition and Scope
  • Inventory Analysis
  • Impact Assessment
  • Improvement Analysis

• LCA does not account for the capacity of ecosystems to supply goods and services

• Techno-Ecological Synergy (TES) accounts for demand and supply of ecosystem services at multiple spatial scales

• Many opportunities for transdisciplinary research and application
Acknowledgments

• Students & Post-Docs
  • Varsha Gopalakrishnan
  • Rebecca Hanes
  • Xinyu Liu
  • Shweta Singh
  • Bob Urban

• Collaborators
  • Tim Gutowski, MIT
  • Satoshi Hirabayashi, USDA Forest Service
  • Michael Lepech, Stanford
  • Dusan Sekulic, U. Kentucky
  • Guy Ziv, U. Leeds

• Support
  • National Science Foundation
  • U.S. Department of Agriculture
  • U.S. Environmental Protection Agency
  • Dow Chemical
  • Eastman Chemical
  • American Electric Power