Life Cycle Assessment (LCA) of Emerging Technologies at Early Stages of Design

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Content

- Life Cycle Assessment (LCA)
- Technology Readiness Level (TRL)
- Streamlined LCA
- Stepwise LCA
- Anticipatory LCA
- LCA model at early stage of design
- LCA-TEA (Techno-economic analysis) Framework
In ISO 14040 LCA is defined as:
“compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle”
Life Cycle Assessment (LCA) of Emerging Technologies at Early Stages of Design
Technology Readiness Level (TRL)

• Technology Readiness Level (TRL) indicates the maturity of a given technology
  
  • pioneered by National Aeronautics and Space Administration (NASA) in the 1980s
  
  • TRL scale ranges from 1 through 9
# Technology Readiness Level (TRL) Scale

<table>
<thead>
<tr>
<th>TRL</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic principle observed</td>
</tr>
<tr>
<td>2</td>
<td>Formulation of concept</td>
</tr>
<tr>
<td>3</td>
<td>Proof of concept</td>
</tr>
<tr>
<td>4</td>
<td>Validation of laboratory</td>
</tr>
<tr>
<td>5</td>
<td>Component testing in simulated environment</td>
</tr>
<tr>
<td>6</td>
<td>Prototype in representative environment</td>
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<tr>
<td>7</td>
<td>Prototype in operation environment</td>
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<tr>
<td>8</td>
<td>System qualification</td>
</tr>
<tr>
<td>9</td>
<td>Technology ready</td>
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Early stages (TRL 2 and TRL 3)

TRL 2: Has a concept or application been formulated?

- Determination of functional requirements
- Identification and partially characterization of basic components
- Confirmation of basic scientific principles from preliminary analysis
- Documentation of preliminary qualitative risk analysis
Early stages (TRL 2 and TRL 3)

TRL 3: Has analytical and experimental proof-of-concept been demonstrated in laboratory environment?

- Validation of predicted capability of technology components through experiments or modeling and simulation
- Identification or development of design technique
- Initiation of scaling studies
Why LCA at Early Stage?

- **80%** of all environmental effects associated with a product or process are determined at design phase
- Greater flexibility for environmental considerations to guide innovation process
Objectives

- To develop a framework for LCA of emerging technologies at early stages of design (TRL 2, TRL 3)
Technology Life Cycle and LCA

Technology LCA

Design LCA

Product LCA

TRL1 → TRL2 → TRL3 → TRL4 → TRL5 → TRL6 → TRL7 → TRL8 → TRL9

Time

Cumulative profit/loss

Research Development

Maturity

Valley of death

Decline

Technology Life Cycle

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Methodological and Practical Challenges

• Comparability of Functional unit and system boundary
• Lack of inventory data
• Scaling issues
• Uncertainty
Streamlined LCA: Environmentally Responsible Product (ERP)

<table>
<thead>
<tr>
<th>Life Cycle Stage</th>
<th>Material choice</th>
<th>Energy use</th>
<th>Solid residues</th>
<th>Liquid residue</th>
<th>Gaseous residues</th>
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<tbody>
<tr>
<td>Premanufacture</td>
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<tr>
<td>Product Manufacture</td>
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<tr>
<td>Product Use</td>
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<tr>
<td>Product Manufacture</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
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<td>Product Delivery</td>
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<td>1</td>
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</table>
Target plot for ERP
Main steps in product development

1. Idea → Analysis → Goal definition → Concept development → Detail development → Establishment of production

Environmental steps of product development

1.1 Define a reference product and determine its life cycle

1.2 Make an LCA computer model of the reference product’s life cycle

1.3 Generate environmental profiles of the reference product

1.4 Identify the environmental “hot spots” in the reference product

2.1 Identify revised conceptual solutions where “hot spots” have been found

2.2 Compare revised conceptual solutions with the existing solutions in the reference product

2.3 Select the optimal conceptual solutions

2.4 Update the LCA computer model with optimal conceptual solutions

3.1 Fill details into the LCA computer model of the selected concept

3.2 Generate environmental profiles of the detailed product

3.3 Identify environmental “hot spots” at detail level

3.4 Identify revised detail solutions where “hot spots” have been identified

3.5 Compare revised detail solutions with existing solutions in the reference product

3.6 Select the optimal detail solutions

3.7 Update the LCA computer model with optimal detail solutions and generate an environmental profile of the final product

Ref: Nielsen and Wenzel (2002)
Research Steps

Model development
- Industry survey
  - Data availability
  - Required outputs
  - What level of detail analysis?
  - Impact categories
  - Speed of execution
  - Learning from previous studies
  - Model development
  - Software tool development

Application
- Case studies (e.g. Biofuels)

Validation
- Validation of the model
Preliminary Evaluation Criteria

✓ Avoid particular materials
✓ Resource depletion
✓ Use of recycle matter
✓ Packaging requirement
✓ Temperature and pressure of the process
✓ Recycle/Reuse/Disposal
Integration of TEA (Techno-economic Analysis) and LCA

- Engineers and designers must simultaneously address economic benefits and environmental risks along with technical and other aspects while designing any process, product or service.

- Techno-economic analysis (TEA) tool is used to evaluate the economic feasibility and optimize different process parameters by developing model considering user defined constraints.

- Therefore, integration of TEA and LCA tools can provide a platform to maximize economic benefits and minimize environmental impacts simultaneously at design phases.
TEA-LCA Framework

User

Process design specifications

Optimized process design

TEA Tool

TEA-LCA Interface

LCA Tool

Process design specifications
References


Acknowledgement

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Dr. Karen High

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Thank you for your attention!!