Environmental Life Cycle Assessment
PSE 476/WPS 576/WPS 595-005

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Lecture 1: Why LCA?
“Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all.”
A common approach

Objectives
• Minimize cost
• Maximize appeal

Environment treated as commons
http://www.paulchefurka.ca/PopulationFoodEnergy.html
Per capita energy use

Cuyahoga river fires

Cuyahoga river in Ohio (runs through Cleveland) caught on fire several times between 1868 and 1969. A catalyst for Clean Water Act of 1972.

November 3, 1952 (Source: U.S. EPA) Sometime in the 1960s (Source: cleveland.com)
Donora smog

Air pollution from U.S. Steel’s Donora Zinc Works combined with an atmospheric inversion resulted in heavy smog that killed 20 people and sickened 7,000 in Donora, PA, near Pittsburgh. October 26-31, 1948.

Source: http://www.wired.com/thisdayintech/tag/smog/
Acid rain

Jizera Mountains, Czech Republic
(Source: Wikipedia)

Source:
http://www.elmhurst.edu/~chm/vchembook/196buildings.html
Changes in GHGs

- Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750.
- Now far exceed pre-industrial values determined from ice cores spanning many thousands of years.
- The global increases in
  - carbon dioxide concentration are due primarily to fossil fuel use and land use change,
  - Methane and nitrous oxide are primarily due to agriculture.
Figure 2. Ice core record from Vostok, Antarctica, showing the near-simultaneous rise and fall of Antarctic temperature and CO2 levels through the last 350,000 years, spanning three ice age cycles. However, there is a lag of several centuries between the time the temperature increases and when the CO2 starts to increase. Image credit: Siegenthaler et al., 2005, Science
Global Warming Predictions

Figure SPM.5. Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. (Figures 10.4 and 10.29)
Climate change

Source: Intergovernmental Panel on Climate Change (2007), FAR, WGI, The Physical Scientific Basis, TS, p. 25

Changing temperature in California.

Environmental Kuznet’s curve

“Inverse-U” relationship between pollution and national income

**Environmental decay:** Higher incomes initially mean more production and consumption, and these activities tend to pollute.

**Environmental improvement:** As income grows, the demand for environmental protection also tends to increase, leading to a development path characterized by both economic growth and environmental quality improvements.
“The Master Equation” (Graedel and Allenby, 1995)

Environmental impact =
population \times [\text{GDP/person}]
\times [(\text{environmental impact})/(\text{unit of GDP})]

Over the next half century
Population … 50% increase
Affluence [GDP/capita] … 300-500% increase
Efficiency [impact/GDP] … ?
Sustainability?

• The ability to supply societies needs without harming the environment or future generations’ ability to meet their needs?

• Often stated in terms of People Planet Profit (PPP)

• We have many options to meet our demands.

• How to choose the “best” option?

• Life cycle assessment helps to inform our choices.
The Brundtland Report, 1987


“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs”

“Living standards that go beyond the basic minimum are sustainable only if consumption standards everywhere have regard for long-term sustainability. Yet many of us live beyond the world's ecological means, for instance in our patterns of energy use. Perceived needs are socially and culturally determined, and sustainable development requires the promotion of values that encourage consumption standards that are within the bounds of the ecological possible and to which all can reasonably aspire.”

Available online at: http://www.un-documents.net/ocf-02.htm
The Grand Objectives (Graedel 1998)

How do we downscale the sustainability concept to create metrics?

The $\Omega_1$ Objective
Maintaining the existence of the human species

The $\Omega_2$ Objective
Maintaining the capacity for sustainable development

The $\Omega_3$ Objective
Maintaining the diversity of living things

The $\Omega_4$ Objective
Maintaining the aesthetic richness of the planet
## Relating environmental concerns to the Grand Objectives

<table>
<thead>
<tr>
<th>Grand Objective</th>
<th>Environmental Concern</th>
</tr>
</thead>
</table>
| $\Omega_1$: Human species extinction | 1. Global climate change  
                                  | 4. Human organism damage  
                                  | 5. Water availability and quality  
                                  | 6. Resource depletion: fossil fuels |
| $\Omega_2$: Sustainable development | 5. Water availability and quality  
                                  | 6. Resource depletion: fossil fuels  
                                  | 7. Soil depletion  
                                  | 8. Optimal land use  
                                  | 12. Resource depletion: other than fossil fuels or soils |
| $\Omega_3$: Biodiversity          | 1. Global climate change  
                                  | 2. Loss of biodiversity  
                                  | 3. Stratospheric ozone depletion  
                                  | 5. Water availability and quality  
                                  | 7. Acid deposition  
                                  | 16. Thermal pollution |
| $\Omega_4$: Aesthetic richness    | 10. Smog  
                                  | 11. Aesthetic degradation  
                                  | 13. Oil spills  
                                  | 15. Odor |

The order of the numbers in the right column is that of Table 1.3.
Environmental concerns by significance

<table>
<thead>
<tr>
<th>TABLE 1.3 Significant Environmental Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crucial Environmental Concerns</td>
</tr>
<tr>
<td>1. Global climate change</td>
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<tr>
<td>2. Loss of biodiversity</td>
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<tr>
<td>3. Stratospheric ozone depletion</td>
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<tr>
<td>4. Human organism damage</td>
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<tr>
<td>5. Water availability and quality</td>
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<tr>
<td>6. Depletion of fossil fuel resources</td>
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<tr>
<td>Highly Important Environmental Concerns</td>
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<tr>
<td>7. Soil depletion</td>
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<td>8. Suboptimal land use</td>
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<td>9. Acid deposition</td>
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<tr>
<td>10. Smog</td>
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<tr>
<td>11. Aesthetic degradation</td>
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<tr>
<td>12. Depletion of resources other than fossil fuels</td>
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<tr>
<td>Less Important Environmental Concerns</td>
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<tr>
<td>13. Oil spills</td>
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<tr>
<td>14. Radionuclides</td>
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<tr>
<td>15. Odor</td>
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<tr>
<td>16. Thermal pollution</td>
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<td>17. Landfill exhaustion</td>
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</tbody>
</table>

The numbers within the groupings are for reference purposes, and do not indicate order of importance.

What is a Life Cycle Assessment?

Life Cycle Assessment (LCA) is a tool to assess the potential environmental impacts of products, systems, or services at all stages in their life cycle [ISO 14001:2004].

Types of LCA

• **Cradle to Gate**: raw materials to finished good (no use or end life considerations)

• **Cradle to Grave**: Considers everything from harvesting materials to the disposal of the finished goods
Life Cycle Stages

- Raw Materials
- Production
- Transportation
- Use
- Disposal/Recycle

Flow of materials and energy:
- Raw Materials to Production
- Production to Transportation
- Transportation to Use
- Use to Disposal/Recycle

Energy and emissions:
- Energy in Raw Materials
- Energy in Production
- Energy in Transportation
- Energy in Use
- Energy in Disposal/Recycle

Waste and emissions:
- Waste from Raw Materials
- Waste from Production
- Waste from Transportation
- Waste from Use
- Waste from Disposal/Recycle

Emissions:
- Emissions to air and water in Raw Materials
- Emissions to air and water in Production
- Emissions to air and water in Transportation
- Emissions to air and water in Use
- Emissions to air and water in Disposal/Recycle

Recycled Materials

Flow diagram showing the life cycle stages with energy, waste, and emissions at each step.
Important Aspects of Life Cycle Assessment

- Goal and Scope Definition
- Inventory Analysis
- Impact Assessment
- Interpretation
Other Definitions of Life-Cycle Assessment

Graedel and Allenby (1995):
The life-cycle assessment is an **objective** process to **evaluate the environmental burdens associated with a product, process, or activity** by identifying and quantifying energy and material usage and environmental **releases**, to assess the **impact** of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to **effect environmental improvements**. The assessment includes the **entire life cycle** of the product, process, or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/reuse/maintenance; recycling; and final disposal.

Wenzel et al. (1997):
To assess a product environmentally is: to define and quantify the service provided by the product, to identify and to quantify the environmental exchanges caused by the way in which the service is provided, and to ascribe these exchanges and their potential impacts to the service.
Improved product design

Objectives
• Minimize cost
• Maximize appeal
• Minimize environmental impact
Our first goal is to find the way to achieve "clean" growth and I want to defend this idea here today. We haven't got to choose between saving the planet and growth. We need to have growth and save the planet. So we need a growth that consumes less energy and fewer raw materials. A new economy must be invented. [Nicolas Sarkozy Speech to UN Assembly, September 2007]
Summary:

Tragedy of the Commons
Velocity of Climate Change
Grand Objectives (4)
Sustainability
PPP
Life Cycle Analysis