Valuation of Life Cycle Inventories: The EPS System

TPP 123
Life Cycle Analysis: Three Stage Process
SETAC Life Cycle Framework

Inputs
Raw Materials
Energy

Life Cycle Inventory

Raw Materials Acquisition
Manufacturing, Processing, and Formulation
Distribution and Transportation
Use/Re Use Maintenance
Waste Management
Reycle

Outputs
Airborne Emissions
Water Efluents
Other Environmental Releases
Usable Products
Solid Waste

Goal

Improvement Analysis
Inventory Analysis

Impact Analysis
Complex When Dealing With A Real Problem
Inventory Analysis Goals

- To Establish Baseline Information for Specific Products or Activities
- To Rank the Relative Contributions from Specific Stages in Life Cycle
- To Understand Relative Environmental Burdens of Competing Products or Activities

- To Use as Guide for:
  - Process and Product Evaluation by Designers
  - Information and Assessment for Consumers
  - Guidelines and Indications for Government

- Issue of Valuation for Improvement Analysis
Improvement Analysis

- Based on Pertinent Metrics, Make Decisions to Improve Environment
- How to Decide Between Two "Evils":
  - Choose Product A which emits 1,000 kg of CO₂  =>  Global Warming
  - Choose Product B which emits 3,000 kg of CO₂  =>  Global Warming
  - Choose Product C which emits 1,000 kg of SO₂  =>  Acid Rain

- Valuation: Balance of Trade-Offs Between
  - Environmental
  - Economic
  - Technological / Engineering
Improvement Analysis & Valuation

- Improvement Stage Has Two Phases
  - Evaluation
  - Implementation

- Evaluation Raises The Question Of Identification Of "Better" and "Best"
  - Difficult To Establish When Multiple Objectives Reached

The Set of Non-Dominated Alternatives
Screening or Constraint Setting Techniques

- Analogous To Regulatory Limit-Setting

- Question:
  Why Alternative 6 and Not 7?
  What About The Relative Importance of A and B?
Value Functions

- Accommodate Tradeoffs

- Linear Value Function:
  - Monetization, or Price/Cost of Impact
  - Constant Tradeoffs

- Non-Linear Value Function
  - Saturation
  - Variable Tradeoffs
Value Functions Necessary When Selections Must Be Made From The Non-Dominated Set

- Development of Such Prioritizing Can Be Done in Some Cases
  - Scope
    - Individuals
    - Controlled Groups

- Cannot Develop A General Value Function For Large Groups

- Potential Methodologies for Estimating Value Functions
  - Multi-Attribute Utility Analysis
  - Analytical Hierarchy Process
  - Environmental Priority Strategies
Environmental Priorities Strategy: EPS

- System Objectives
  - Introduce Environmentally Sound Product Development
  - Establish Common Database for Life Cycle Inventories
  - Develop PC-Based Tools for Eco-Product Design
  - Delineate Environmental Effects throughout Product Life
  - Inform & Educate Industrial Target Groups
Features of Environmental Priority Strategies

- Based on Swedish Parliament's *Safeguard Subjects*:
  - Biodiversity
  - Production (reproduction of biological organisms)
  - Human Health
  - Resources
  - Aesthetics

- “Environmental Burden” Determined For Activities & Processes
- System Designed to Allow “Objective” Decisionmaking
- Monetization Reduces Complex Data To One Numerical Value
- “Environmental Load” Assigned To Each Resource, Emission & Activity On A Per Unit Mass Basis
- Load Applied For Each Element Of LCA Inventory & Summed
Institutional Features of EPS

- Scientific Analysis of Effects of Emissions
  Done at Chalmers Institute

- Inventory Work To Be Done By Individual Firms

- Values From Various Sources
EPS Basic Principle

Environmental \times \text{Quantity} = \text{Environmental Load Index} \times \text{Load Value}

Units for ELI: Environmental Load Units / quantity
= ELU / kg or ELU/part or ELU/ m^2

Units for ELV: Environmental Load Units
= ELU
Case I: Polypropene Bucket

- Weight: 0.7 kg
- Material: Polypropene
  - Environmental Load Index: 0.68 ELU / kg
- Process: Injection Molding
  - Environmental Load Index: 0.08 ELU / kg
## EPS Calculation of ELV for Bucket

<table>
<thead>
<tr>
<th>Materials &amp; Processes</th>
<th>ELV = ELI * Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material:</strong> Polypropene</td>
<td>0.68 ELU/kg * 0.7 kg = 0.48 ELU</td>
</tr>
<tr>
<td><strong>Process:</strong> Injection Molding</td>
<td>0.08 ELU/kg * 0.7 kg = 0.06 ELU</td>
</tr>
<tr>
<td><strong>Total Environmental Load Value:</strong></td>
<td>0.48 ELU + 0.06 ELU = 0.54 ELU</td>
</tr>
</tbody>
</table>
Defined Safeguard Subjects

- Biodiversity
- Human Health
- Production
- Resources
- Aesthetic Values
"Unit Effects" for Safeguard Subjects

- Human Health: Unit Effects for CO$_2$
  - Excess mortality due to increased temperature in tropics
  - Temperature increase leads to flooding and therefore accidental deaths
  - Global warming leads to increased desertification; less food; more starvation
"Value Factors" for Unit Effects

- F1: Relative Cost to Reduce 1 kg Emission
- F2: Extent of Affected Area
- F3: Regularity of the Problem
- F4: Duration of Effect
- F5: Significance of 1 kg Substance wrt Total
##EPS Valuation Bases

<table>
<thead>
<tr>
<th>Biodiversity</th>
<th>Impact</th>
<th>ELU of impact</th>
<th>sd factor</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extinction of medium sized animals and plants</td>
<td>1.0E+15</td>
<td>10</td>
<td></td>
<td>10 ELU per person per year; 1E+09 persons; 1E+05 years</td>
</tr>
<tr>
<td>General and global impact on biodiversity</td>
<td>5.0E+11</td>
<td>5</td>
<td></td>
<td>100 ELU per person; 5E+09 persons</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biological Production</th>
<th>Impact</th>
<th>ELU of impact</th>
<th>sd factor</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg of crop seed</td>
<td>0.2</td>
<td>2</td>
<td></td>
<td>economic value</td>
</tr>
<tr>
<td>1 kg of wood</td>
<td>0.025</td>
<td>2</td>
<td></td>
<td>economic value</td>
</tr>
<tr>
<td>1 kg of meat or fish</td>
<td>1</td>
<td>3</td>
<td></td>
<td>economic value</td>
</tr>
<tr>
<td>1 kg of fresh water</td>
<td>0.003</td>
<td>4</td>
<td></td>
<td>economic value in areas with water deficit</td>
</tr>
</tbody>
</table>

**Notes:**
- **ELU** (Equivalent Loss of Utility) per person per year
- **sd factor** (standard deviation factor)
## EPS Valuation Bases (continued)

### Energy

<table>
<thead>
<tr>
<th>Impact</th>
<th>ELU per impact</th>
<th>sd factor</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MJ renewable electrical</td>
<td>0.02</td>
<td>2</td>
<td>economic value</td>
</tr>
<tr>
<td>1 MJ renewable thermal</td>
<td>0.01</td>
<td>2</td>
<td>economic value</td>
</tr>
</tbody>
</table>

### Human Health

<table>
<thead>
<tr>
<th>Impact</th>
<th>ELU per impact</th>
<th>sd factor</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 excess death</td>
<td>1,000,000</td>
<td>10</td>
<td>normalized from</td>
</tr>
<tr>
<td>1 man-yr painful morbidity</td>
<td>100,000</td>
<td>10</td>
<td>several studies</td>
</tr>
<tr>
<td>1 man-yr other morbidity</td>
<td>10,000</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1 man-yr severe nuisance</td>
<td>1,000</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1 man-yr moderate nuisance</td>
<td>100</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Environmental Load Index:

\[
\text{ELI} = \sum_{k=1,5} \sum_{j=1,n} \prod_{i=1,5} F_{ijk}
\]

- safeguard subjects
- unit effects
- value factors

Units for ELI: Environmental Load Units / quantity
= ELU / kg or ELU/part or ELU/ m²
**EPS Concept**

\[
ELU = \frac{kg \times ELU}{kg}
\]

**Environmental Load Value**

**Quantity**

**Environmental Load Index**

**Environmental Unit Effects on Safeguard Subjects**

\[
a + b + c + d + e + ... + j + k + ... + p + q + ... + x + y + ...
\]

**F1:** Value - relative cost to reduce one kg emission

- F1a
- F1b
- F1c

**F2:** Extent of affected area

- F2a
- F2b
- F2c

**F3:** Frequency, regularity of problem in affected area

- F3a
- F3b
- F3c

**F4:** Duration of effect

- F4a
- F4b
- F4c

**F5:** Contribution to total effect

- F5a
- F5b
- F5c

**Safeguard Subjects**

- Human Health
- Biodiversity
- Resources
- Production
- Aesthetics
## EPS Estimated Emission Indices for CO₂ ELI

<table>
<thead>
<tr>
<th>Substance</th>
<th>Activity</th>
<th>Subject</th>
<th>Effect</th>
<th>Impact</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>ELI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>air emiss</td>
<td>Health</td>
<td>Death: heat</td>
<td>Temp.</td>
<td>1E+06</td>
<td>-3E+06</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>-0.087</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Health</td>
<td>Death: flood</td>
<td>Temp.</td>
<td>1E+06</td>
<td>1E+04</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>0.00029</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Health</td>
<td>Death: starv</td>
<td>Temp.</td>
<td>1E+06</td>
<td>1E+05</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>0.0029</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Health</td>
<td>Starvation</td>
<td>Temp.</td>
<td>1E+05</td>
<td>5E+07</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>0.145</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Biodiversity</td>
<td>Decrease</td>
<td>Temp.</td>
<td>5E+11</td>
<td></td>
<td>1</td>
<td>2</td>
<td>100</td>
<td>2.9E-16</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Production</td>
<td>^ wood</td>
<td>Temp.</td>
<td>2.5E-02</td>
<td>-7.2E+10</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>-0.0000522</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Production</td>
<td>^ crops</td>
<td>Temp.</td>
<td>2E-01</td>
<td>-2.3E+11</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>-0.001334</td>
</tr>
<tr>
<td></td>
<td>air emiss</td>
<td>Production</td>
<td>v crops</td>
<td>Temp.</td>
<td>2E-01</td>
<td>1.2E+10</td>
<td>1</td>
<td>100</td>
<td>2.9E-16</td>
<td>0.0000696</td>
</tr>
</tbody>
</table>

ELI = 0.0888734
ELU s for Processes

For Process: \( \text{ELU} = [\text{ELI}] \times [\text{Inventory}] \times [\text{Quantity}] \)

- Matrix Multiplication
  - ELI Dimensions: \( 1 \times n \)
    - With \( n \) emissions, resources used
  - Inventory Dimensions: \( n \times m \)
    - With \( m \) subprocesses represented
  - Quantity dimension - Scalar
    - Input by User

Summing Subprocesses: \( \text{ELU(process)} = \sum \text{ELU(subs)} \)
# Environmental Load Value For Steel Grill Opening Panel

<table>
<thead>
<tr>
<th>Material/Product</th>
<th>Process/Activity</th>
<th>Environmental Load Unit</th>
<th>Quantity</th>
<th>Environmental Load Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galv. Steel</td>
<td>Manufact</td>
<td>0.98 ELU/kg</td>
<td>9.0 kg</td>
<td>8.82 ELU</td>
</tr>
<tr>
<td></td>
<td>Stamping</td>
<td>0.06 ELU/kg</td>
<td>9.0 kg</td>
<td>0.54 ELU</td>
</tr>
<tr>
<td></td>
<td>SpotWeld</td>
<td>0.004 ELU/spot</td>
<td>48 spots</td>
<td>0.19 ELU</td>
</tr>
<tr>
<td></td>
<td>Painting</td>
<td>0.01 ELU/m²</td>
<td>0.6 m²</td>
<td>0.01 ELU</td>
</tr>
<tr>
<td>Steel Scrap</td>
<td>Recycled Material</td>
<td>-0.92 ELU/kg</td>
<td>3.0 kg</td>
<td>-2.76 ELU</td>
</tr>
<tr>
<td><strong>Product Use</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel /Petrol</td>
<td>Manufact/Combustion</td>
<td>0.82 ELU/kg</td>
<td>48 kg</td>
<td>39.36 ELU</td>
</tr>
<tr>
<td><strong>Disposal</strong></td>
<td>Material</td>
<td>-0.92 ELU/kg</td>
<td>6.0 kg</td>
<td>-5.53 ELU</td>
</tr>
<tr>
<td>Galv. Steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>TOTAL:</strong> 40.64 ELU</td>
</tr>
</tbody>
</table>
## Environmental Load Value: GMT Composite Grill Panel

<table>
<thead>
<tr>
<th>Material/Product</th>
<th>Process/Activity</th>
<th>Environmental Load Unit</th>
<th>Quantity</th>
<th>Environmental Load Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMT- Comp</td>
<td>Manufact</td>
<td>0.58 ELU/kg</td>
<td>4.0 kg</td>
<td>2.32 ELU</td>
</tr>
<tr>
<td></td>
<td>Pressing</td>
<td>0.03 ELU/kg</td>
<td>4.0 kg</td>
<td>0.12 ELU</td>
</tr>
<tr>
<td></td>
<td>Painting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMT- Comp</td>
<td>Recycled Matl</td>
<td>-0.58 ELU/kg</td>
<td>0.3 kg</td>
<td>-0.17 ELU</td>
</tr>
<tr>
<td><strong>Product Use</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel/Petrol</td>
<td>Manufact/Combustion</td>
<td>0.82 ELU/kg</td>
<td>29.6 kg</td>
<td>24.27 ELU</td>
</tr>
<tr>
<td><strong>Disposal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GMT- Comp</td>
<td>Energy Reuse</td>
<td>-0.21 ELU/kg</td>
<td>3.7 kg</td>
<td>-0.78 ELU</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>25.76 ELU</strong></td>
</tr>
</tbody>
</table>
Limitations of EPS

- Monetary Value of Each Resource and Emission Determined By:
  - Market Prices
  - Government Allocations
  - Contingent Valuation

- Money As A Measure of Value
  - Implies Construction of Linear Value Function
  - Each Unit Effect Adds Linearly to Final ELI
    → Independent of Size of Each Unit Effect