Environmental Effects – Life Cycle Assessment of Bridges, Methodology Overview

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Content of this Presentation

• ETSI Sub-Project 2 Environmental effects
  – Aims
  – Deliverables

• Introduction to LCA
  – LCA methodology in general (why, how)
  – LCA methodology for bridges (how)

• Future challenges
  – Research and development work?
  – Implementation, testing and distribution for use?
Life Cycle Environmental Impacts

- Production, Transport & Construction
  - EMISSIONS & IMPACT
  - Extra traffic
  - OM&M
  - Design, materials & location
  - Exposure, wear & tear
  - EMISSIONS & IMPACT

- Waste disposal
  - Recycling & recovery
  - Demolition
  - Andøybrua

- MATERIALS & ENERGY
  - EMISSIONS & IMPACT
  - EXTRA TRAFFIC
  - OM&M

- Design, materials & location
  - Andøybrua

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ETSI – SP2 Aims

• To perform a state-of-the-art study
  – Important environmental factors and their causes for various types of bridges and their elements
  – Critical factors of the life cycle (production, use, end-of-life phase)
  – Learning from other types of infrastructure transferable to bridges
  – How LCA and LCC can be integrated

• To develop a methodology for LCA of bridges
  – Choice of a set of relevant indicators for bridges
  – Usefulness for decision-making on bridge design and management

• To develop a practical tool for LCA of bridges
  – Database of emission coefficients for material and energy consumption of bridges in a life cycle perspective
  – Cost-coefficients for relevant emissions to the environment
  – Environmental performance results to understand the bridge system
ETSI – SP2 Deliverables

• State-of-the-art report
• Part of the ETSI Stage 2 final report
  – Life Cycle Assessment – LCA
  – The BridgeLCA environmental assessment tool
  – Case study of three bridges
• LCA standalone tool
  – BridgeLCA (Excel and Matlab Compiler)
  – BridgeLCA Simplified (Excel)
  – Documentation and User Manual reports
• Publications
  – 2 or 3 articles in international scientific journals
  – 1 popular scientific article in each Scandinavian country
The LCA framework (ISO 14041)

Life cycle assessment framework

- Goal and scope definition
- Inventory analysis
- Impact assessment:
  - classification
  - characterization
  - normalization
  - weighting

Interpretation

Direct applications:
- product development and improvement
- strategic planning
- public policy making
- marketing
- other
Goal and Scope Definition

• Defining the goals of the LCA
  – Internal or external purpose
  – Comparison of alternatives, stepwise improvement, environmental declaration, product labelling, etc.

• Defining the scope of the LCA
  – System borders – what to include (space and time)
  – Environmental impact categories to be included (GWP, AP, EP...)
  – Method of impact assessment (valuation, aggregation, weighting)
  – Input data quality requirements and data availability
  – Functional unit
    • Ex.: Person mobility: Transportation of one person 30 km per day for one year, at a given location
    • Ex.: Bridge design: Bridge crossing at a given location and capacity including 100 years of operation and maintenance and demolition
  – Allocation principles (ex.: when recycling is included)
Life Cycle Inventory Analysis (LCI)

Example – A bridge system:

- Production of elements
- Transportation to bridge site
- Construction on site
- Operation, repair & maintenance
- End-of-life management

Service to society (Functional Unit)
Extra traffic generation

LCI = Quantifying the environmental stressors from the system

- Resource consumption (Renewable resources, non-renewable resources)
- Emissions to water, air and soil (NH₃, NOₓ, SO₂, P, CO₂, CH₄, NO₂, CFC-11, CO, etc.)

Tromsø bridge

Tromsø bridge
Flowchart for the life cycle of a bridge
System Tree for Concrete
System Tree for Converter Steel

- Blasting
- Water

IRON ORE

- Limestone
- Quicklime

SINTER IRON

- Iron pellets
- Limestone
- Water

PIG IRON

- Iron scrap
- Quicklime
- Dolomite
- Ferronickel
- Water

CONVERTER STEEL

- Electricity
- Diesel
- Electricity
- Natural gas
- Coal/coke
- Natural gas
- Coal/coke
- Electricity
- Coal/coke
- Natural gas
System Tree for Electric Steel
(Scrap based steel)

IRON SCRAP
Includes collection, transport to scrap-yard, sorting and pressing to blocks

Electricity  
Diesel

Iron scrap  
Quicklime  
Refractory  
Anode  
Oxygen

ELECTRIC STEEL

Electricity  
Coal  
Natural gas
System Tree for Glue Laminated Wood

Gravel, crushed

Landuse

Lubricating oil

Land occupation

Melamine formaldehyde resin

SOFTWOOD, IN FOREST

THINNING AND FINAL CUTTING, IN FOREST

DEBARKING, AT FOREST ROAD

SAWING AND DRYING, AT SAWMILL

GLUE LAMINATION, AT PLANT

Laminated wood, outdoor use

Diesel

Diesel

Diesel

Electricity

Electricity

Diesel

Heat
System Tree for Diesel

- **Crude Oil, In Ground**
  - Inorganic chemicals
  - Organic chemicals
  - Natural gas, in ground
  - Water

- **Crude Oil, At Production Offshore**
  - Sweet gas
  - Natural gas
  - Diesel

- **Diesel, At Refinery**
  - Other inputs...
  - Nitrogen, liquid
  - Iron sulfate
  - Hydrochloric acid
  - Water

- **Diesel, At Regional Storage**
  - Electricity
  - Fuel oil
  - Refinery gas
  - Coal / coke

- **Diesel, Burned in Building Machine**
  - Water
  - Lubricating oil

- **Diesel**
Environmental Impact Categories
(According to the CML Impact Assessment methodology, Leiden Univ.)

• Resource depletion
  – Abiotic depletion potential (ADP)
• Impact to soil and water
  – Acidification potential (AP)
  – Eutrophication potential (EP)
• Impact to air and atmosphere
  – Global warming potential (GWP)
  – Ozone layer depletion potential (ODP)
  – Photochemical ozone creation potential (POCP)
• Toxicity impacts
  – Human toxicity potential (HTP)
  – Freshwater aquatic ecotoxicity potential (FAETP)
  – Marine aquatic ecotoxicity potential (MAETP)
  – Terrestrial ecotoxicity potential (TETP)

SETAC states:
The human toxicity and ecotoxicity categories do not yet meet the ISO requirements regarding the natural science background, and need further development.
Life Cycle Impact Assessment (LCIA)

- CLASSIFICATION
- CHARACTERIZATION
- NORMALIZATION
- WEIGHTING

In equivalents
Dimensionless quantities

Characterization indicator i
Normalization factor i
Weighting factor i
Environmental Impact Assessment

Production → Midpoint indicators → Normalization and weighting factors

<table>
<thead>
<tr>
<th>ETSI name</th>
<th>Concrete</th>
<th>Steel, construction</th>
<th>Stainless steel</th>
<th>Reinforcing steel</th>
<th>Steel, lower grade</th>
<th>Glue laminated wood</th>
<th>Sawn timber construction</th>
<th>Sawn timber formwork</th>
<th>Aluminium</th>
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<tr>
<td>Unit</td>
<td>m3</td>
<td>ton</td>
<td>ton</td>
<td>ton</td>
<td>ton</td>
<td>m3</td>
<td>m3</td>
<td>m2</td>
<td>ton</td>
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<td>Abiotic depletion</td>
<td>kg Sb eq</td>
<td>ADP</td>
<td>5.66E-01</td>
<td>1.53E+01</td>
<td>3.88E+01</td>
<td>8.08E+00</td>
<td>1.02E+01</td>
<td>1.40E+00</td>
<td>6.40E-01</td>
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<tr>
<td>Acidification</td>
<td>kg SO2 eq</td>
<td>AP</td>
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<td>2.68E+01</td>
<td>3.53E+00</td>
<td>4.28E+00</td>
<td>1.02E+00</td>
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<td>Eutrophication</td>
<td>kg PO4--- eq</td>
<td>EP</td>
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<td>Global warming</td>
<td>kg CO2 eq</td>
<td>GWP</td>
<td>2.60E+02</td>
<td>1.79E+03</td>
<td>5.20E+03</td>
<td>9.53E+02</td>
<td>1.20E+03</td>
<td>1.80E+02</td>
<td>8.91E+01</td>
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<tr>
<td>Ozone layer depletion</td>
<td>kg CFC-11 eq</td>
<td>ODP</td>
<td>8.58E-06</td>
<td>7.13E-05</td>
<td>2.21E-04</td>
<td>5.61E-05</td>
<td>5.62E-05</td>
<td>1.87E-05</td>
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<tr>
<td>Photochemical ozone creation</td>
<td>kg C2H4</td>
<td>POCP</td>
<td>1.57E-02</td>
<td>8.95E-01</td>
<td>1.71E+00</td>
<td>4.17E-01</td>
<td>6.03E-01</td>
<td>8.21E-02</td>
<td>2.60E-02</td>
</tr>
</tbody>
</table>

**Normalization factor**
- abiotic depletion: 1,48E+10
- acidification: 2,73E+10
- eutrophication: 1,25E+10
- global warming: 4,81E+12
- ozone layer depletion: 8,33E+07
- Photochemical ozone creation: 8,26E+09

**Inverse normalization factor**
- 6,74E-11
- 3,66E-11
- 8,02E-11
- 2,08E-13
- 1,20E-08
- 1,21E-10

**Weighting factor**
- 5
- 5
- 5
- 16
- 5
- 6

**Total emissions in Western Europe 1995**

**ALTERNATIVE WEIGHTING FACTORS:**
- EPA: 5, 5, 5, 16, 5, 6
- Harvard: 7, 9, 9, 11, 11, 9
- Bees default (equal weights): 9, 9, 9, 9, 8, 8
- EDIP: 0, 1.3, 1.2, 1.3, 23, 1.2
- OWN:
### Midpoint Indicators for Bridge Parts

Calculated on basis of LCI results (amount of stressors per bridge part)

<table>
<thead>
<tr>
<th>Category</th>
<th>Klønevågen</th>
<th>Fretheim</th>
<th>Hillersvika</th>
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</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>2.4E+00</td>
<td>1.2E+00</td>
<td>2.0E+00</td>
</tr>
<tr>
<td>Pile</td>
<td>2.9E+01</td>
<td>1.4E+00</td>
<td>2.0E+00</td>
</tr>
<tr>
<td>Erosion protection</td>
<td>7.0E+00</td>
<td>3.0E+00</td>
<td>3.5E+00</td>
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<tr>
<td>Embankment</td>
<td>4.5E+02</td>
<td>1.8E+00</td>
<td>4.7E+00</td>
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<tr>
<td>Slope protection</td>
<td>4.0E-05</td>
<td>2.2E-05</td>
<td>3.4E-02</td>
</tr>
<tr>
<td>Abutments</td>
<td>2.9E+01</td>
<td>1.2E+00</td>
<td>1.7E+00</td>
</tr>
<tr>
<td>Slab and deck</td>
<td>1.5E+01</td>
<td>6.4E+01</td>
<td>1.8E+01</td>
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<tr>
<td>Beam, girder</td>
<td>1.6E+01</td>
<td>6.1E+01</td>
<td>1.6E+01</td>
</tr>
<tr>
<td>Truss</td>
<td>1.0E+00</td>
<td>1.1E+00</td>
<td>1.1E+00</td>
</tr>
<tr>
<td>Arch, Vault</td>
<td>3.8E+01</td>
<td>5.7E+01</td>
<td>4.7E+00</td>
</tr>
<tr>
<td>Cable system</td>
<td>1.4E+01</td>
<td>5.1E+01</td>
<td>6.9E+00</td>
</tr>
<tr>
<td>Pipe, Culvert</td>
<td>1.0E+00</td>
<td>1.1E+00</td>
<td>1.1E+00</td>
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<tr>
<td>Cross beam</td>
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<td>1.1E+00</td>
<td>1.1E+00</td>
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<tr>
<td>Wind bracing</td>
<td>5.0E+00</td>
<td>6.2E+00</td>
<td>5.9E+00</td>
</tr>
<tr>
<td>Bearing and Hinge</td>
<td>2.5E+00</td>
<td>2.5E+00</td>
<td>2.5E+00</td>
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<tr>
<td>Edge Beam</td>
<td>1.0E+00</td>
<td>1.0E+00</td>
<td>1.0E+00</td>
</tr>
<tr>
<td>Insulation, Water proofing</td>
<td>3.3E+00</td>
<td>2.2E+00</td>
<td>3.9E+00</td>
</tr>
<tr>
<td>Surfacing</td>
<td>8.4E+00</td>
<td>4.7E+00</td>
<td>8.4E+00</td>
</tr>
<tr>
<td>Parapet, Railing</td>
<td>7.1E+00</td>
<td>8.6E+00</td>
<td>7.1E+00</td>
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<tr>
<td>Expansion joint</td>
<td>7.2E+00</td>
<td>5.0E+00</td>
<td>5.0E+00</td>
</tr>
</tbody>
</table>

**IMPACTS PER CATEGORY SPLIT UP IN BRIDGE PARTS AND LIFE CYCLE STAGES**

**Sum = 2.5E+05**
Weighted Overall Environmental Impact
Contribution by each impact category

Typical situation:
- We would like to know
  - Which design is the better?
  - What environmental impact categories are most important?
Tradeoffs Between Impact Categories?
One bridge design is not necessarily the best choice for all impact categories

- We would like to know
  - Is the result (and conclusion) robust regardless of the type of impact category?
  - If not, will weighting factors be important?
Accumulated Environmental Impact
For each bridge part and activity in the life cycle

- We would like to know:
  - Which parts of the system contribute the most?
Type of Impact for Each Bridge Part

- We would like to know
  - How much does each bridge main element contribute to each of the environmental impact categories?
Role of Materials and Inputs
Global Warming Potential (GWP) for each input variable to the system

- We would like to know
  - Can we focus LCA improvements mainly on some few materials?
  - If yes, which are they and how can they be improved?
Future Challenges

• Research and development work?
  – Streamlining the BridgeLCA tool for user friendliness
  – Integrating the BridgeLCA tools to the ETSI web-based system
  – Closer examination of the methodology for toxicity issues, in particular creosote leakage and impact from wood bridges

• Implementation, testing and distribution for use?
  – Developing BridgeLCA database on basis of more case studies
  – Material groups with focus on national differences and LCI data modifications (for selected materials and energy systems)
  – BridgeLCA management policies within the national road authorities – How?
  – Testing and final modification work
  – Dissemination and user support
Skarnsund bridge
(RV755, north of Trondheim, Mid-Norway)